A STUDY OF REMOTE, COLD REGIONS HABITATIONS AND DESIGN RECOMMENDATIONS FOR NEW DORMITORY BUILDINGS IN MCMURDO STATION, ANTARCTICA

A Dissertation

by

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ABSTRACT

In this dissertation I examine how, despite a very cold, remote location, a holistic approach to the design of a housing facility in McMurdo Station, Antarctica, should simultaneously optimize energy efficiency and occupant comfort and minimize site impact. Because a U.S. scientific presence in Antarctica will continue for the foreseeable future, having a modern, energy efficient station that maximizes human comfort and minimizes human impact on the site is crucial for its scientific mission.

The purpose of this thesis is to provide a new decision tool for the evaluation of architectural and HVAC designs for a McMurdo Station employee habitation that addresses the issues above. This is intended to encourage: 1) increased efficiency of buildings and energy systems, 2) improved quality of life, and 3) reduced environmental impact and enhancement of long-term sustainability by reducing the reliance on fossil fuels. The design tool is based on: 1) a review the station's architectural, mechanical, and structural evolution up to the present day; 2) an analysis of on-site data collection of current conditions of building interiors; 3) questionnaire responses of contract workers; and 4) energy simulations of selected features of these designs using the energy simulation software DOE-2.1E.

Results showed that: 1) final scores in the matrix indicated the need for a significant improvement in the existing station and the current proposed redesign of the station, which offered many good ideas, but still fell short of an ideal dorm design; and 2) an improved energy simulation showed initial savings of 21% from the application of

Energy Efficiency Measures (EEM) based on a modified base case. The matrix provided a useful visual aid that indicated the “push/pull” dynamics” between decisions of design, EEM, and human health and comfort for the unique location and requirements of McMurdo Station.

DEDICATION

For my mother and father.

ACKNOWLEDGEMENTS

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1. IMPORTANCE OF THE RESEARCH AND INTRODUCTION

1.1. Statement of Intent

The goal of my dissertation was to evaluate the design criteria to improve sustainability for a dormitory facility at McMurdo Station, a large U.S. Federal research station operated by the National Science Foundation (NSF) and located in Antarctica (Figure 1). McMurdo Station is located in one of the most remote and inhospitable places in the world, so it provided me with the perfect case study for sustainable design and engineering in extreme environments. I also selected this station because I had the opportunity to spend two late-winter seasons in McMurdo making observations on the form and function of the existing design, engineering, and living conditions, as well as surveying the opinions of the civilian contractors working there. This provided a unique

Figure 1: McMurdo Station, Antarctica

opportunity for someone interested in architectural design to peer deep inside a facility that has served as an analogue to living off-planet by the National Aeronautics and Space Administration (NASA).

Because of its history dating back to the Heroic Age of Antarctic Exploration (ca. 1895) and the long (since 1956) legacy of the station as a Naval installation, the current station consists of a complex assortment of structures that vary in age and were built without a master plan. There is now a realization by the NSF that the station is outdated and needs to be rebuilt to meet the programs scientific goals for the next 50 years. In addition, an architectural firm (OZ Architecture) had already prepared preliminary plans for rebuilding the station. I was therefore left with the challenge of evaluating the existing station and the proposed rebuild as a case study for sustainable design. It became clear to me that I needed a quantitative method of evaluation that incorporated architectural design and engineering but included human factors of livability based on direct experience and the opinions of the occupants. I therefore created an evaluation matrix that included historical information (i.e., building technology that had been tried and tested previously) and the results of an energy model that used actual design and weather data. This required extensive research to obtain archival documents, the compilation of a formatted weather file, and detailed design analysis. As with any modeling project, most of my efforts to create a design evaluation matrix were spent in acquiring accurate and reliable data for the variables; without good data, the results would be meaningless. However, I was successful, and the result was a detailed and quantitative evaluation of the existing station, the proposed rebuild, and an ideal station based on my analysis and direct experience that provides informed design recommendations that maximize sustainability and are applicable not only to McMurdo Station but other habitations in extreme environments.

1.2. Introduction

The United States government's McMurdo Station, located on Ross Island in Antarctica (Figure 1), is the largest and one of the most remote research facilities on the continent.[1] Each year it serves as an important laboratory and logistical hub for hundreds of scientists from around the world conducting research on and around Ross Island and as far away as South Pole Station.[2] More like a small town than any other Antarctic station, McMurdo was established in the 1950s under the direction of the United States Navy (USN); later it was transferred to the National Science Foundation (NSF). Today, the station supports a summer population of approximately 1,200 and a winter population of about 200 civilian support personnel and a few scientists. Annually, the station requires approximately 521,000 gallons of fuel for heating buildings and 1.16 million gallons of fuel for electricity generation.[3] It also requires 15 million gallons of desalinated sea water for fresh water requirements (RSA Engineering [RSA], 2008, p. 8). The station's design, construction, and renovations have evolved

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[1] McMurdo is located 2,000 miles from the nearest populated country (New Zealand) and 8,000 miles from the U.S. (Figure 1,Figure 9). The average annual temperature is 0°F, with extremes recorded at -58°F and 46°F respectively. The average annual wind speed is 11 mph, with a peak recorded gust of 116 mph during the winter of 1968 (Office of Polar Programs [OPP], 1997, p. 25).
[2] Ross Island is 729 nautical miles from the South Pole (Klein, et al., 2008, p. 3).
[3] The U.S. Navy uses a fuel known as JP-5 in Antarctica because of its high combustion point. JP-5 and another type of fuel, AN-8, are stored in McMurdo. While AN-8 (gels at -70°F) is required for South Pole Station and most deep-field camps, JP-5 (gels at -50°F) is adequate for McMurdo (Blaisdell, 2008).

over half a century with a succession of master plans and single building renovations and replacements. Although the station has succeeded in performing its primary function of science support, it has done so with less than optimal quality of life, energy efficiency, and environmental impact.

Housing on Ross Island has taken many forms over the years, from the prefabricated wooden shelters and canvas tents of the early explorers to the USN's temporary Jamesway structures and the current three-story college-style dormitories. Although the conditions on this desolate, volcanic island have not changed during the past 100 years, the housing needs and living conditions of the people working at McMurdo Station have. While housing has generally improved as the station grew and building technology improved, currently it is not as energy efficient as it could be. Antarctica is so cold and remote that energy (i.e., power and heat) is a matter of life and death. However, the cost of fuel can be astronomical (because the location is so remote), so having energy efficient buildings that provide a comfortable and safe working environment is important.

At the same time, the current agency overseeing the station, the U.S. Antarctic Program (USAP), acknowledges that quality of life and comfort issues, including the lack of private rooms, affects the agency's ability "…to recruit and retain highly qualified participants …" (OPP, 2003, p.5). Currently there are 16 dormitories of varying age and condition at the station. Since the 1950s several plans for housing improvements have included upgrades for dormitories, including increasing single room capacity, a practice considered standard for "…private sector camps in remote locations

…" (OPP, 2003, p.5). However, double-occupancy rooms are still standard,[4] and the idea of designing for comfort alongside energy efficiency has not been fully explored. In the literature review I document how housing design has changed as technology has improved so that we can better understand what has worked and what has not. It is only then that we may make informed decisions about how best to proceed with improvements to the station.

1.3. A Land of Extremes

Nearly every description of Antarctica begins with a list of the continent's extremes: temperature, wind speed, average altitude, and relative humidity. Like space travel, being in Antarctica is something humans can only do with great effort and outside support, for the landscape –while striking– is both desolate and unforgiving. The same beauty captured in countless photographs over the last century can be a dangerous distraction from the fact that, if cut off outside logistics and supplies, people face grim prospects and no chance of long-term survival. However, just like space travel, we have advanced from small, cramped enclosures to large, modern research facilities. The focus has shifted from mere survival and *getting by* to one of long-term occupation (i.e., creating a sense of place in an alien environment, and making it sustainable).

Another extreme, one often omitted from the usual list, is the continent's lack of history, for no native peoples ever settled there. Unlike the Artic, Antarctica remained isolated, covered in perpetual ice and surround by the tempestuous Southern Ocean. It

[4] Except during the winter season when the populations drops to fewer than 200.

may be said that Antarctica has a rich, even colorful recent history, but it barely spans a 200 year period. Although the theory of a great southern continent –a *Terra Australis Incognita*– existed since the time of the Ancient Greeks and through the Age of Discovery,[5] the earliest recorded sightings of the frozen Antarctic coast occurred as recently as 1820, the same year a sperm whale sunk the *Essex*,[6] and less than a century after the invention of the marine chronometer.

Figure 2: Ortelius World Map "Typvs Orbis Terrarvm" 1570.
http://en.wikipedia.org/wiki/File:OrteliusWorldMap1570.jpg

In the midst of the Industrial Revolution, machines and technology were propelling mankind into the modern era faster than ever before. Only one year had passed since the discovery of land south of 60^{o}S.[7] The unknown world was gradually shrinking, but it still held mysterious places, and mapmakers could only guess what lay at the bottom of the world (Figure 2).

[5] 15th century – 18th century
[6] An event that inspired Herman Melville to write *Moby Dick.*
[7] That is, the South Shetland Islands.

For years explorers attempted to sail farther south in search of this mythic, extreme southern land. Discovering *Terra Australis Incognita* was one goal of British explorer Captain James Cook during his first voyage (1768-1771), which brought him as far south as New Zealand (41^{o}S); during his second voyage he became one of the first people to sail across the Antarctic Circle, reaching as far south as latitude 71^{o} in 1774. Ross Island (77^{o}S, the future location of McMurdo Station) (Figure 9, Figure 10), was not discovered until 1841 by the British explorer James Clark Ross, who never set foot on the island but named the large volcano Mt. Erebus after one of his vessels (Neider, 1974, p. 17). In Greek mythology Erebus was the gatekeeper to the underworld: a fitting name for the smoldering sentinel he discovered at the edge of the Great Ice Barrier[8].

The continent of Antarctica[9] remained relatively unexplored for five more decades. Today it peacefully hosts thousands of people from dozens of countries. Its land, waters, and flora and fauna are legally protected: a land dedicated to the pursuit of scientific inquiry. It boasts of no early human history; it has no cultural artifacts, traditions, or memory of war. It has no local architecture; like everything else, it must be imported.

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[8] That is, the Ross Ice Shelf

[9] Generally recognized as such after reports from hundreds of whalers and sealers who flocked to its rich coastal waters in search of profit.

2. REVIEW OF ARCHITECTURAL HISTORY OF MCMURDO STATION

This purpose of this section is to provide a single source of information about the architecture of McMurdo Station (and beyond when applicable). During the writing of this dissertation it became clear that there was plentiful information on this topic, but it was fractured into various sources, and not without holes. As a result I decided to compile a single narrative in order to have a useful historical context for the station.

This section contains a discussion of the historical buildings used by early explorers, some of which were erected on Ross Island. The focus then shifts to the efforts of the USN in founding the early station (i.e., temporary, tent-like buildings in which the focus was portability and ease of construction) and then making it more permanent (i.e., larger, more conventional buildings). The push towards permanency was continued by a series of private contract holders who took over after the NSF gained control of the station. Besides building type and construction techniques, this section also looks at how the station grew into what it is today by examining a series of *Long Range Development Plans* (LRDP) made for the station and executed to various degrees.

Also included here is a snapshot of a few recent international research stations on the continent, none of which compare with McMurdo's location or size and scale, but all of which hold lessons that could be adapted if put in their correct historical context.

2.1 The Heroic Era (1895-1917)

The first wave of Antarctic exploration, generally known as the "Heroic Age," began in 1895 (Figure 11). By this time there were still lands and geographic landmarks to be explored, claimed, and conquered; even the North Pole had not yet been attained. Those drawn to the South Pole went in search of adventure, glory, and to an extent, scientific recognition. The name itself, "Heroic Age," bestows upon those journeys a great sense of romantic adventure, and when reading the first-hand accounts of these men, it becomes clear that they found it and much more.

These explorers sailed to the southern continent and established base camps along the coast which allowed small exploratory teams to penetrate deeper into this strange, inhospitable land. Over time the coast of Antarctica has become an icy time capsule for a number of surviving buildings and memorials from this time period, all in various stages of disrepair, but mostly well preserved by the cold, dry air, and the efforts of preservationists. People working at today's modern Antarctic stations –complete with power, heat, and nearly every modern convenience– can visit these historic sites as tourists. These buildings are often labeled monuments to the human spirit despite their humble classification as "huts."

The historical huts of the Heroic Age offer insight into the past and show what was humanly possible even under the most extreme and remote conditions. Pearson (1992) categorizes the huts into three styles: Scandinavian, British, and Australian, each with its own characteristics, design successes, and shortcomings.

1) Scandinavian-style Antarctic huts had heavy plank walls with cellulose-based insulation, gabled roofs with lofts, no verandah, oil-burning lamps, and a spatial organization that did not separate enlisted men from officers (i.e., they were "egalitarian"). Two examples of this style include the huts built by Carsten Borchgrevink[10] in 1889 (Figure 12) and Roald Amundsen in 1910 (Figure 13).

2) British-style huts –lashed down with ropes– had timber frames clapped with weatherboarding and insulation, gabled roofs without lofts, protected entrances without a verandah, acetylene lighting,[11] and a spatial organization that separated the party leaders from the enlisted men, if not all the officers from the men. Two examples of this style include the huts built by Sir Ernest Shackleton in 1908 (Figure 14), and Sir Robert Scott in 1911 (Figure 15).

3) Australian-style huts had timber frames insulated with felt or cork, a pyramidal roof over a large square area, a verandah on three sides, framing posts sunk directly into the ground, and a spatial organization that separated the party leaders from the enlisted men. Two examples of this style include the huts built by Scott in 1901(Figure 16), and Sir Douglas Mawson in 1911 (Figure 17).

These three styles of Heroic Era huts each have their strengths and weaknesses, but what is clear is that besides keeping the shelter adequately heated, maintaining a balance between comfortable temperatures and healthy ventilation rates was one of the difficulties they faced by these expeditions. Only one hut, Amundsen's Framheim,

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[10] His camp at Cape Adare has come to be considered the first building in Antarctica.
[11] Acetylene was produced by combining calcium carbonate with water in a small tank and then distributing the gas through a series of small diameter metal tubes to flame lamps.

successfully achieved this balance, but did so in part by being subnivean[12] (buried beneath the snow) with a working (if somewhat temperamental) ventilation system. Amundsen placed great importance on proper ventilation (controlled air intake and exhaust) not only on the ship (the *Fram*) but in their winter hut (*Framheim*). He considered it not a luxury but necessity for comfort and health, and blamed reported health woes in other expeditions on poor ventilation (Amundsen, 1913, p. 199). Even so, there were still problems with thermal stratification, a problem that persists in McMurdo today, although mostly in older buildings.

Both Pearson (1992) and Harrowfield (1995) offer comprehensive reviews of Antarctica's historic huts, looking not only at their historical importance and preservation but construction methods, inspirations, lifespan, and their individual merits and drawbacks according to accounts from the men who lived in them (Figure 18). With this information in hand it is possible to gain a better perspective on why these various huts differ in appearance and degrees of success. Each provides valuable lessons that helped pave the way for future explorers to survive the climate and the long, dark winters. For more information about the buildings of the Heroic Age, see Appendix A.

[12] This choice carries with it some disadvantages and risks, such as increased risk from fire and loss of visual connection to the outside world. This solution is not feasible everywhere in Antarctica (e.g., along rocky coasts), or for long-term settlements.

2.2 McMurdo Station Growth and Development (1956-Present)[13]

> *Our seven major bases in Antarctica were designed to last through the International Geophysical Year that ended with 1958. And they did. Then Congress established a permanent office of U. S. Antarctic Research Programs to continue the scientific work begun during the IGY. Logistical Task Force 43 has the job of consolidating and building permanent facilities to support the new program.*[14]

Small Antarctic expeditions were not uncommon between 1914 and 1940, but it was not until after WWII that activities on the southern continent began to escalate. For many years the geopolitics of Antarctica were unsettled, with a number of countries jostling for a position at the table. Until the Antarctic Treaty[15] was signed in 1959, there were no internationally recognized laws governing the continent, including the presence of the military, the use of nuclear energy and testing, or mineral rights.[16] The treaty helped set the precedent that the continent would remain peaceful and devoted to scientific pursuits, such as the International Geophysical Year (IGY).

With the success of the first IGY, the U.S. decided to extend its Antarctic mission beyond 1959 and replace the temporary facility at McMurdo with a more

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[13] For an exhaustive history of the events leading up the IGY and Operation Deep Freeze, see Dian Belanger's book titled *Deep Freeze: the United States, the International Geophysical Year, and the Origins of Antarctica's Age of Science*.

[14] Admiral David Tyree, Operation Deep Freeze's Naval Support Force Commander, in Dempewolff, 1961, p. 105.

[15] The treaty was signed in December 1959 and went into effect June, 1961. The original signatories were Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the Soviet Union, the United Kingdom, and the United States.

[16] Recognizing no other nations' claims to Antarctica, the U.S. nevertheless wanted a permanent presence in Antarctica, and the best way to stay in the circle of countries deciding the fate of the continent was to be a signatory member of the Antarctic Treaty. This document, now signed by 50 countries, keeps the continent free of standing armies and reserved for peaceful, scientific cooperation. Subsequent amendments include the protection of Antarctic flora and fauna, and the preservation of the pristine nature of the continent, for example, the "Protocol on Environmental Protection to the Antarctic Treaty," sometimes known as the Madrid Protocol, which was adopted in 1991.

permanent one (Hoffmann, 1974, p. 2). Prior to this decision there were few facilities for conducting scientific research at Naval Air Facility, McMurdo Sound (NAF McMurdo), which mostly served as an airlift base for aircraft servicing other stations or nearby field camps.[17] After a few years it became clear that the station needed a plan for its upkeep and expansion. The Navy ordered the Naval Civil Engineering Laboratory (NCEL) to create a long-range development plan so that the current, short-term facility would be able to aid scientific efforts on site and at remote stations, mainly the new station at the South Pole. A long-range plan for the station was also deemed necessary to maintain a political presence on the continent. It was the first of several subsequent long-range plans for the station. For an expanded discussion about McMurdo Station Growth and Development since 1956, see Appendix B.

2.3 Summary

Although McMurdo Station began as an naval air field nearly 60 years ago, its appearance and organization little reflect its current status as the largest, farthest reaching research station on the continent, hosting or supporting 90% of the U.S. traffic into the continent, as well as scientists other countries working in Antarctica. Clearly, as a preeminent, long-term research station with a population that can exceed 1,000 people, it has not benefited from being treated as a collection of disparate buildings and from not

[17] The facility was set up for gravity measurements, aerology (meteorology), and "special studies" (e.g., dental health). After a few years, a small biology lab appeared.

being able to implement a variety of long term plans for the balancing of their maintainability, habitability, lifespan, and energy demands.

It is easy to dismiss the run-down, chaotic appearance of the station, to be dismayed by its aging, haggard appearance, but trying to address a problem that evaded the best efforts of several long-range plans without understanding the complicated, often loosely documented history of the place, itself dooms contemporary efforts to failure. The history of the station and its evolution through the years under different management (Appendix B) lays the foundation for future work. Armed with a coherent architectural history and knowledge of more recent architectural achievements on the continent, one may avoid the pitfalls of the past and focus on the successful designs and endeavors to create a well-informed, optimal design.

2.4 Future of McMurdo Station

Lockheed Martin currently holds the civilian support contract for McMurdo Station, and it is continuing the tradition of issuing a station report. In 2013 Lockheed commissioned a Colorado architectural firm to create a new plan for the station, to guide (or completely revamp) the station over the coming decades. The Master Plan proposed builds on the extensive 2012 report about the future of all the U.S. Antarctica stations science and logistics. Authors of the 2012 report, issued by the USAP Blue Ribbon Panel, observed that despite science being the main reason for maintaining a presence in the Antarctic, it is the supportive logistical effort that required the most time and money, nearly nine times as much; the report likened the 1:9 ratio to that of the weight of an iceberg below and above water. The panel noted that "U.S. activities in Antarctica are very well managed but suffer from an aging infrastructure, lack of a capital budget, and the effects of operating in an extremely unforgiving environment" (Augustine et al., 2012, p.7). In McMurdo these problems are highly visible, ranging from old, drafty buildings to scattered and nearly derelict warehouses, to an outdated inventory system. Therefore it may not be a surprise that the Colorado firm's proposal, rather than once again recommending small fixes, instead recommends replacing nearly every building in McMurdo over the course of several years.

As the title of the Blue Ribbon report indicates,[18] the members of the panel found that the majority of problems including both the overall cost and the ability to accommodate scientists are the result of out-of-date logistics and a crumbling infrastructure; often this was the result of diverted funding going towards science as long as the logistics and infrastructure could survive another season. The report noted that there is a choice between "… repairing a roof or conducting science, science usually prevails" (Augustine et al., 2012, p.7). However, at some point this becomes a self-defeating policy.

The panel focused on streamlining logistics and updating parts of all three U.S. stations in Antarctica.[19] The goal to reduce the percentage of the budget spent on support and logistics would in turn provide more funding for Antarctic science grants. Some improvements included the need to restore the U.S. polar ocean fleet, to decrease

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[18] "More and Better Science in Antarctica Through Increased Logistical Effectiveness"
[19] While the new South Pole Station as just dedicated in 2008, it is still included in this panel report because it must be included in future maintenance plans.

the number of LC-130 flights to McMurdo and the Amundsen-Scott Base, and to decrease the contractor personnel by 20%. This might bring McMurdo Station's peak population close to or under 1,000 people.

Regarding McMurdo Station specifically, the panel acknowledged the haphazard arrangement[20] of the station but also concluded that there was no better location (logistically)[21] and that an investment in a new station the size of McMurdo Station located elsewhere would reach $220 million (Augustine, et al., p. 12). Rather, improvements to the station could help make up for any of the less-than-optimal conditions. Of the ten main recommendations, three relate directly to architecture and engineering.[22] Naturally, one of these is to increase the energy efficiency of the station and its use of renewable energy, with the panel pushing for more wind turbines, a way to incinerate solid waste and waste oil for extra heat, and improved insulation in several key buildings. The second recommendation focused on reducing operational costs through an updated master plan of the station, and well as an improvement to dormitory

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[20] This phrase seems to be passed from one report to the next, and indicates there may be no better way to describe the current condition of the station, although "organic" might also be an applicable phrase.
[21] Criteria for this assessment included: 1) presence of a deep water harbor, 2) direct access for offloading on an ice shelf, 3) distance to the south pole (by air), 4) access for wheeled aircraft, 5) reasonable sea ice conditions for ship access, 6) the need to employ and ice breaker, 7) suitability for a long-term installation, and 8) access to the rest of the continent via overland route. McMurdo excelled in all these categories save two: the sea ice conditions and the need to employ an icebreaker (equipment the U.S. has let fall into disrepair, unlike Russia).
[22] 1) Continuation of Antarctic presence at current stations, 2) Restore polar ocean fleet, 3) Improve logistics and transportation, 4) Upgrade or replace aging facilities at McMurdo and Palmer, 5) Establish a long-term capital plan for facilities, including a phased modernization plan, 6) Reassess certain parts of science proposals, 7) Modernize communications, 8) Increase energy efficiency of power systems and buildings, 9) Pursue additional areas for international cooperation, 10) Review and revise existing government documents that govern U.S. presence in Antarctica (Augustine et al., 2010, p. 207-209).

facilities.[23] These are all important because (the third recommendation) the scientific program is to be continued at the existing station.

These recommendations may sound familiar, but the panel countered this by adding that, despite a workforce that takes great initiative in doing what it can with the available resources,

> [s]imply working harder doing the same things that have been done in the past will not produce efficiencies of the magnitude in the future; not only must change be introduced into *how* things are done, but *what* is being done must also be reexamined. (Augustine, 2012, p. 21)

With Lockheed Martin now at the helm of logistical support, this may be an ideal time to do just this: look at the fundamentals of *how* and *what* at McMurdo Station, the largest facility on the continent.

A sustainable future for McMurdo Station will hinge on the resolution of fundamental problems that have developed over several decades of budgeting challenges and neglect. While many of these problems fall outside the scope of this work (see Section 1), a number exist in the realm of architecture and a few specifically within the intersection of design, energy efficiency, health, and comfort. Other nations have proved that smaller-scale installations are capable of providing safe, comfortable, and energy efficient scientific research stations. McMurdo Station, however, is a different challenge because it is more like a town than any of these small stations, which tend to have a more intimate feel to them.

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[23] Specifically, these improvements are in regards to the reduction of the spread of communicable disease in these buildings.

One area yet again singled out for improvement in McMurdo Station is housing. The panel report acknowledged that housing was a significant factor in the well-being and morale of the station, with conditions being so demanding and the location so remote (Augustine, 2012, p. 140). An initiative announced in 2012 to move the Air National Guard quarters[24] to one of the older dorms (Building 210) and increase the number of single bedrooms for the rest of the population (science grantees excluded) is a first step in addressing this challenge (Rejcek, 2012a). Although design drawings have not been released, double rooms converted to single-person rooms will necessarily become smaller. Additionally, recommendations for streamlined logistics may reduce the overall number of people required to run the station, thus lessening the strain on housing availability.

By 2014 the following recommendations had been implemented. 1) By moving certain groups into the smaller, older dormitories,[25] larger, newer dormitories (e.g., Buildings 206-209) are made available for more "permanent residents" (those staying 98 days or longer).[26] 2) All science grantees are housed in the 203 series dormitories regardless of length of stay, removing some principle investigators previously allowed to live in Building 209. 3) A system based on duration of deployment determines the

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[24] The Air National Guard out of Schenectady, NY, pilots the C-130 aircraft flying to and from Christchurch, NZ, to McMurdo and beyond to other locations like the South Pole. The pilots have rest requirements which put them at the top of the list for single rooms on the station (Rejcek, 2012).

[25] That is, military personnel (Bldgs. 202, 210 and 211) and the SPAWAR Office of Polar Programs (OPP) (Building 201).

[26] Permanent Residents stay for 98 days or longer; Transient Residents stay for 28 to 98 days; Temporary Residents: stay for 27 days or less. (Rejcek, 2012a).

category of dormitory, with the old systems of “ice time” no longer used.[27] While these proposed changes may be welcome, they are not yet part of an overall plan to approach and design McMurdo Station as a community.[28]

For instance, the traditional double-loaded, straight-line corridor may be the most efficient way to house people, but it is not the most welcoming sight. Lounges located at the ends of the hallways (on most floors) are not acoustically isolated from those trying to relax or sleep in the rooms nearby. This style is typical of the 16 dormitories currently in McMurdo. Since each building is detached (e.g., Buildings 203-211, MMI, HoCal), it is necessary to go outside to reach another dorm or any other building, making visiting other dorms –or perhaps the gym or social hangout- less convenient, often undesirable, and sometimes impossible (i.e., during severe weather). Finally, the collection of dorms has no sense of connection, and is sorely lacking in private and semi-private space.

2.4.1 OZ Architecture LRDP, 2013

It was with these problems and recommendations in mind that a design firm engaged by Lockheed Martin, OZ Architecture of Denver, Colorado, proposed a long-range plan for McMurdo Station that was the latest in the succession of long-range plans previously described. Their vision for the station takes an old idea –consolidation– to a new extreme, with nearly every function of the station contained in one massive

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[27] The number of months one has spent “on the Ice” (in Antarctica) (see Appendix Q).

[28] Also, there does not yet seem to be a proposal to provide people working the night shift a better way to sleep undisturbed and socialize in their dormitories; currently these residents share floors –and sometimes rooms– with day workers, which can lead to tension over noise.

Figure 3: OZ Proposal for McMurdo Station early rendering. (OZ, 2013, p. 10.)

structure. Excluded are the Vehicle Maintenance Facility (VMF), Medical, the helicopter hangar and dive locker, the generator warehouse and water and wastewater treatment plants. In the proposal the NSF Chalet will be transformed into the new Coffee House. The brand new Science Support Center (SSC) (Figure 19) will be converted into a facility for field staging and cargo handling, possibly replacing the Berg Field Center (BFC). Finally, all current dormitories will be demolished and rebuilt as appendages on the single large building. A few of these buildings will be connected by surface ("structured") or elevated ("overhead") walkways.

In addition to footprint consolidation and increased energy efficiency, the proposal mentions several design aspects such as visual clutter, pedestrian safety, and an increased use of multipurpose rooms. The look of the station, while not visually impressive or distinct, is modern and presumably more energy efficient (Figure 3). In a radically different approach to station design, multiple buildings are combined into one large complex, separated by fire walls. This building combines all recreational, commissary, office, and housing functions. This is useful especially during winter, but massing such a large building carries with it special challenges (see Section 4.1.5).

A few concerns with housing are apparent from the early OZ design drawings. The large, three story dorms unfortunately go one step farther than today's double-loaded corridors, and include four rows of interior rooms with no windows, a feature disliked by current residents and listed as a potential fire safety issue in earlier LRDP and energy studies. The walkways, while protective and convenient, are underutilized as extra space for people to occupy as lounges or viewing areas. (For a discussion of dormitory design, see Appendix G).

2.5 Overview of Housing in Selected non-U.S. Antarctic Bases

The Antarctic research stations of other countries have achieved success in design and energy efficiency using different approaches. Many have greatly reduced their station footprint and their reliance on fossil fuels, successfully combined design with energy efficiency and comfort, and even integrated alternative energy sources into their power grid without sacrificing performance or safety. Although all of these stations are smaller than McMurdo Station, usually operating under different circumstances,[29] and none are large logistical hubs, there are many lessons regarding their design and improved energy efficiency that could benefit future changes for McMurdo Station. See Appendix F for more information.

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[29] For example, location (rock or ice), program, size, and annual schedule (whether or not the station operates during winter).

2.6 Summary: Lessons From a History of Housing Design

Several lessons can be drawn from this chapter, many of them having to do with achieving the right balance between: 1) decentralization and environmental footprint; 2) convenience and fire prevention; 3) flexibility and simplicity; 4) heating and ventilation; 5) trusted and new building technology; 6) privacy and the cost of square footage; 7) convenience and shift housing segregation; and 8) expediency and the importance of the quality of the interior. Additionally there is importance information from 9) non-U.S. stations; and 10) the legacy of McMurdo Station

1) Balance decentralization and environmental footprint: Compartmentalization of supplies and building functions is a health and safety issue because of the great time and distances between a station and relief in the event of an emergency. In addition, the time required to repair or rebuild a damaged building or non-functioning piece of equipment (e.g., power generator) makes backup power, emergency supplies, shelters, fuel, and other necessities a top priority. In a large station, the magnitude of this task increases.

At the same time, as functions are duplicated (for safety) a large station becomes larger still. The amount of land disturbed by humans increases. Since 1961 it has been a goal to keep McMurdo Station compact, but it was easier not to do so. As is apparent now, more numerous small-to-midsize buildings mean more exterior walls, higher construction costs, and higher rates of heat loss (compared with fewer, larger structures). When it comes to fire protection, recent technology (e.g., fire walls, see Appendix J) is making it safer to rely on fewer buildings, but it is clear that the decision to consolidate buildings should not be taken lightly.

2) Reduce Risk Through Fire Prevention Techniques: In such a dry environment, fire detectors and fast response sprinkler systems can often determine whether or not the building survives and whether the fire spreads or is contained.[30] Large, multi-purpose buildings should also have fire breaks, in essence becoming multiple buildings under one roof. General measures such as a non-smoking policy and official cigarette disposal containers help reduce the risk from accidents. In addition, buildings should be spaced to allow heavy vehicle and emergency access. Again, although the extra distance between buildings is becoming less necessary as a fire safety measure, the decision to consolidate buildings under one roof means that other decisions about fire protection will come to the forefront (see Appendix J).

3) Balance Flexibility and Simplicity: Not despite, but because of the remote location, buildings in McMurdo should be flexible enough to accommodate the short and long-term "24/7" needs of a large station, with its stark seasons and annual fluctuating population through simple, straightforward designs that are easy to maintain. Flexibility and simplicity were two hallmarks of the early naval structures: customizable, easy to transport and erect. As the station grew larger and the program stretched into the long term, these buildings allowed flexible growth but could not withstand the elements, the need to conserve energy, and the changing composition of the workforce.

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[30] Today McMurdo Station complies with multiple guidelines set by the NFPA (the National Fire Protection Agency), but sometimes, because of the extreme and unusual conditions, meeting the intent of the code is as close as fire inspectors can get (Fey, 2011).

Today, with careful planning and foresight, is it increasingly possible to achieve these goals while maintaining both simplicity and flexibility. For example, prefabricated building parts feature an improved insulated envelope; made in a factory setting, they are crafted more precisely and come together more easily on site. Flexibility comes with stockpiling spare parts and building pieces.

4) Balance Heating and Ventilation: The first obvious HVAC need in McMurdo Station is of course space heating. Creating a tight, well-insulated (i.e., airtight) building is an important factor in thermal comfort. However, there is also a need to introduce fresh air. While older buildings relied on natural infiltration to provide extra fresh air, modern, well-sealed buildings need mechanical systems to keep the air fresh (and free of pathogens). This is important in keeping people healthy and productive. Most of the HVAC equipment does not have to be highly specialized but it does have to be chosen well and maintained properly.[31] (See Section 4.2).

5) Balance Trusted and New Building Technology: With such difficult logistics, materials lists are often made a year or more in advance. Over the long winter it is unlikely that new parts or personnel would be flown in just for a maintenance issue or construction conflict. In this situation trusted, well known systems, materials, and methods are the most reliable, even if they are no longer the most efficient. There is a wealth of information about cold climate construction and building technology, with some specific modifications for Antarctica. It is essential that this body of knowledge be

[31] Today, systems such as air-to-air heat-recovery, ventilation systems provide fresh air more efficiently to buildings, they save energy (by reusing waste heat), can sometimes help provide adequate humidification, and contribute to healthy indoor air quality by introducing fresh air (see Section 3.3.2).

used and understood. It is also necessary to stay abreast of the latest technologies to see if they could (now or in the future) be used in Antarctica. New buildings and building renovations benefit from this information. (See Chapter 4 for more information).

6) Privacy and the Cost of Square Footage: Small spaces are easier to heat but can add to occupant stress because conditions are more cramped (see Chapter 3). Most of the time, people end up creating their own privacy to the best of their ability. Today this translates to the desire for more single occupancy rooms and other places in which individuals or small groups can get some time away from the rest of the people at the station. It must be balanced of course with the reality that single rooms for 1,000-1,200 people may not be feasible, or even necessarily required. One solution may be a room hierarchy based on length of stay or other special need.[32] The industry standard is pushing McMurdo Station closer to being able to grant more single rooms, but the promise of single rooms has yet to be delivered.

7) Reasons for Segregation: The traditional separation of officers and enlisted men may seem anachronistic, but it was considered an important practice when most expeditions had a naval background. With the current population of mostly civilian scientists and contract workers, this type of segregation is now discouraged (although currently in McMurdo Station there are some groups of people who receive priority housing, such as research PIs, pilots, and upper management). The main source of segregation today is self-imposed (i.e., social cliques), but perhaps the best reason for an

[32] For example, the Air National Guard members who pilot flights in and across the continent have always received personal quarters because of their need to rest well before a mission.

official housing segregation is between the day and night shift workers. This is because roommate schedules and noise complaints are severely complicated by mixing day and nightshift workers (United States Antarctic Program [USAP], 2010). Additionally, there is still reason for the separation of those higher up in the NSF or contact holder bureaucracy and those associated with the military or a military project, such as the SPAWAR OPP personnel.[33] In a recently announced housing plan (Rejcek, 2012), these groups of people will be first receive single bedrooms.

8) Importance of the Quality of the Interior Environment in Extreme Locations: The quality of the interior environment is extremely important when nearly all of one's time is spent inside. Some design challenges are also important to consider alongside issues like proper ventilation and energy budget. Besides areas for exercise, entertainment and socialization, these include: 1) the provision of adequate areas for privacy; 2) access to natural lighting and adequate artificial lighting; 3) access to nature (plenty of views to the ocean and mountain beyond); 4) greenery (e.g., hydroponic greenhouses), and 5) artificial types of "nature" (e.g., artificial plants and artwork).

9) Lessons from Non-U.S. Stations: From the stations Halley VI and Scott Base (Appendix F) we learned it is possible and desirable to connect buildings for safety and comfort without creating a fire hazard, whether one is on an ice shelf or solid ground.[34] It is also desirable to create places in the station which feel homey and comfortable after

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[33] The Air National Guard pilots are required to rest for certain periods of time between flights and have always had private rooms.

[34] Another lesson learned is that buildings not located on solid ground have a different set of challenges when it comes to their foundations, and that this tends to affect the approach taken towards the lifespan of the structure. The new South Pole Station was designed to operate optimally for at least 25 years (Ferraro & Brooks, 2002, p. 223).

a day (or more) spent in a lab or out in the field. Quiet places to relax and sleep are important, but so are places to socialize. From the Princess Elisabeth base we learned that passive buildings are possible, but (so far) only on a limited scale and time frame. Because this base is a single building, one design feature that helps make this possible is a nested design to protect sensitive equipment from extreme thermal fluctuations, minimize pipe and duct lengths, and free the building envelope for access to natural light and views.

From Mawson Station and Scott Base we can observe a hybrid energy system that seems the most likely path to a low-emissions, reliable, year-round energy system for Antarctic research stations. While this may not yet include emissions sources like transportation (i.e., air, land, and snow), it is far beyond a system totally reliant on diesel or nuclear power.[35] From these two stations we can also observe a hyper-vigilant approach towards safety with two different responses: connected versus stand-alone buildings.

10) Legacy of McMurdo Station: It is necessary to think of McMurdo Station in terms of long-term town or city planning. The civilian support contract holder may change every decade (or so), but this should not impose limits on planning foresight.

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[35] Also without the use of foreign species. Up until the 1960s sled dogs were still in use at Scott Base, despite the Environmental Protocol banning their existence on the continent. When motorized toboggans ("tin dogs") became more practical, the use of the dogs began to decline. Once Weddell seals became protected it was even more difficult to justify their presence, since each year up to 40 seals were slaughtered for dog food. There was also a question of whether diseases like canine distemper could spread to the seal population. The dogs, mostly Greenland huskies, were not completely removed until 1987. (ANZ, 2005, "FAQ")

As many of the newer international stations have shown, the design of these remarkable places becomes a symbol in itself, something of a "'…statement of national pride,' competing with one another in stylishness, size, and technical complexity" (Science, v. 341., p 441). McMurdo's track record is undoubtedly impressive, and its ability to assist other countries and other stations is undeniable; however, its image and appearance are far from a statement of national pride.

The architectural/planning history of the station, including the decisions of the multiple contract holders, should be well documented in a single location so that designers and planners in the future may learn from past mistakes and successes.

For a large, older station like McMurdo, the momentum behind it makes change more difficult than a small station like Princess Elisabeth or a nimble station like Halley VI. But as has been pointed out, change is inevitable, and the station is in need of new solutions. A recent panel committee on the future of U.S. Antarctic stations noted that "[s]imply working harder doing the same things that have been done in the past will not produce efficiencies of the magnitude needed in the future" (Augustine, et al., 2012, p. 30). McMurdo Station must look to the long term if the USAP wishes it to continue to function as a logistical powerhouse as well as a world-class research station.

3. REVIEW OF BEHAVIORAL STUDIES IN EXTREME ENVIRONMENTS

The remote nature of Antarctica has historically made it a "natural laboratory" for an array of scientific research,[36] including human physiology and psychology in Isolated and Confined Environments (ICE) (Suedfeld & Weiss, 2000), a subset of Extreme and Unusual Environments (EUE) [37] (Suedfeld & Steel, 2000). When the U.S. established a permanent presence in Antarctica, organizations such as the Navy Bureau of Medicine and Surgery (BUMED) –and later NASA and other agencies– commissioned studies on how very cold conditions and prolonged periods of light, dark, and isolation affected human physiologically (Duncan, 1988; Keatinge 1961; Palinkas, 1986) and psychologically (Bluth, 1985; Gunderson, 1973; Mocellin et al., 1991; Strange & Klein, 1974; Vallacher and Gunderson, 1974). These studies included group dynamics and the effects of isolation during long deployments in submariners (Daives & Morris, 1979; Kinney et al., 1979; Weybrew & Molish, 1979; Weybrew & Noddin, 1979) or Antarctic stations, which were viewed as analogous environments.[38] Many of these studies were published between 1960 and the early-1990s.

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[36] For example, astrophysics and geospace sciences, earth sciences, glaciology, integrated system science, ocean and atmospheric sciences, and Antarctic organisms and ecosystems

[37] In this case, "extreme" "…indicate[s] physical parameters that are substantially outside the optimal range for human survival…" and "unusual" indicates "…conditions that deviate seriously from the accustomed milieux [sp] of most (but not necessarily all) human communities" (Suedfeld & Steel, 2000, p. 228).

[38] Antarctica was often used as an "analogue environment" for outer space, allowing studies of human behavior and physiology response to a remote, dark, and alien landscape (Harrison, Clearwater, & McKay, 1991). The analogue between Antarctica and outer space environments was used for many years to inform

Their primary focus was the physical and psychology health of deployed men[39] and their ability individually and collectively to execute orders and achieve mission goals. Therefore, little interest was paid to the built environment (beyond the engineering of basic survival mechanisms like a breathable atmosphere[40] and heating/cooling) until later when psychosocial issues of small groups in confined environments (e.g., "capsule environments"[41]) came to the forefront. In Antarctica, the USN provided rooms for recreational activities and exercise, but little beyond. For some time NASA "…generally downplayed the probability of psychosocial problems among its rigorously selected astronauts, but the Soviet space program and its Russian successor [were] much more open to the issue" (Suedfeld & Weiss, 2000, p. 10). In the 1980s, with the real possibility of a space station on the horizon, attention turned towards the psychological implications of long-term habitation in space (Bluth, 1985, p. 204).

In Antarctic studies of human behavior, the focus has recently turned away from the negative effects of wintering-over in Antarctica –the so-called "winter-over syndrome" – to positive ones, including improved health,[42] feelings of accomplishment, and increased problem-solving skills (Carrére, Evans, & Stokols, 1991; Palinkas, 1991). Most notions of Antarctic mid-winter psychological breakdowns have been reduced to

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research on human existence off the planet, since it was easier to simulate, study, and train in an analogous environment than in space. Eventually the information flowed both ways, with information from NASA about "… functional requirements, volume, privacy, windows, color, and décor…" applicable not only to space vessels but in Antarctic research stations (Harrison, Clearwater, & McKay, 1989, p. 255).

[39] Women did not appear at USAP stations until 1969/1970.

[40] It is important, however, to ensure high indoor air quality is maintained when so much time is spent inside. See section 4.3.4 for more information.

[41] Remote, difficult to access, artificial habitations located in places hostile to human life, e.g., the South Pole or outer space. See Appendix Q.

[42] Often these improvements were temporary, the positive effects receding within one year of leaving Antarctica.

anecdotes, isolated incidents, or exaggeration, but problems stemming from overreactions to minor setbacks and boredom brought on by the monotony of daily life persist (Suedfeld & Weiss, 2000). Spending six months or more confined to an interior environment while the outside is either in near or total darkness or daylight will have an effect on most people, more so on those predisposed to boredom or depression. While there are certain factors (such as the weather) that cannot be changed when working in Antarctica, the design of the interior environment is largely controllable and –when done well– may contribute significantly towards the inhabitants' health and happiness (Carrére and Evans, 1994, p. 709).

3.1 McMurdo Station as an I.C.E. Community

McMurdo Station, with its size, relative accessibility, and most recently, satellite voice communication, television and radio, and high-speed internet,[43] no longer experiences the same degree of isolation as in the past. Indeed, the station was identified by those studying the space analogue as an excellent model for simulating not the small, confined spaces that will be typical of early space expeditions, but "… the transition from isolated group to isolated community, a transition that will occur on the moon, Mars, and elsewhere when initial camps are replaced by permanent work bases" (National Commission, in Harrison, Clearwater, & McKay, 1989, p. 254-255). With

[43] Until the end of the 20th century, the main means of communications outside the station was ham radio (which offered no privacy) or "snail mail," letters by post, which could take weeks to reach the U.S. and even to reach McMurdo, where they were considered low priority compared with food and fuel. The midwinter mail drop (by plane) stopped around 1996 with phone lines and the internet becoming easier to use. Eliminating the midwinter mail drop to McMurdo and South Pole Stations saved around $1 million (in 1996) (Browne, 1996).

these changes to McMurdo station –including unprecedented access to Antarctica and McMurdo Station[44]– further studies are required focusing on a larger, more diverse group of people working in physical (but not so much social) isolation from the rest of the world.

There are still many unusual aspects to daily life in a large Antarctic research station, beyond the extremely cold temperatures, dry air, and sun's unusual position. Because of its relative (physical) isolation and "lifeless" terrestrial environment, some people have likened it to living in a lunar colony. Although it may be the size of a small town, there are no minors (under the age of 18) and proportionally there are fewer women than men.[45] Most people are confined for six to nine months (and up to 14) to the few square miles that make up the station. McMurdo is composed largely of legacy naval buildings, leading numerous reports to describe it as a combination of an old army outpost, a mining town, and a college campus (DMJM, 2003, p. 1-2). Even so, the opportunities for socialization, isolation, and sight-seeing at McMurdo Station –a city by Antarctic standards– far outnumber smaller and more remote stations.

The composition of the station population is different from previous decades when it was dominated by military men. There are now more women, nearly no active-duty military personnel,[46] and more people accustomed to internet access. They know that standard housing for other private industry job positions in remote locations such as

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[44] Flights to the station during seasons previously considered logistically to difficult or dangerous (mid-winter and later winter, because of weather conditions and darkness) are becoming increasingly feasible, if not yet common. Limited tourism has begun.

[45] During Mainbody the ratio is roughly 30% women, 70% men.

[46] Since the Navy left in the mid-1990s, these are mostly Air National Guard (ANG), who make up roughly 12% of McMurdo's population during Mainbody.

Alaska and off-shore drilling platforms is single occupancy (with shared bathrooms), regardless of the season (DMJM, 2003, p. 3-37). Currently McMurdo offers single rooms only during times of reduced occupancy during the winter. This provides additional comfort and privacy to the winter-over crew, but leaves the crowded summer population at a disadvantage. The Office of Polar Programs recognizes that "… the current double occupancy standard impacts the USAP's ability to recruit and retain highly qualified participants …" (OPP, 2003, p. 5).[47] This in turn increases operational costs because new employees must be trained more often.[48]

3.1.1 Common Sources of Stress at McMurdo Station

While McMurdo Station may be less isolated than in the past (and relatively less isolated than other stations) and while its larger size often means it is less confined, it remains a physically isolated research station in which residents (sometimes over 1,000) spend all or a significant part of their day indoors because their job or the weather requires it. Because of the station's size and large population, the confinement of residents to indoor spaces and to its borders (both political and physical) means that space is at a premium. Increasing the number of single bedrooms at the station has been a recommendation for years, but between spikes in energy costs and a prolonged contract renewal process (Mervis, 2011), these new dormitory facilities remained just over the horizon for many years.

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[47] Occupants of comparable locations like drilling rigs, even those living on the International Space Station- have private rooms.

[48] The Antarctic contract is awarded every decade or so to a new company (so far no contract has been awarded to the same organization twice) to keep this from happening. While experience working at the station is invaluable, there is also good to be had from "new blood." To the extent possible, overlapping seasons should be used to pass on experience to new hires.

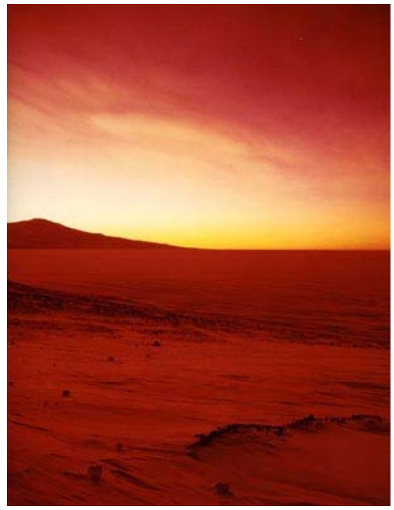

Figure 4: A low sun angle creates a Mars-like feel to the white continent.

Generally, sources of environmental stress found in McMurdo Station are similar to those reported by early astronauts: color (either a lack of it, or the wrong color), too few windows (for Earth gazing), too much noise, too few good smells, too few sensory stimuli like plants or small animals, and not enough personal space (for privacy and personalization) (Bluth, 1985, p. 203). It is worth noting just how accustomed we are to a planet that boasts such variety (i.e., color, biodiversity, weather, and human interaction) that its absence is felt psychologically. For many inland Antarctic stations, especially those on the polar plateau like South Pole Station (U.S.) and Vostok Station (Russia), the view generally consists of a white and blue, unbroken horizon, although there are still moments of magnificent displays of meteorological phenomena (Figure 4, Figure 20).

Residents of coastal stations (like McMurdo and Palmer Station) have more access to the natural environment; some enjoy views of the shore-fast ice breaking out annually and sometimes animals (such as marine mammals and seabirds). For most people these views are possible from the edge of the station of from a window view (for safety, leaving the station is generally not allowed for purely recreational purposes). During the winter there is constant darkness, a smaller (and static) population, no scheduled flights or ships, and colder temperatures. These require that even more time be spent indoors, although because of its size and layout, people must still exit a building to get from dormitory to cafeteria, work, gym, bar, and nearly any other building in the station. This itself can become a source of stress for some, especially those suffering from dry and irritated skin on their hands and face, and those recovering from respiratory ailments.[49]

Even if most people in McMurdo are not severely affected by its hardships, problems persist. Some are more affected by the prolonged darkness or isolation. Symptoms of the noted winter-over syndrome include depression, irritability, exhaustion, cognitive impairment, altered states of consciousness, withdrawal, apathy, psychosomatic problems, neglect of personal hygiene, sleep disorders (“big-eye”), lack of concentration (“long eye”) and impaired cognition (“driftiness”) (Oliver, 1991). These run parallel with typical signs of stress and are generally counterproductive to working well with other people. The opposite extreme of this issue is the perceived overcrowding during the summer season (Mainbody).

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[49] That is, from a cold. People with chronic respiratory problems would never pass the medical qualifications required to work in Antarctica.

To some working at McMurdo Station, the winter season is preferable because it is less crowded; everyone has a single bedroom, there are fewer people in line at the galley, and in general there is less commotion around the station. While many people finish a season in McMurdo with positive memories, the employee retention rate is 50-60% (Augustine, et al., 2012, p. 71; Pomeroy, 2004), which is still a relatively good number for such an unusual and demanding job.[50] However, the costs of training new employees and the loss of knowledge gained by experienced employees are high.[51] It is of benefit to the station and science program to provide a positive, comfortable setting for the people that keep the station operational (OPP, 2003).

If a well-designed interior environment improves the quality of life and employee retention, then it should be considered a major factor in the design of the station, along with energy saving measures, and not just as an afterthought. Therefore, it is important to study these challenges and the corresponding potential design solutions, and then integrate these solutions with energy efficient designs or improvements to better enable McMurdo Station to continue its mission sustainably, not just by saving energy, but by fostering a satisfying work environment that attracts and retains high-level employees.

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[50] It is difficult to compare this rate with anything else since McMurdo Station offers numerous types of jobs ranging from janitor to medical doctor. Most scientists do not work at McMurdo, per se, but travel there to execute a project and then leave. Lower level jobs (e.g., dishwasher) may have higher turnover rates than lab assistants, and since nearly everyone is offered an annual contract, there is no clear path for advancement for staying long term. Even a comparison with an analogue environment – for instance, an oil driller in Prudhoe Bay- does not serve well because those conditions –while extreme– are still too dissimilar for an accurate comparison. The turnover rate for offshore oil rig workers (regardless of location) can be 15-35% (McConnon, 2009). Note: turnover rates are not the inverse of retention rates.

[51] Contract employees who complete a full season are eligible for bonus based on performance evaluations; those who remain for consecutive summer or winter seasons are rewarded with a bonus, $1,000 at McMurdo and $1,500 at South Pole Station (Pomeroy, 2004).

3.2 Designs to Mitigate the Effects of I.C.E.

> *The professional care and attention to detail given to the engineering problem of having the spacecraft in orbit and keeping the humans in it alive is proportionate to the neglect of basic architectural and psychological issues, which, if considered at the beginning of the design process, would actually reduce costs and could contribute to the development of space habitats that are more than inhabited machines.* (Vogler & Jørgensen, 2005.)

This is an interesting and important notion to remember, as it appears many times over the course of the history of human occupation in hostile environments, including Antarctica. Addressing the deeper needs of the human condition is often overshadowed by the initial feat of merely surviving in extreme conditions. Actually, the disconnect in the design of human habitats between what is seen as functionally necessary for survival and how humans actually live is most apparent in extreme environments, but perhaps nowhere is its resolution more important (Haines, 1991; Vogler & Jørgensen, 2005).[52]

A good example of this is a story from the early days of manned spaceflight. During the design phase of NASA's Mercury program (1959-1963), there was a dispute over whether to provide a window for the manned capsule. Gus Grissom and John Glen had to fight for the inclusion of window on their tiny capsule, an idea which was deemed unsafe at first but eventually afforded them a spectacular view of the earth without becoming a safety problem (Haines, 1991, p. 351). In this case the window was not necessary to the mission, but what a missed opportunity if it had been omitted.

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[52] Haines, (1991) goes on to write that the need for visual stimuli (escape) increases the longer one spends in a confined environment; however, if the outside environment is considered "hostile," then time away from the window was also desirable (Haines, 1991, p. 355). These conflicting contexts must be considered for McMurdo Station.

3.2.1 Design Guidelines for Increased Health and Productivity

In a recent survey[53] of people working at McMurdo Station, 50% of respondents listed “Experience the Antarctic environment” as an “essential” part of their decision to work “on the ice” (National Research Council [NRC], 2010). Yet, at McMurdo Station many people find themselves working, living, and recreating indoors, with few opportunities to explore outside the station. Some studies suggest that interior environments with pleasing views (that include some part of the natural environment) can help alleviate mental fatigue brought on by the effort required to concentrate on a task (Kaplan, 1993). In the Antarctic, where a window can be viewed simply as a source of heat loss and where the landscape may be “devoid of life,” a window still affords those confined to the indoors a connection to the outdoors: a view of the sky,[54] severe weather conditions, changing shadows and light levels, and (when present) nearby physical features.

Providing extra privacy through more extensive single-room availability would possibly increase the square footage requirements,[55] but would also bring the station up to modern standards and provide relief to long-term residents (not just winter-overs). In the UFC design criteria for Arctic and Subarctic construction, this recommendation is listed under the heading “Morale,” which also includes other recommendations like extra

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[53] For more information, see Appendix P.

[54] Sky conditions can be highly variable during the spring and fall seasons, with the presence of nacreous clouds (Figure 20) and other colorful displays due to the sun’s low and constant angle. During winter, if there is not too much light pollution, auroras are also visible.

[55] Efforts to streamline logistics may, in the long term, reduce the overall size of the staff needed to maintain the station; however, until that level of efficiency is achieved, the station population may remain large, especially if there is extra staff on site for construction projects. Unfortunately, this may mean that the number of funded science projects may temporarily decrease.

rooms for indoor spaces, multiple indoor recreational options, and high-quality bedrooms that can provide a restful environment (e.g., rooms with "… proper temperature and soundproofing" (DOD, 2004, p. 1-1). Although it is not stated, the implied quality is that one may have a sense of *control* over his or her *own* space.

In response to environmental stressors listed by the astronauts (lack of color and windows, noise, levels of sensory stimuli, and personal space), a number of studies and publications called for increased attention to the way people use space and the way humans need certain amounts of sensory stimuli as well as private and public spaces, even in the extreme environs of outer space (Haines, 1991; Stuster, 1996, p. 200-201; Suedfeld & Steel, 2000; Vogler & Jørgensen, 2005). Besides a few unique requirements regarding weightless environments, these suggestions could be applied to any ordinary indoor environment, but are often neglected in extreme situations (like space travel) because functional requirements often override any consideration of them. What these authors argue is that in extreme environments and confined spaces, these "soft" or "aesthetic" considerations should not be sidelined and should be considered as part of the success of a mission.

Vogler and Jørgensen (2005) discuss different types of architectural space and how they apply to space habitats –and by extension, polar research stations.[56] They list four types of space (physiological, perceptible, psychological, and sociological), explaining how each one plays a part in creating a habitable space that does not

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[56] In their paper Vogler and Jørgensen (2005) connect architecture, anthropology, and psychology to the design of space habitats.

contribute to the stress of the inhabitants (Vogler & Jørgensen, 2005, p. 393). For instance, psychologically, humans need a balance between privacy and social interaction. In a confined environment with no "outside" or "away" as a retreat, there must be a physical space for both of these activities.[57]

3.2.2 Design Guidelines for Increased Health in Hospitals

Although residents of McMurdo Station (and other Antarctic research stations) are able-bodied and have undergone medical examinations before deployment,[58] it is possible to draw some parallels between the design of the station and the design of restorative spaces in hospitals. See Appendix L for more information.

3.3 Summary of Behavioral Studies and Recommendations

Translating design guidelines for ECEs and ICEs to McMurdo Station is a challenge because of the scale of the operation and the tradition of providing functional spaces that did not take into account how people would actually use them. In his chapter on the importance of window design in confined environments, Haines (1991) argues that while the aesthetics of a window are typically considered after functional needs such as light, heat, and ventilation, such considerations in confined environments become more important. "Every window installation should be conceptualized very early in the design process in order to achieve the best overall compromise in design (Haines, 1991,

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[57] The transition between and demarcation of these two zones –often involving doors and windows– was the focus of their paper.

[58] This process is called being "PQ'd." If one is deemed PQ (physically qualified) then the rest of the travel arrangements to Antarctica can proceed. If one is NPQ (not physically qualified) it means that there is either a missing test, vaccination, an unresolved medical issue, or a test result has shown that the person has not passed basic physical requirement tests.

p. 352). This frame of mind must be applied at the entire building scale and, for McMurdo, the station/community scale. In addition, a number of other design changes could improve not just the look of the station (universally derided), but its ability to provide safe, healthy, and comfortable places for its many denizens.

The importance of the interior environment is heightened when the occupants spend most of their time inside (because of severe weather conditions). If a well-designed interior environment improves the quality of life and employee retention, it should not be an afterthought of the design process, but a major part of it. Even NASA, designing for a much more hostile environment than Antarctica, has conceded this. It is important to study these challenges and corresponding design solutions, and integrate these solutions with energy efficient designs to enable McMurdo Station to continue its mission sustainably, not just by saving energy, but by fostering a satisfying work environment that attracts and retains high-level employees.

Therefore the following are recommended:

1) McMurdo must commit to the creation of more single bedrooms *without resorting to interior windowless rooms*. These rooms will not only allow residents (especially those staying more than 90 days) a chance at some privacy every day, but also a space to personalize. This will mean no longer having to "wall off" a roommate with bulky dorm furniture.
2) More attention should be given to the functional segregation of certain groups, such as night shift workers, supervisors, and Air National Guard.

3) At the same time, certain connections must be forged, both literally and figuratively. While maintaining high standards of fire safety, there should be a way to move among dorms and the galley without going outdoors. This idea should extend to some –if not all– activity areas including gym facilities or humidified greenhouses/lounges. Being able to visit other dorms should be easier. With the long days and work weeks (9 hours or more, 6 days a week), it is not easy to find the motivation and energy to go outside for a visit to the gym, which itself is not large or well-equipped. The physical connection to this area would allow people access without having to go outdoors and be a modern, inviting facility to exercise.[59]
4) The connection between buildings should be more than a passageway but a destination in itself, providing extra community space that is open and inviting. With well-placed windows it would provide a figurative connection for the station residents and a protected way to view the outside environment, something not every room or office offers. It would not be the only option, and if one does want to walk outdoors that should also be possible.

Although a community passageway among buildings would come at a cost both in terms of square footage and energy, but that cost could be mitigated by increased

[59] The current gymnasiums at McMurdo Station are limited and scattered about the station in some of the older buildings. In an old Quonset hut near the helicopter pad is a half-size basketball court and small rock wall. In a T-5 building near the Coffee House is "Gerbil Gym," which has a small selection of stationary bicycles, treadmills, old weight machines, and a small "floor aerobics" area with mats and free weights. A weight gym located across from the library in Building 155 has larger weight machines for body building exercise. It is in the north section of Building 155, which is not accessible from the south section.

energy efficiency, and from other areas of energy conservation at the station. All this would be aside from providing positive health benefits to the people working at the station. As Tom (2008) notes, if we refuse to acknowledge the importance of a healthy, comfortable design, we run the risk of focusing too much on saving energy and money (worthy goals) and “forgetting the primary reason why the energy consuming systems were installed in the first place. The purpose of these systems … was to provide a comfortable and healthy place for people to work” (Tom, 2008, p. 19).

4. REVIEW OF CHALLENGES FOR MODERN BUILDINGS IN VERY COLD, DRY CLIMATES AND REMOTE LOCATIONS

The extremely cold and dry climate of Antarctica requires more than the normal cold-weather design and engineering to achieve energy efficiency as practiced in the U.S., including Alaska. The effects of freezing and thawing on buildings as well as the wide temperature range (inside/outside, summer/winter) mean that materials and mechanical systems must be sturdy, resilient, and flexible. In addition, McMurdo Station's remote location requires a large initial investment in transportation of materials –usually relying on traditional, carbon-emitting sources of energy– no matter what material or structural systems are chosen.[60] Although the primary reason for occupying the continent may be geopolitical, polar science ostensibly the reason for our presence as specified in the Antarctic Treaty. Therefore, the goal of preserving the environment[61] while ensuring financially sustainable logistics to support the ongoing research program makes it a challenging effort.

[60]Depending on the definition of an energy footprint, the manufacturing and delivery of materials to Antarctic may never be a low-emissions endeavor. Although certain options may decrease transportation costs of materials or HVAC systems, it is important to remember that these choices will have an effect elsewhere in the big picture, which is where the design matrix (Appendix O) becomes useful.

[61] The environment of Antarctica itself is a subject of study, not just a setting for other experiments. Like any other scientific experiment, it is imperative that the observers not interfere with (contaminate) the subject.

A good way to maximize the investment[62] is to make McMurdo Station as energy efficient as possible. One conclusion made clear by the history of McMurdo Station is that –especially in such a challenging and remote location– well thought-out design and engineering choices made prior to construction are crucial to the long-term success of a building. Unfortunately, McMurdo Station has a long legacy of poor maintenance and delays in facilities upgrades.[63] Most efforts to improve the station have focused on small-scale improvements. This chapter includes several building, mechanical, and structural topics, which collectively are referred to as *Cold Regions Best Practices* (CRBP). The focus will be on best practices for new buildings rather than the renovation of existing structures.[64] Issues discussed include site planning, building form, building envelope, fire safety, natural and artificial lighting, HVAC, structural systems, and material choices.

4.1 Introduction

Problems common to all extremely-cold and remote locations include: 1) fire safety and containment, 2) moisture and mold in structures not properly sealed, heated,

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[62] Presidential Memorandum 6646 states that "[e]very effort shall be made to manage the program in a manner that maximizes cost effectiveness and return on investment (OPP, 1997).
[63] A statement in the 1997 report from the Blue Ribbon Panel puts it this way: "[a] consequence of the NSF's traditional focus on the conduct of science, together with the character of the federal budgeting process — which, unlike commercial practice, does not ordinarily include a depreciation account to provide for the renewal of fixed assets — is that aging U. S. facilities in Antarctica are costly to maintain and, in some cases, of arguable safety. The Panel believes that the U. S. would not send a ship to sea or a spacecraft to orbit in the condition of many of the facilities in Antarctica — and especially those at the South Pole. The efforts of the individuals assigned responsibility for operating these facilities are heroic — nonetheless, steps need to be taken without delay to remedy the existing conditions" (OPP, 1997, p. 2).
[64] For a list of recommendations for the station as it begins to upgrade its buildings, see the report issued by RSA Engineering (RSA, 2008).

and ventilated, 3) icing and snow drift (even in wind-protected areas), which causes damage to buildings and impedes normal access and emergency egress, 4) proper window construction with regards to heat loss and daylight, 5) location and siting of building(s) for wind and sun, 6) foundation design in permafrost, and 7) and water delivery and waste management.

Challenges specific to McMurdo Station include 1) the remote location, which exacerbates the embodied energy in the station as well as the station's lack of natural resources and waste disposal sites;[65] 2) a relatively large (i.e., 200-1,100 persons) population that must be fed and housed; and 3) the continuous requirements of maintaining the station infrastructure and serving the scientific program. Currently, those who run the station and manage its energy use must also contend with older, inefficient buildings and amenities.

Unfortunately, because of the size of the science program (the largest on the continent), McMurdo's current energy requirements are high and will remain so for the foreseeable future. The challenge remains to make the best of the station's current state with smart renovations, informed decisions, and a long-term comprehensive plan for the station that avoids the mistakes of the past.

However, much of what has already been tried is scattered in myriad documents, reports, and lost archival material. This represents a significant hole for any case study analysis. For this study, a great deal of effort went into finding these documents and

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[65] The exploitation of natural resources in Antarctica (i.e., mining, drilling) is prohibited by the Antarctic Treaty (U.S. Department of State, "Protocol" Art. 7, 1991).

putting them chronologically in the history of the station. For example, a document from 1972 written by individuals from the NCEL (see Section 2.3.1)[66] outlined the findings from almost three decades of working and building in the Antarctic. Updated in 1974, the *Engineering Manual for McMurdo Station* offers insight into construction methods at the time, some of which are still applicable today. On the whole, the document is now out of date,[67] but it nonetheless provides a good foundation, and its role in the station's history is acknowledged. It is a mix of observations and actual research that was intended to "…maintain a record of successful operating methods and [provide] sufficient background to prevent duplication of previously tried ineffective methods" (Hoffman, 1974, p. 1). The document contains descriptions of the environment and working conditions in and around the station, chapters on ice and snow properties, and instructions for building design, maintenance, and utility distribution.

Other sources of information include:

1) ASHRAE, which provides standards and design guides for determining thermal comfort and creating base-case designs, 2) the U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL), in New Hampshire, which provides information on materials and methods for cold climate construction;[68]

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[66] Sponsored by the U.S. Naval Support Force, Antarctica.

[67] Additionally, it never represented a comprehensive approach that included quality-of-life measures alongside chapters on foundations, heating and ventilation systems, and building maintenance. The latest plan for the station, OZ Architecture's Master Plan, includes a provision to "[c]onsciously revisit the Master Plan on a regular interval of every 2 - 3 years as it is a living document and to confirm the direction of the plan as the needs of Antarctic science and available technologies change" (OZ Architecture, 2013). If this goal is kept, is to be commended.

[68] This agency also oversaw the nuclear program in Antarctica.

3) the Unified Facilities Criteria (UFC)[69] for Arctic and Subarctic Construction, released by the Departments of the Army and Air Force, which provides guidelines and information about the construction and engineering of military establishments in very cold climates;

4) the Journal of Cold Regions Engineering, published by the American Society of Civil Engineers (ASCE) and sponsored by the Technical Council on Cold Regions Engineering, for a variety of topics including fire safety, fuel, and building standards;

5) the National Research Council (Canada) (NRC)[70] in Ottawa, which is currently producing research papers on evacuated panel insulations systems with an R-60 rating;

6) the National Renewable Energy Lab (NREL) in Colorado, which has completed studies on housing in cold climates as well as a preliminary study on the viability of a wind power on Ross Island;

7) the Center for Cold Regions Engineering, Science, and Technology (CREST) at the State University in Buffalo, New York, which is no longer in existence at the university but provided a tome on Cold Regions Engineering; and

8) the Cold Climate Housing Research Center (CCHRC) in Alaska, which contains a library on construction and design in cold climates;

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[69] The UFC system provides planning, design, construction, sustainment, restoration, and modernization criteria for projects of the Military Departments, the Defense Agencies, and the Department of Defense Field Activities.

[70] There is also an NRC agency in the U.S., but the two entities are distinct.

9) other individuals who have written about cold climate engineering and were usually residents themselves of cold regions, such as Alaska, Russia, and Scandinavia. All of these sources provide useful information that helped inform the more holistic approach used in this study.

4.2 Architectural Considerations

Architectural features that affect building performance and energy use in very cold climates considered in this section include: site planning; building form; building envelope; lighting (artificial and natural); and fire safety. These features are distinguished by not being a part of the mechanical systems of the building, but rather features that affect the appearance of the building and how it is constructed. Mechanical systems in Section 4.3 include: balancing thermal comfort and ventilation, heat recovery, interior air quality, and (again) fire detection and prevention. Later, in Section 4.4, structure and materials are considered, including logistics, noise control, and the pros and cons of different structural systems and materials (including fire safety).

4.2.1 Site Planning

A number of factors affect the layout of a group of buildings and the orientation of an individual building. One of them, site planning, is such a fundamental design decision for buildings that it should be acknowledged early in the design process [71] (National Renewable Energy Lab [NREL], 2004, p. 9). For example, site planning plays

[71] It is not clear how much direct solar gain could benefit buildings in McMurdo Station, given the extreme outside air temperature and the extreme swings between continuous sun and continuous dark. Building orientation to benefit from solar gains may not apply, unless one considerers solar tracking systems.

a role in large decisions like location of water delivery systems and more detailed decisions like daylighting design. McMurdo Station's location has turned into one of its most valuable assets. With its natural harbor, ice-free terrain, its ability to accommodate an ice runway,[72] access to both sea ice and the ice shelf, close access to the continent (i.e., the Dry Valleys), and a good position relative to the South Pole, it is ideally suited for its mission as a logistical hub and international scientific research facility (see section 2.2.1)

Factors that affect the layout and orientation of McMurdo Station include: its *historic legacy, topography, roads and fire safety, utilities, proximity to the ocean, sun path, and prevailing winds*. For an expanded discussion about these features, see Appendix H.

The best application of site planning at McMurdo Station is not clear, but it will probably break with conventional guidelines. With no families or permanent residents, the station is not quite a town. However, it is a community to the occupants who must live there for months on end with extremely limited opportunities to leave. The concept of *livability* arises when one thinks of land use and how people conduct every-day tasks; in other words, it is "… an appropriate arrangement, organization and management of housing, employment, services and recreation with effective access and connections

[72] McMurdo Station has had up to three runways: a snow-covered "permanent runway" on the ice shelf (blue ice runway) named after a C-121 that crashed there in 1970 (Pegasus, see Appendix Q), an annual sea ice runway in front of the station, and another snow runway called Williams Field (see Appendix Q). Recently, the decision was made to abandon the idea of an annual sea ice runway, favoring permanence over convenience. Should operations shift towards year-round operation, the permanent runway would make more sense.

among these components" (Pressman, 1988, p. 11). It is also necessary to consider how these buildings "fit together," in other words, how their form may affect their layout.

4.2.2 Building Form

Because Antarctica had no indigenous people – no ancient culture, no artifacts, no ruins – much of the relevant, previous literature regarding high latitude responses to cold climates focus on the Arctic and sub-Arctic and is not necessarily applicable to Antarctica. If mentioned at all, Antarctica is labeled "similar" to these regions, but not discussed further. Unfortunately this is misleading. The architecture of the high Arctic not only exists (because there is a history of people living there) but is moderated by a growing season, even if it is short (around 150 days) (Cook, 1996, p. 279). This might be applicable to sub-Antarctic regions (e.g., South Georgia Island, Macquarie Island, and King George Island) and possibly some areas of the Palmer Peninsula, but not to the rest of the continent and certainly not to Ross Island.

One possible solution for McMurdo is one that brings together building form and site planning to make aerodynamic, well-insulated shapes with connections between buildings that become distinct interior spaces. This is similar to the layout of the British station Halley VI (see Appendix F), but on a much larger and more complex scale. A connected station would still require a rational and coherent layout to allow easy access among certain buildings (e.g., dormitories-dining hall-exercise space, science labs, staging areas, equipment storage, and field supplies). These connections would also require extensive fire safety precautions and would not impede ground-level access, especially for emergency vehicles. These interior connections would allow passage among buildings but also become their own destination by providing more spaces for people to meet, relax, exercise, enjoy entertainment, and enjoy their location at the bottom of the world.

Contemporary Examples of Cold Climate Building Form

Modern examples of building form designed to withstand extreme conditions are the Princess Elisabeth base and Halley VI station (Appendix F). These stations were designed to withstand high winds and minimize snow drifting (Rodrigo et al., 2007) through their form. However, their locations (on a *nunatuk* and on an ice sheet, respectively) do not make good comparisons for McMurdo Station because those experience more snow drift. In addition, these examples represent single buildings or a few connected modules designed for under 100 people, not a collection of structures closer to a small town, or one very large building.

Igloo Design

While an igloo is an iconic demonstration of a bioclimatic approach to architecture (Olgyay, 1963) as well as a case study in the physics of the insulating properties of materials and the importance of building form, it is a small, temporary structure not suitable for a literal translation into a large-scale, scientific research station. For more information about igloo design, see Appendix I.

Surface-to-Volume Ratio

Domes (e.g., igloos) offer the best surface-to-volume ratio when it comes to minimizing heat loss, although for other reasons they are not always the best solution. Boxy buildings or offshoots from a single spine (as in the 1950s subnivean Arctic and

Antarctic naval stations; see Appendix D) tend to prevail mostly because they are easy to design, transport, and construct. Therefore care should be taken to reduce heat loss from the building in other ways, and designs that maximize exterior walls (e.g., “Habitat” style buildings, should be avoided (Rice, 1996, vii).

On a larger scale, the so-called composite-style station (single centralized building with most functions located under one roof) fit this description, far out-performing the organic (i.e., sprawling) multi-building station (e.g., McMurdo Station in its current form) (Figure 21).

Multi-building vs. Composite Building Station Layout

Aside from the point of view of heat loss through building form, it is important to step back and view the form of the station as a whole, not just at the individual building level (see also Pressman, 1998). Some Antarctic stations are relatively small, composed of one main building along with some older or ancillary structures (e.g., storage) and utility buildings. Others like McMurdo and Mawson stations (see Appendix F), have developed over the decades and are spread out, with dozens of buildings of various sizes.

This dichotomy holds positive and negative aspects for both sides, so it is important to understand the implications of having either a single large structure or multiple smaller structures, and design them so that the negative aspects are mitigated. Although it can be argued that composite-building approach, with its fewer exterior walls (and therefore lower-surface-to-volume ratio and material costs) is more energy efficient, and that any fire safety concerns can be addressed through smart materials choices and modern fire detection/suppression systems, it could also be argued that this layout works best for remote and *small* installations (DOD, 2004). McMurdo Station outgrew this label decades ago. For an extended discussion about this topic, see Appendix H.

Building Form for Communities

Building form at the community scale addresses cold climate design for more than just a single building, which is a reality for McMurdo Station. Areas of focus include snow drift between and around multiple buildings (see Eranti and Lee, 1986; and Sundsbø & Bang; 1998). Unfortunately most of these studies leave out a hydrology-based model of the snow melt patterns. For an expanded discussion of site planning for snow drift prevention and snow melt, see Appendix H.

Beyond the layout of an entire civilian community or military base, Pressman (1988) discusses ways to create successful "winter cities," meaning a holistic approach that addresses all aspects from building density, snow drift protection, and ways to keep people outside their homes and engaged in stimulating activities all year. Pressman, writing for the Canadian urban context,[73] provides some ideas for creating a sense of place in an area with harsh winters, such as protected walkways among buildings and "winter gardens and "indoor parks" (p. 14). As long as these amenities comply with the

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[73] In the case of Canadian cities and other Arctic and sub-Arctic communities, there is an actual season of vegetative growth. On the other hand, at McMurdo Station, seasonal change only occurs in the ocean: by December and January the sun is above the horizon 24 hours, the sea ice begins to breaks up (sometimes) around January, a variety of marine mammals appear in the water and on the ice, and perhaps some sea birds migrate to the continent to breed. However, there are no native plants or trees in Antarctica, and only a few species of algae live within porous rocks or in fresh water lakes and seasonal ponds. If anything, the station turns from a place covered in powdery snow to a place covered in dusty, volcanic soil (and sometimes mud).

Antarctic Treaty, providing access to greenery and live organisms could be of great psychological benefit, especially during the winter.[74]

Vestibules

One feature that is applicable no matter the scale of the project is the presence of vestibules or "arctic entrances," as they are sometimes called. Like an airlock in a space vehicle or station, the vestibule keeps the cold, outside hostile environment from directly intruding on the more comfortable interior environment. In cold regions the vestibule may not be as comfortable as the rest of the structure, but is protected enough to act as a staging area for people to don or shed layers of clothing before transitioning to the next area. Vestibules also reduce the escape of warmed interior air displaced by a blast of cold outside air that results in condensation formed by the mixing of the two air masses (McFadden & Bennett, 1991).

This space must be sized properly and laid out efficiently based on traffic and needs, or else the airlock effect will be diminished by both sets of doors being opened at the same times. A cramped vestibule becomes even more so when the doors must open inward into tight spaces (inward to prevent them being blocked by snow drift).[75]

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[74] Not all of Pressman's proposals are applicable to McMurdo Station as it exists today. For example, providing access and activities for the elderly or disabled is not an issue for most of Antarctica because they are absent in the population. However, developing more efficient, livable solutions that can accommodate how the station changes throughout the year as a result of the changing seasons and the population density should be a major goal of a long-term plan so that the station is a comfortable, efficient, and productive place to live and work.

[75] In Building 155, which has a central hallway that also acts as a protected walkaway between the dorm area and the other side of the station, this occurs when periods of high traffic open up both sets of doors on either side of the building which causes cold air to blast into the building. The "back door" to Building 155 also has the added inconvenience of connecting a public entrance with the staircase to a dorm area on the second floor with no acoustical dampening. This results in the transfer of noise (e.g., door slamming, people talking) from the vestibule to the rooms upstairs. Most buildings in McMurdo Station, including

4.2.3 Building Envelope

The building envelope in cold climates acts as a physical barrier against the (often) brutal outside temperature and wind conditions. The building should be made as airtight as possible for energy efficiency as well as comfort. Insulation is an important part of any energy efficient building, but in extremely cold climates the need for an efficient thermal and moisture barrier is essential. To keep out the cold and to regulate moisture, building envelopes need to be extremely robust and well-constructed, yet this does not mean that all buildings should look like an impenetrable, thick-walled fortress. New materials such as vacuum insulated panels allow walls to be relatively thinner and lighter with improved R-values (see Section 4.3.2).

Regardless of season, access to outdoor light is easier with advances in translucent and transparent materials with good thermal resistance (e.g., aerogel). This in turn makes a daylighting system more feasible, helping to make up for the many months when no daylight exists (and the station becomes reliant on artificial light). Finally, McMurdo Station has just begun to look at Dark Sky compliance. These efforts should be continued, even if no current winter projects are in existence.

A report from RSA Engineering Inc. in 2008 provided significant information about the current condition of the buildings at McMurdo Station and their energy demand (some of this information was used in the base case simulation for this study).

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the dormitories, feature vestibules, although not all of them are designed well. For example, the Gerbil Gym's vestibule is very tight when two people try to pass through it at the same time. Similarly the Coffee House entrance is very narrow, resulting in awkward movements and unpleasant drafts when a large group of people enter.

Many of their recommendations address the building envelope, including improved windows. The RSA recommendations are directed at existing structures, many of them very old, not new structures.

Insulation and the Air and Moisture Barrier

In terms of the building envelope, what is required is something that could be thought of as the "perfect" envelope, something that featured "… generous insulation and a sheet membrane free of penetrations and containing all the wiring, plumbing, communications, and HVAC services" (Lstiburek, 2009, p. 56). Currently no buildings in McMurdo feature this cold climate construction technique, but buildings at neighboring Scott Base resemble this "wrapped house" design (Figure 22).

Looking to other similar buildings, ASHRAE recommends that small hotels/motels in Climate Zone 8[76] trying to achieve energy savings (as condensed in *Advanced Energy Design Guide (*AEDG*) for Highway Lodging*[77]) have at least R-13+R-21.6/in^3 insulation in steel framed walls (ASHRAE et al., 2009), which is also the minimum stated in Std. 90.1-2013. For reference, the walls of South Pole Station feature SIPs that provide R-50 insulation.

Insulation is an important part of any energy efficient building, but in extremely cold climates the need for *properly installed* thermal insulation and moisture barriers is essential. When temperatures regularly reach -40^{o}F,[78] seemingly insignificant thermal

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[76] This is the coldest climate zone in the U.S. and includes the Alaskan Interior and lands above the Arctic circle. It still has fewer HDD_{65} than most of Antarctica.

[77] The guide's recommendations are intended to provide hotels with 30% energy savings when compared the same hotels designed to the minimum requirements of ASHRAE Standard 90.1-1999.

[78] At -40^{o} the Fahrenheit and Celsius scales cross. Essentially, -40^{o}F = -40^{o}C.

bridges need special attention, windows need triple glazing or better,[79] and actual vapor barriers (not just vapor retarders) are required (Lstiburek, 2009, p. 56).[80]

The air barrier should be continuous and rigid, limit the air leakage to 1/10 of a cubic inch of air per second per square foot; it should be continuous and rigid, be able to withstand the maximum loads (e.g., highest winds, mechanical pressure), and should be maintainable over the life of the building (Lischkoff & Lstiburek, 1980, p. 30). Importantly, locating the air barrier on the warm side of the envelope allows the wall to drain easily, helping to extend the life of the air barrier and insulation.

The UFC Arctic criteria state the normal retarder materials should not exceed 0.5 perms, higher than Lstiburek's recommendation of 0.1 perms;[81] however, the document goes on to describe the retarder as a continuous layer of 100% protection, so the same, basic idea is there.[82]

Roof and Ground Connection

A well designed roof is also essential, as it must be very well insulated and watertight, but not vapor tight (Lstiburek, 2009, p. 57). ASHRAE 90.1-2013

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[79] One example is aerogel, which is lightweight with a low density and thermal conductivity, but also allows the transmission of light (see Section 4.3.2). While the cost for these fixtures would be very high, their thermal benefits can be worth it, as can be seen in the Halley VI station (See section 2.4.1).

[80] NREL (n.d.) reports that vapor retarders are adequate for Arctic and sub-Arctic regions (p. 21), but the climate in these regions might be considered less severe than McMurdo's because there is no spring or summer "growing season." Additionally, the UFC criteria specifically state that vapor retarders (on the warm side of the wall) –not vapor barriers– are the preferred method (DOD, 2004, p. 2-9), but later state that this layer should provide 100% protection (making it what Lstiburek suggests: a full barrier) (DOD, 2004, p. 2-12).

[81] The UFC criteria date from 1986, whereas Lstiburek's work is from 2009

[82] Specifically, the guidelines stat that "[t]he vapor retarder should consist of a not less than 1/2-ounce copper sheet, or 2 to 3-mil-thick aluminum foil adhered to heavy kraft paper with glass fiber reinforcing spaced not more than 1/4 inch in each direction, or 4 to 8 mil polyethylene sheet" (DOD, 2004, p. 2-12)..

recommend at least R-60/in3 for attic spaces; for reference, South Pole Station sports R-70 SIPs for horizontal surfaces.

Even in cold but dry climates, special attention to the design of the eaves (which should be as small as possible) can prevent ice dams[83] from forming over attic spaces (Tobiasson, Buska, & Greatorex, 1998; DOD, 2004, p. 2-5). By properly installing insulation in the attic, making sure it does not impede air flow, and by keeping a continuous air barrier between the heated living space and the cooler attic, most problems with ice dams are preventable (Tobiasson, Buska, & Greatorex, 1998, p.2). McMurdo Station, with its dry air and minimal precipitation, can still experience accumulation from blowing snow, so ice dams, while not necessarily a pressing problem, should not be ignored.

Care must also be given to how the structure meets the ground, if at all. Most builders elevate their buildings to prevent the frozen ground from melting and creating pooled water (ice ponds), which is a problem in some buildings in McMurdo.[84] In a place plagued with blowing snow, it may also be necessary to elevate the buildings to avoid snow drifting, thus solving two problems at once since snow does not accumulate quickly under a raised building.

ASHRAE 90.1-2013 does not have a warning about permafrost, listing mass and slab-on-grade floors together. Steel-joist floors have a recommended R-38 minimum.

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[83] An ice dam forms when a small amount of heat from the warm interior melts snow that has accumulated on the roof, causing it to run down the slope of the roof and refreeze at the edges, often becoming large, dangerous icicles that hangover the eaves. Proper ventilation and insulation of the roof (attic or cathedral) can prevent this.

[84] In some cases it is also necessary to elevate the building over natural drainage paths, the so-called "McMurdo River," which appears in January as a result of snowmelt Figure 23).

The AEDG for Highway Lodging (ASHRAE et al., 2009) recommends only unheated slabs with a minimum of R-20 for every 24 inches.

Windows

While well insulated walls are paramount, it is important to remember that buildings cannot be perfect, windowless boxes, even if this does improve the overall R-value and performance of the building. Even multiple layers of glass have lower R-values than a simple, well-insulated wall system, and in the Arctic or Antarctic this difference is magnified. For Climate Zone 8 ASHRAE 90.1-2013 sets a minimum of R-3.1 (U-0.32) non-metal fenestrations, and R-2.5 (U-0.40) for operable, metal framed fenestrations. Again, this is for a Climate Zone significantly warmer than most of Antarctica and would be quite a thermal contrast in a wall that is R-70 (as is at South Pole Station).

When one considers the appreciable contribution of daylight during the brief (but intense) summer months, window design becomes even more complicated.[85] For these reasons, windows must be well designed *and* constructed, and also placed thoughtfully and appropriately to allow for a minimum acceptable number of windows that also minimize the overall glazed area.[86] UFC Arctic criteria offer a rule of thumb that

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[85] In high latitude areas, windows can also offer some savings on lighting during the long hours of the summer. If designed correctly (i.e., for local sun conditions and room type), windows can become part of a daylighting system, offsetting some of the costs incurred by the high price of fuel and the near constant need for artificial lighting during the winter months. In McMurdo Station, the population swells in the summer, creating potentially savings though daylighting.

[86] Windows at Antarctic bases tend to be small and as well insulated as was possible at the time of installation.[86] Some areas (usually the general meeting/dining areas) feature larger windows (e.g., bay windows). This has only become possible as the technology improvise. For examples, windows at Scott Base are unplasticised (i.e., rigid) poly vinyl chloride [86] with triple-glazed (R-9.46) glazing.[86] The lounge

"…window area should not exceed 10 [%] of the floor area served by the window(s) in any given room" (DOD, 2004, p. 2-8). This would be interesting to apply alongside a LEED daylighting minimum requirement.

An imperfect but intriguing alternative to windows is simply to replace them with an artificial view. The recent advancements made with large-screen LED screens is already allowing certain spaces with limited access to exterior walls –such as rooms on cruise ships- to nonetheless provide a few (if not an ocean breeze) to even the interior cabins. The screens received a live feed of the actual view from an exterior cabin, so passengers there may view the port of call as the ship arrives. The characteristics of a wall with no windows are not only more airtight but also less expensive.[87] In McMurdo, occupants in LED TV-equipped rooms might choose a real-time view of the station, or they may opt for a selection of lush, green, artificial landscape to break the monotony of the long, dark winters. They might choose to simulate a dawn and dusk cycle to help them sleep and wake up more easily.[88] While nothing may top a real view, in unusual or limited circumstances, this may be the next best option.

However, one down side of having windowless bedrooms is safety. Windows can also play a role in fire safety. Some standards require sleeping rooms (especially those above the ground floor) to have operable windows, but others do not. Rooms with

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area by the bar features several oversized (tall) windows that look out onto the frozen ocean. Britain's Halley VI features gas-filled triple-glazed windows, and the large glazing in the common area is even more robust, being filled with a silica aerogel (see Section 4.3.2).

[87] Future work would include pricing the cost of the screen for interior rooms (or all rooms), the electricity demand from the screens running six or more hours per day, and would also need to consider any integral heat gains from the screens.

[88] It would be interesting to observe which rooms became more popular –those with and those without real views.

LED screens instead of windows would need additional safety measures which would have to be balanced against cost savings. See Appendix J for more information about windows and fire safety in dormitories.

4.2.4 Artificial Lighting

The RSA Engineering report makes a few recommendations, some of which have already been implemented (e.g., updated exterior and interior luminaires). At the time of the RSA report, the firm noted that with essentially no daylighting systems in place, most of the electric load came from inefficient and outdated lighting systems (RSA, 2008, p. 9). In general, the authors recommend replacing older fixtures such as high pressure sodium street lights with new LED technology. These new fixtures would be Dark Sky compliant,[89] use programmable electronic ballasts, and use occupancy sensors with dimming capabilities and staged levels of brightness. Future designs for buildings on the station should consider the energy savings created by efficient lighting systems and maximize natural daylighting systems when possible.

4.2.5 Fire Safety[90]

The specter of a structure fire in Antarctica drives many decisions in the design and layout of the station, and this will continue to be the case (DMJM, 2003, p. 2-13). The magnitude of losing an entire structure to fire –be it at the height of the season or the dead of winter– is eclipsed only by the loss of multiple buildings should the fire spread.

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[89] This is something not currently being discussed at McMurdo because there are few –if any– winter studies that require a dark sky. There is an aurora observatory oat Arrival Heights (Figure 24), which is a protected area, but it is not clear if that location is used every winter. Of note, however, is that light spilling from McMurdo may also affect any light-sensitive projects at Scott Base.

[90] For information about fire Detection and First-response systems, see Appendix J.

As many Antarctic explorers (both past and present) have learned, it is important not to concentrate all supplies in one area, less that critical sled or person or structure be lost (see Section 2.1). Even with a mild breeze the speed with which fire spreads in the cold, desert air is alarming, and with supplies of liquid water at a premium, fires simply burn until there is nothing left. Often the best outcome is that the fire be contained to a single building or single part of a building. This makes building separation –by physical space or by the appropriate fire walls– a very important design decision.

As with Mawson Station, McMurdo divides and separates its buildings.[91] This allows room for roads and pipes to pass between buildings, and it also provides an extra degree of fire safety (emergency vehicle access). On a smaller scale, McMurdo's neighboring station, Scott Base, has taken a different approach, although their basic plan could be described as similar: "… stringent fire prevention measures backed up by 'early detection and massive, rapid response' (Cudby, 2010, p. 22). (For information about Scott Base's and its fire protection measures, see Appendix F). Should McMurdo Station shift towards connecting its buildings, taking a cue from Scott Base would be a good place to start.[92]

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[91] The 2003 Long Range Development Plan (LRDP) pointed out, "…McMurdo Station was originally expeditionary in nature and was not intended to be a long-term, scientific research facility. Therefore, earlier facilities construction did not follow a logical or well-conceived development plan" (DMJM, 2003, p. 3-7).

[92] A recent proposed update to the station by OZ Architecture (see Section 2.2.4) included walkways between certain buildings (e.g., the station core, the Crary Lab, and medical). Although further details are not currently available (including anything pertaining to fire safety), these walkways are simply ways to allow passage from one building to another, not destinations themselves. While the effort to improve safety and walkability is commendable, these structures have not yet reached their full potential

There is also a risk in keeping diesel, mogas, and heating oil stored in multi-million gallon tanks that are grouped together. Ideally these tanks will eventually be reduced in number and their contents used as a back-up supply of energy, or as part of a wind-diesel hybrid system (see Section 5.3 and Appendix F). If the station layout changes significantly, the location of these behemoths and any fuel lines extending from them should be considered not only as a potential environmental hazard but also a potential fire hazard. Currently, all fuel tanks are now in the pass between McMurdo Station and Scott Base and are not likely to change location.

Fire Safety in Dormitories

Few fire hazards are unique to dormitories, but some occur at higher incidences, and are therefore represented in code. For information about fire safety specifically in dormitories, see Appendix J.

4.3 Mechanical Systems and Equipment Considerations

In a very cold and remote location like Antarctica, all mechanical systems must operate at very low temperatures, be efficient and even reclaim heat or energy when possible, be relatively easy to maintain,[93] and contain significant levels of redundancy in the event of partial system failure.

Recently there have been improvements to the efficiency of the McMurdo Station's mechanical equipment, but generally the approach remains the same: use the

[93] This point is stressed in the UFC guidelines for Arctic construction, with inaccessibility named as a major problem when it comes to designing for mechanical systems (DOD, 2004, p. 4-4).

hardiest equipment suited for extreme cold and icy conditions, keep an adequate supplies of spare parts, and ensure the knowledge to maintain them is passed on or made readily available. The latest push to new technology (new diesel generators and an integrated wind-energy system) signals the future of the station, which must achieve higher energy efficiency in order to survive. By keeping these standards, the station's energy use might be reined in, the occupant comfort improved, and unnecessary maintenance avoided.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides information on a variety of issues ranging from flue sizes, tank vents, snow hoods, to how to humidify very cold air used in the ventilation system (see Section 3.3.2) (Armstrong, 1993). However, the operating conditions of Antarctica require designers to refer to articles in which the author focuses on mechanical systems and construction methods for extremely cold climates, information normally outside the scope of U.S. HVAC and energy specifications.

4.3.1 Interior Heat

Constant and on-demand interior heating are both important for comfort and the function of research laboratory, especially for certain temperature-sensitive scientific equipment. Gone are the days when coal supplemented with seal blubber was the only source of heat (see Section 2). Yet buildings in McMurdo are still heated with oil-fired boilers (JP-5 jet fuel): a relatively old and dirty technology, but one that represent a trustworthy, safe, and easily-maintained technology.

Advantageously, these boilers can be linked as modules, which allow buildings to be heated more efficiently. The 60-degree temperature difference between summer and winter months makes a one-size-fits-all boiler inefficient. During those periods when outside temperatures are moderate, modular boilers can solve this problem because they can be scaled back or be partially shut down during summer months when temperatures can climb above freezing.[94]

Another positive aspect of having each building independently heated is that they are less vulnerable to station-wide disruptions shutting down the heat, although an all-electrically heated station would again have to ensure multiple levels of redundancy. If a secure, inexpensive source of electricity could be established, however, it would be worthwhile to revisit the possibility of an electric heating system.[95]

McMurdo's buildings are not generally heated with electricity, although some buildings feature electric water heaters (others use glycol heat exchangers). Most buildings contain their own forced-air oil-burning boiler, which solves much of the problem of connecting the entire station to an electrical heating system. The 206-209 dormitories are heated with a hydronic system: radiators and oil-fired glycol boilers, and the oil supply tanks that feed these systems are refilled by a fuel truck as needed (Figure 25). Unfortunately this is a cumbersome task[96] but it allows each building to operate

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[94] This is the type of system currently used in many larger buildings, including the larger dormitories, the Crary Science Lab, and Building 155.
[95] As a reminder, McMurdo Station currently uses roughly 500,000 gallons of fuel for building heat and an additional 1,000,000 gallons for electricity annually.
[96] The frequent transfer of fuel (e.g., between main holding tanks, trucks, and individual huts or buildings) is also a weak point in a system set up to lower the risk of fuel spills.

independently, as opposed to being connected to a single central system.[97] UFC guidelines describe this kind of system as being well-suited for residential buildings since it is quiet and easy to maintain (DOD, 2004, p. 4-2).

Switching to an all-electric system would put an enormous load on the generators, which already provide electricity for lights, appliances, tools, communications, engine warmers, etc. Power generation would have to increase; the most likely solution being an increase in the number of generators, generator houses, and wind turbines. Electrically heated buildings would also require a distribution grid not currently in place (but generally the distribution system for electrical heating is not complicated).

One possible method which could augment an all-electric system is thermal storage, which would potentially work very well with the increased need for heat between 5pm and 8am, and the decreased need during the day (except Sundays). These devices could supplement/replace the existing radiator baseboards in each room, allowing thermostat control of individual space.

Other alternatives, as described in the UFC Design Guidelines for Arctic Construction, include hot air heating and steam heating systems. The advantage of the former is its overall simplicity; the latter excels in simple heat distribution. The downside of hot air heating is that shipping costs increase for the extra ductwork; for steam heating, the problem is one of maintenance during any kind of leak (it must be

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[97] It is also easy to track the amount of fuel used by each building, although those numbers are not generally available.

dealt with immediately). Steam systems also tend to be noisier and ill-suited for residential or office buildings (DOD, 2004, p. 401).[98] McMurdo's hydronic heating systems is a positive choice for the dormitories, but the continued use fossil fuels in the boilers is a negative. For a continued discussion about McMurdo's boilers, see Appendix H.

4.3.2 Balancing Thermal Comfort and Ventilation

Heat loss, infiltration, and the need for clean, fresh air are at odds in well-sealed buildings. Anyone who has spent time in a hut buried in the snow will know this.[99] In McMurdo Station, "[t]he two primary sources of heat loss from a building are conduction through the building envelope and loss of heated air through ventilation or infiltration. Ventilation loads dwarf conduction loads in cold climates" (RSA, 2008, p. 34). It is therefore imperative that along with a well-insulated, well-constructed building (see previous section), mechanical systems efficiently preheat the outside air, keep the air intake free of ice, and maintain the interior temperature of well-insulated spaces.

However, it is not just warm, draft-free spaces that are needed. Indoor humidity also affects both health and comfort. "Dry air robs moisture from everything exposed to it" (Freitag & McFadden, 1997, p. 335), such as wooden furniture, wood used in building framing (which can shrink and warp), and adhesives, which can dry and lose

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[98] Building 155 has two Bryan low-pressure steam boilers (4,800,000 Btu/hr. each) –probably a holdover from the Navy days). The building distributes heat using steam to glycol heat, and hot water is supplied by steam heated water tanks (two tanks, 680 gallons each). Usually only one water tank is online at a time.
[99] See also Richard Byrd's account in *Alone* (1938), in which he describes long-term physical ailments and near death caused by a faulty stovepipe that emitted carbon monoxide.

strength (DOD, 2004, p. 3-1).[100] This is especially true when HVAC systems warm the outside air to a comfortable indoor temperature: the warmed air will be even drier than outside (i.e., lower RH). A low indoor RH makes it not only uncomfortable for occupants but with the increased risk of static electricity shock, it can also be dangerous for electronics, such as computers and scientific equipment. Yet, there is also a need to keep the RH under a certain level because excessive moisture can also be uncomfortable to occupants, cause other health problems, and be detrimental to building insulation, windows installations, etc.

Unfortunately it can be difficult to adjust humidity appropriately for mechanical systems, electronics, building insulation, and occupants. Generally in cold climates a good RH level tends to be lower than that recommended by ASHRAE's comfort zone or even just below, as people will adjust to a slightly lower RH.[101] This lower RH will also help keep the windows from frosting over most of the time (Freitag, & McFadden, 1997, p. 338). A report from RSA in 2008 included a recommendation for smarter ventilation in the station's buildings through the installation of carbon dioxide (CO_2) sensors in the return air stream of air handling units (AHUs). This step would reduce outside air requirements.[102]

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[100] Although proximity to the coast makes the outside air less arid than inland locations, the cold air keeps the humidity in check (outside average absolute humidity 63%).

[101] This claim from 1997 (and in an earlier edition from 1991) would have been based on ASHRAE standards from 1989, i.e., ASHRAE Handbook of Fundamentals and "Ventilation for acceptable indoor air quality," Std. 69-1989. Current standards (i.e., ASHRAE Standard 55-2010 does not specify a lower limit for the humidity ratio of the defined Comfort Zone, although it does note that non-thermal comfort factors will come into play, such as dry skin and eyes, among others (see Std. 55-2010, section 5.2.2).

[102] "CO_2 is a known tracer gas for human metabolic activity, and has been recognized by ASHRAE and code authorities as a credible way to reduce minimum outside air requirements in …AHUs. [In such

In addition, RSA recommended using programmable set-back thermostats for rooms not continuously occupied. The use of these instruments could be a significant source of energy savings, especially in buildings that are not fully occupied during part of the day (e.g., dormitories). The selection of the ventilation system itself needs special attention, and it should be remembered that the main purpose of ventilation is health and comfort, not energy efficiency (Lischkoff & Lstiburek,1980, p. 16).[103]

The architectural firm that designed the Crary Lab in the 1990s knew that well-regulated temperatures were crucial to the sensitive equipment housed in the lab. They designed the system not only to preheat the air, but constantly protect itself from freezing.

> Air taken into the facility at -65° F, needed to be first preheated to 40° F by steam coil elements before it could be heated by the oil fired boilers. All exhaust ducts and vents needed to be heat traced with electric heaters to prevent ice buildup when the warm moist air of the building interior, at 70° F, 30 percent humidity, reached the cold, dry ambient air of the

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systems] [t]he CO_2 sensor would drive the outside air dampers to provide return air from the rooms with CO_2 levels at or below CO_2 set-point, (typically <750 PPM CO2), thus avoiding over-ventilation of the space" [while maintaining proper ventilation] (RSA, 2008, p.34).

[103] ASHRAE Standard 62.2-2010, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings recognizes three types of whole-building ventilation systems: exhaust-only, supply-only, and a combination, sometimes called "balanced." The third system generally indicates either a heat-recovery ventilator (HRV) or energy-recovery ventilator (ERV). Since these "balanced" systems both supply and remove air, they are also known as air-to-air systems. HRVs and ERVs work by using exhaust air to pre-condition fresh air by transferring (sensible) heat (an HRV system) or heat and moisture (sensible and latent) (an ERV system) from one side of the air flow to the other. These systems can reuse 60-80% of the heat in the exhaust air to precondition colder, fresh air (Freitag & McFadden, 1997, p. 341). The UFC guidelines for Arctic construction suggest this type of system be reserved for places which require 100% outside air and exhaust, such as maintenance shops (see also Section 4.3.3). In McMurdo this would not be dorms, but places such as the VMF. In very cold, dry climates, some argue ERVs could potentially return some moisture to the fresh air, yet others maintain that ERVs are best suited to warmer, more humid climates where they more efficiently remove moisture from the air ("Energy recovery ventilators," 2005; Dieckerman, 2008; Ouazia, Swinton, and Barhoun, 2008). It is unclear how well an ERV would work in McMurdo Station since all of these studies refer to cold climates which are still warmer, on average (e.g., Minneapolis), than McMurdo Station.

> exterior. (Ferraro Choi, 2010, "Final Design of the Replacement Science Facility.")

This is an example of a system that requires energy to run and keep itself from freezing (functional). In less extreme conditions, a heat recovery system can help offset the cost of heating (or cooling) outside air, but in the extreme cold of Antarctica, such systems can sometimes run into problems, leaving the best solution to be simple, straightforward systems working in well-designed, well-constructed buildings.[104]

When it comes to windows and air leakage, UFC guidelines for Arctic design follow the American Architectural Manufacturer's Association's Voluntary Specification for Aluminum Prime Windows (AAMA 101) and the National Woodwork Manufacturer's Association's Industry Standards for Wood Windows (I.S. 2-80). They require that

> …the air infiltration rate [does not] exceed 0.5 cubic feet per minute (cfm) per foot of crack of all operable sash when tested in accordance with American Society of Testing Materials, ASTM E 283. In the arctic, the tested air leakage rate should not exceed 0.15 cfm per lineal foot of crack for a pressure difference of 0.3 in. of H_2O across the window. (DOD, 2004, p. 2-8).

This should make for well-sealed windows, even if they are still heat sinks. Even the newest windows in McMurdo have a cold area near and around them; some are draftier

[104] To calculate the ventilation rate required for a low-rise residential building according to ASHRAE 62.2-2013, it is necessary not only to have certain information about the building, such as square footage and number of rooms, and information from ASHRAE standards, but also information from a blower door test. This would be appropriate if housing in McMurdo were multifamily residences or single family houses, however, current and future plans for the station continue to base housing design on dormitories. These kinds of buildings are covered by ASHRAE Standard 62.1-2013, which specifies between 5 CFM/person or 0.06 CFM/ft^2. UFC guidelines for Arctic construction concur (DOD, 2004, p. 4-4).

than others (probably depending on wind speed and direction). A few allow significant spin drift to enter at the edges, representing a larger problem than just heat loss.

4.3.3 Heat Recovery

Begun as a Canadian experiment in the mid-1970s, heat recovery is increasingly accepted an integral part of the energy efficient[105] airtight building –especially in very cold climates– since there are no savings if the same amount of cold, outside air is brought inside (Lischkoff & Lstiburek,1980, p. 15). Unfortunately, in very cold climates building ventilation systems that include heat recovery face problems with icing. Ice build-up causes the systems to work increasingly less efficiently until they fail. However, devices that prevent icing diminish the energy saved by the heat recovery system because they usually require heat to prevent icing. Solutions that would alleviate occasional problems in sub-Antarctic climates are not hardy enough for locations where the average temperature is 0^{o}F. There have been some advances to reduce the energy needed to protect these systems from icing, but currently there are no commercially available solutions (Kragh, et al., 2007). (For more on heat recovery, see Appendix H.)

4.3.4 Interior Air Quality (IAQ)

Indoor air quality is another factor that links health and comfort with energy systems and savings. In colder climates –where well-sealed buildings are more desirable than more open, naturally ventilated ones– it is important to make design decisions that will limit odors, toxins, and pathogens in the air. These unwanted elements usually

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[105] Heat recovery saves on heating costs but has no effect on air quality or moisture control, so it is not essential unless the goal of energy efficiency is desired. The more heating degree days, the more cost-efficient the system is.

originate from outgassing of materials such as paint, glue, some types of insulation (especially in new construction), cooking, cleaning chemicals, and people (i.e., metabolic processes), and may collect in high concentrations in an unventilated building.

Fresh air intake is important, but the locations of these intakes should also be carefully considered. They must be protected from snow infiltration with the use of a snow hood that uses baffles to prevent frost build-up and to "…dissipate wind, causing snow to drop out" and let melt water escape (DOD, 2004, p., 2-11). Also they should not be near sources of outdoor pollutants such as power generation exhaust, smoking areas, or parking spaces[106] (Figure 26).

The reuse of air in a building should also be limited; one solution is the use of air-to-air heat exchanger systems that do not mix incoming and outgoing air, but rather transfer heat/moisture from outgoing air to incoming air. In McMurdo, where disease (e.g., common colds and influenza) can spread very quickly, it is important to keep air as fresh as possible, especially in areas of higher density such as dormitories and in special areas like the hospital.

ASHRAE 62.1-2013 specifies 5 cfm/person and 0.06 cfm/ft^2 of outdoor air for bedrooms (dormitories), the same as for barracks or a prison cell. In the current study dorm rooms at McMurdo Station were monitored with portable data loggers and CO_2 sensors (Figure 27, Figure 28). The results showed good ventilation (sometimes too much when windows were opened); interior rooms with no windows were not tested for

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[106] This is more of a problem in cold climates because many people tend to leave their vehicles idling rather than risk problems with the vehicle freezing up because there is not always a place to plug in the engine heater.

ventilation rates. Older buildings (e.g. the Coffee House) showed high infiltration but also high accumulations of CO_2 during peak hours. Supplying pre-heated, fresh air into buildings is not only an opportunity for potentially large energy savings, but should also be considered a health and safety measure.

Pressure differences are another way to control airflow. They are also useful in keeping heated air in and cold air out. The downside is that these pressures must be maintained all the time, which is both a maintenance issue and building design issue (e.g., the flow of traffic through a vestibule). This is also of great potential energy savings for McMurdo Station, when the temperature difference between outside and in can span 100^{o}F.

Air humidification is important to occupant comfort: the uncomfortable way the air dries the skin and tickles the lungs is quite noticeable, especially to new arrivals.[107] Dry air that is reheated becomes even drier, but it should be noted that generally in cold climates acceptable RH level tends to be lower that or even just below what is stated in ASHRAE's design guidelines (see Section 4.2.2). Excess humidity inside warm buildings leads to condensation problems on windows, causing structural problems and generally undermining the intent of the window. Therefore, RH levels may need to be capped around 30% with no detriment to the occupants.[108] However, it has also been

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[107] A constant reminder of the dry air is also the static shock on receives walking across a carpeted room up to a metal door handle, or turning over in bed in a darkened room while wrapped in a wool blanket (the charge is visible).

[108] UFC guidelines for Arctic construction describe what might have been normal in an earlier time at McMurdo, noting that men in barracks hanging up wet clothing could drive up the humidity levels in a room very quickly. Of course this is no longer the case. More relevant to today, the guidelines also

reported that RH levels lower than 35% and above 65% provide a breeding ground for air-borne illnesses (DOD, 2004, p. 4-10).

4.3.5 Pathogen Control

IAQ control must extend to airborne pathogen control, as it does in many hospitals. Antarctica may have an abundance of wide open spaces, but where people congregate tends to be enclosed, small spaces that lack privacy. As a result colds and viral infections have the potential to spread quickly, especially if people are stressed or if their bodies are unprepared for an influx of new people and accompanying new viruses (arriving at the end of the Winter season). Because of these conditions, the "McMurdo Crud" (see Appendix Q) makes its rounds every year, confining people to their (shared) rooms and causing some delays. Its flu-like symptoms, especially coughing and sneezing, make it particularly easy to spread.

Certain engineering solutions can do much to limit the spread of disease through HVAC systems. These systems may not be battling the spread of *tuberculosis* amongst a group of immune-compromised patients, but thinking that "the McMurdo Crud" is *merely* a flu-like virus does it an injustice. Proper ventilation[109] may be the best way to control the spread of disease (Beggs, 2002). This of course must be balanced with the enormous cost of pre-heating and heating outside air, and then circulating it within a building. The use of room air cleaning devices, like high efficiency particulate air

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suggest placing exhaust fans in gang-style shower rooms not within the individual stalls, but rather by the exit (DOD, 2004, p. 4-7 – 4-8).

[109] I.e., the supply of outside air to a room, not to be confused with "room air movement," which should be thought of as recirculated air (an energy saving measure) (Beggs, 2002, p.3).

(HEPA) filters,[110] ultraviolet germicidal irradiation (UVGI) lamps, and electrostatic filters can aid in the cleaning of this air; they are not a large investment but do have long-term maintenance costs (Beggs, 2002, p.6).[111] UV lights could also help disinfect rooms which may contain hard-to-clean surfaces (Rutala, Gergen, & Weber, 2010). (For information on the role of mechanical systems in pathogen control, see Appendix H.)

On a different scale, room cleaning is an easy, first-level approach to keeping germs at bay, whether it is done by a room occupant or a station janitor. This is one reason "common" or gang-style bathrooms/showers would stay cleaner, since it would be a daily task for a janitor. It would be less likely that sink, toilets, and private showers would be cleaned so often.[112] These surfaces should mimic those in hospitals: continuous surfaces with no crevices for bacterial growth, no-splash sinks with foot-pedals or automatic sensors, toilets that flush once the lid is closed, and even fixtures and countertops with anti-microbial copper oxide surfaces (as opposed to stainless steel). Drinking fountains and doorknobs are also important to keep clean, and in studies CU-oxide surfaces have shown great success in prevent bacterial growth (Grass, Rensing, & Solioz, 2011).[113]

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[110] It should be noted that the optimal location in ductwork for HEPA filters has not been satisfactorily proven, and also that ductwork with HEPA filters requires larger fans to maintain proper airflow, a potential energy savings drawback. UGVI lamps do not have this drawback, and can be installed in air ducts to fight pathogens. In McMurdo, the recirculation of air may be of great potential energy savings; installing devices that make sure that air is as free of pathogens as can be helped, another positive design for occupant health.

[111] It should be noted that all plastic in the room must be able to withstand UV light.

[112] Also available are hand sanitizer dispensers, located near the galley and in many other buildings like the Crary Lab. Disinfectant spray and paper towels are also available in the workout rooms, but not in dormitory lounges, where some people set up impromptu gyms during the winter.

[113] The hand washing station outside the galley entrance has been credited with greatly reducing the spread of disease in McMurdo Station; in fact, it may be the single most effective way to keep "the crud" and

4.3.6 Fire Detection and Prevention

Today most of McMurdo Station's buildings are equipped with smoke detectors and sprinkler systems (for more information, see Appendix J). All buildings are required to meet National Fire Protection Association (NFPA) codes,[114] although in some cases building managers can only strive to fulfill the intent of the regulation (DMJM, 2003, p. 2-14).[115] Aside from the fire station in town, the airfield (on the ice shelf) also has its own dedicated fire-fighting force.

Some buildings have special fire protection measures.[116] Some older structures (or those slated for demolition) have bare-bones protection.[117] A number of older buildings were recently identified as lacking windows or secondary exists on upper floors, which has been considered "…a serious life/fire safety issue" (RSA, 2008, p. 39). Plans for new buildings should consider windows not only as a potential energy saver in terms of daylighting but also a necessary fire safety design issue.

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other viruses from spreading (Martaindale, 2006). Unfortunately, it is somewhat undersized, which causes some people to skip it at peak meal times. In addition the auto sensor is also sensitive to the radio frequencies from hand held devices that many people carry with them, making the large sink vulnerable to total breakdown and a maintenance issue. Some view the "highly encouraged" behavior suspiciously, but overall it is a positive addition to the station

[114] NFPA codes are numbered but not by year, as individual codes are updated at different intervals. McMurdo relies on NFPA codes such as NFPA 72, National Fire Alarm and Signaling Code; NFPA 70, National Electrical Code; NFPA 101, Life Safety Code; NFPA 75, Protection of Information Technology Equipment; NFPA, 76 Fire Protection Telecommunication Facilities; and NFPA, 10 Portable Fire Extinguishers. No years for these codes are stated, but it is assumed that as new codes appear these changes go into effect.

[115] Once instance of not being able to meet code is described by Fey (2011, p. 59): because some buildings are allowed to "go cold" when not in use during the winter, their fire detection systems are exposed to temperatures not allowed in the code (NFPA 72). To combat this, maintenance staff must perform a detailed inspection of the systems when the building is rewarmed every year.

[116] Buildings like the Crary Lab and the power plant have Halon dispersal systems in critical rooms (e.g., chemical storage in the Crary Lab) as well as automatic sprinklers throughout the rest of the building. The reverse-osmosis system treats seawater for potable water and maintains a reserve for fighting fires.

[117] I.e., they only have fire detection systems or only sprinklers in the furnace room.

One unusual aspect of the detection prevention systems is that older, time-tested systems are preferred over newer ones. Because McMurdo has so many buildings, building types, and buildings dating from the 1950s to present day, proven systems have the advantage of being more consistent and low maintenance, two prized characteristics in remote areas (Fey, 2011, p. 56). If McMurdo were to homogenize and update all of its structures, this might still be the case. However, this would require limited small-scale testing of new systems to make sure they would before large-scale deployment takes place.

System Redundancy

With the word "remote" taking on a new meaning when working in Antarctica, it is imperative that all mechanical equipment be easy to maintain by people who are knowledgeable about the systems and capable of maintaining them. "Redundancy" can not only be the difference between success and failure, but is an important safety factor (Rejcek, 2011; Rice, 1996). Many large and critical buildings in McMurdo Station (e.g., Building 155 and most dormitories) have modular boilers for heat. This redundancy makes both repairs and maintenance easier, as well as providing an extra level of backup should one or even two boilers fail; the building may chill but will not go completely cold before repairs can be completed (Fey, 2009).

Until 2009 when power plant upgrades were completed (a seven-year project), McMurdo Station had all of their (aging) generators in one building, a definite safety risk in the event of a major fire. Today, the station enjoys the peace of mind of new Caterpillar generators housed in two separate facilities. Ideally, the primary energy source should not be a source of carbon emissions or other air pollutants, a goal that has not been achieved. However, with the New Zealand wind turbine project and a shared power grid, McMurdo may be on the right path.

4.4 Structure and Materials

4.4.1 Logistics

The distance from the continental U.S. (CONUS) to McMurdo Station makes transportation of materials, supplies, and manpower a true logistical feat. The enormous costs and logistics of this transport needs to be acknowledged but is not within the scope of this study to identify and price each stage of production, delivery, and then carbon footprint for a lifecycle cost. However, it is recognized that such an accounting is needed, especially when considering the journey all building materials must make in terms of distance, weight, dimensions, ease of construction, longevity, and durability.[118] These challenges are amplified by the very cold temperatures, unpredictable weather delays, and a very short construction season. (For an expanded discussion of this topic, see Appendix H.)

4.4.2 Sound and Vibration Control in Dormitories

The importance of noise control cannot be overstated, especially in a high-density housing situation like a dormitory. Even with the presence of roommates, the dorm is the most private place available to people living in McMurdo, and obviously the

[118] This is also relevant with regards to the need to minimize fuel demand and reliance on fossil fuels. This is addressed in Chapter 5.

only place where they sleep. Ideally single occupancy, each room should provide a refuge from what can be a hectic scene at the station. A quiet room can provide a welcome break, and it should also be a place where the occupant can sleep well. Creating this kind of space in a crowded dormitory does not happen with proper design.

It should go without saying that mechanical noise (including building-borne and noise from laundry/drying machines) should not interfere with the quality of the interior environment, and quiet hours should be enforced in lounge areas when people are sleeping. However, the presence of “day sleepers” (nightshift workers) complicates the situation, leaving few hours when the building occupants are *all* sleeping. People may move in and out of the night shift as needed, so segregating them to a single floor or building is not necessarily the best option (i.e., it may require them to change rooms more than once a season).

Rooms themselves should be quiet places that provide auditory privacy. Lounges, on the other hand, are for small-scale socializing. It is essential for them to be soundproofed; otherwise, they are at risk of being either underutilized or sources of annoyance. Once again it is possible to establish basic guidelines for McMurdo Station by looking to industry standards, including the field of healthcare design, where is has been noted that “[t]he key to achieving a quiet healthcare building is found mainly in appropriate design of the physical environment, not in modifying organizational culture or staff behavior” (Ulrich, et al., 2006, p. 42). (For an expanded discussion on sources of noise in McMurdo Station dormitories and possible solutions, see Appendix H.)

4.4.3 Pros and Cons of Different Structural Systems and Materials

At a temporary station such as Byrd (1961), it was possible and sometimes desirable to bury the buildings in the snow. This not only partially alleviated the snow load on the roofs,[119] but protected the walls from the force and noise of the wind (NSF, 1962, p. 58). A similar approach was used at Camp Century in Greenland (1959 - 1966), in which 21 massive tunnels were created below the snow, in part an effort to camouflage the station (Clark, 1965) (see Appendix C). Amundsen and his men found that once their hut became buried by snow, not only were they better insulated from cold and noise, but were able to tunnel in the snow, expanding the total square footage of their winter dwelling.[120] Today most stations built on ice shelves are designed to resist being buried (see Appendices D and F). In McMurdo, which is built on the dark, hard soil[121] of Ross Island's active volcano, Mt. Erebus, it is not possible to dig into the snow to gain its protection, and there is no need to resist the movement of an ice sheet. Instead, structures must remain above ground, anchored to frozen soil, and must be able to withstand the full force of wind and blowing snow.

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[119] "Trenches are cut with 'Peter' snow-milling machinery and are roofed over with arches of corrugated iron; insulated buildings are then constructed in the trenches and thus the pressure or snow on roofs is minimized" (National Science Foundation [NSF] 1962, p. 58).

[120] The solution to these comforts was discovered by accident. As well as Amundsen had prepared, somehow he and his men had forgotten to pack any snow shovels. As one expedition member set out to make some, the snow drifted alongside the Framheim, until they day the shovels were ready. A suggestion to tunnel into the drift instead of clear it away was instantly accepted (as they were in dire need of a place for a carpenter's shop), and before long they had an entire "underground village" allowing each member to have a small private work area (Amundsen, 1913, p. 269-270).

[121] Specifically, black basaltic bedrock and rocky soil. "Below 8 to 24 inches … the ground is permanently frozen and generally consists of angular basaltic rock particles cemented with ice" (Keeton & Stehle, 1969, p. 1-2)

Early Structural Systems

The earliest structures built by the USN on Ross Island were prefabricated rectangular huts, metal Quonset-style huts, and Jamesways, a tent-like structure similar to Quonset huts (see Appendix C). Built for military defense forces working in many different climates, Quonset huts were easy to construct and modify to specific site conditions or programmatic needs.[122] They were in particular well suited to the demanding conditions of the Antarctic, provided they were fitted with extra insulation. They were also easy to package and transport on a large aircraft like a C-130.

Wood Frames

Wood is a very good material for cold environments if builders take proper precautions. Wood is lightweight (compared with steel), easy to work with, durable, and even gains some strength when the temperature drops (Eranti & Lee, 1986, p. 377). As long as proper adhesives are used (water-resistant and able to endure the freeze-thaw cycles), the only other problem faced by wood is exposure to water or excessive moisture, which can lead to shrinkage, cracking and rot (Eranti & Lee, 1986, p. 379).

However, wood frames tend to be more susceptible to the spread of fire, and over time these buildings also tend to age poorly.[123] They are also not capable of the size and strength of steel-framed buildings, which are now the most common sight for large buildings and new stations, especially those which must resist snow drift, like Halley VI

[122] It is still possible to see Quonset huts on the station today, but because of their age and limited lifespan, they are no longer as well insulated as newer structures and are generally not being renovated.
[123] The wind takes toll on the wood, and the dry air will further desiccate the material (Freitag, & McFadden, 1997, p. 335).

(see Section 2.3.1). Mostly wood studs are used for interior walls only. (For more on this topic, see Appendix H.)

Metal Frames and Applications

While aluminum is a very good choice for building in cold climates, steel tends to dominate. Aluminum has no ductile-to-brittle transition[124] (like wood, it tends to increase in strength as the temperature drops); it has few problems with corrosion, is easy to weld, and has a low weigh-strength ration (Eranti & Lee, 1986, p. 380). Steel is nearly as good and tends to be less expensive, thereby becoming the choice for most arctic construction. Aluminum is preferred for smaller applications, such as window frames, bolts, and corrugated sheets (Eranti & Lee, 1986, p. 380). It is also possible to treat steel for increased ductility at low temperatures[125] (DOD, 2004, p. 3-1).

Metal buildings tend to be stronger and more permanent. In a metal building the risk of fire is somewhat lessened, especially with the use of fire walls.[126] Moisture is less of a problem, although interior walls still tend to be wood-framed and therefore vulnerable. Heavy, metal-framed buildings also tend to be more difficult to disassemble,

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[124] "The ductile to brittle transition is characterized by a sudden and dramatic drop in the energy absorbed by a metal subjected to impact loading. …. As [the] temperature decreases, a metal's ability to absorb energy of impact decreases. Thus its ductility decreases. At some temperature the ductility may suddenly decrease to almost zero" (Meier, 2004).

[125] One method is by adding nickel to the steel composition, but it may also increase costs (DOD, 2004, p. 3-2).

[126] Fire walls should be strong enough to remain upright even when adjacent walls have collapsed because of a fire, for the length of time identified in their rating (e.g., 1-hr, 2-hr, etc.). Fire walls are generally created by applying fire-rated sheet rock (5/8") to a stud wall. Every 5/8" layer of sheet rock adds 30 minutes to the wall's fire rating, so a stud wall with a layer of sheet rock on either side creates a 1-hour fire rated wall, provided that any penetrations (pipes, windows, doors) is sealed per NFPA standards, e.g., NFPA 80: Standard for Fire Doors and Other Opening Protectives; NFPA 105: Standard for the Installation of Smoke Door Assemblies and Other Opening Protectives.

a tradeoff of their permanence. In McMurdo there is need for a balance between large, permanent structures and smaller, lighter, and more temporary buildings.

Concrete

The use of concrete construction Antarctica has a limited history, but its very presence was one signal that McMurdo Station would indeed become a permanent establishment. By 1968 this change was in full swing, with the newly-completed, relatively huge Building 155 replacing several Q-huts and Jamesways. Consolidation was the word of the day, and it was seen not only as a way reduce maintenance costs but also to conserve energy, i.e., "… economy of heating and compact utility systems" (U.S. Navy [USN], 1968, p. 36).

According to the UFC design guidelines (DOD, 2004), the use of concrete in the arctic and subarctic regions is favorable, as long as certain precautions are taken (DOD, 2004, p. 2-1 and 3-2). In this document it is described as durable and with high fire-resistant qualities, but it must be protected from moisture penetration (i.e., air entrained).[127] Quality control in the field is also more difficult, and the document cautions that the architect must carefully weigh the costs of shipping cement and aggregate versus shipping precast pieces.[128] (For more information on the use of concrete in Antarctica, see Appendix H.)

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[127] See Appendix Q

[128] Recently, concrete foundations for the Ross Island wind farm were imported rather than poured in place (which is typical). The decision was made in order to protect the environment from scraping for aggregate –which may be found to be inferior. The resulting "spider" foundation design was prefabricated and shipped to the site (Miller, 2010, p. 16). See Section 5.2 for more information about the wind turbines.

How often aggregate is mined for concrete in McMurdo today is unclear, but most concrete pieces are precast off-site, and large scale pouring is not feasible (Law et al., 2006, p. 6). Slab-on-grade would never be desirable in this location because

> [s]oils [here] are predominantly volcanic gravel containing very little moisture (other than ice crystals). Voids in the lower lava and basalt formations and immediately below the rock surface are commonly filled with ice from refrozen snow melt. The ice-rich permafrost thus has more ice than pore space and earthslides or mudslides could result if the thawing occurs. Antarctic design parameters require that buildings be elevated to prevent heat transfer. The crawl space below needs to be accessible, this cross bracing or other framing [should be] minimized. (Law et al., 2006, p.1444)

This cold-climate solution is also extolled by Lstiburek (2009) as an elegant solution to protecting the integrity of the permafrost.

Prefabricated Building Parts

The "historic huts" from the turn of the century were all prefabricated buildings, labeled and shipped in pieces. Today's prefabricated buildings offer not only speed of construction but also a higher precision of the building components and connections. It can also be an economical choice; however, it is important to remember that these savings can be offset by higher shipping costs, especially when being transported to Ross Island on palates loaded in a C-130 or on the annual supply ship (DOD, 2004, p. 1-8).[129]

Prefabrication of buildings is one solution to a short building season although it also has its problems. For instance, if everything is built to high precision in an off-

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[129] This might weigh the decision to use prefabricated concrete parts, an option praised in the UFC Arctic design criteria (DOD, 2004, p. 2-2), but perhaps not well suited for a site as remote as McMurdo Station.

continent factory, it is more likely to be well sealed. Both Princess Elisabeth station (Belgium) and Halley VI (UK) were built this way. However unless there are spare or duplicate panels, if one of these large, prefabricated parts is damaged during transport or construction, there may not be an easy way to replace it on site, especially if it is a unique piece. These problems can be addressed with careful handling, detailed planning, and spare parts. This might include relying on keeping a surplus of a limited number of pre-fabricated types.

High precision construction can ensure tight seals between joints the help lower air infiltration, one of the principal factors behind the building's overall energy efficiency. Walls, windows, and roof structures must also withstand very low exterior temperatures, large pressure differences (depending on the orientation to the wind), and spindrift of both snow and fine volcanic soil. Prefabrication also reduces on-site construction waste (and subsequent shipping loads). Structural insulated panels (SIPs) and vacuum insulated panels (VIPs) are examples of a type of prefab construction method already in use in Antarctica (i.e., SIPs) and possibilities for the future (i.e., VIPs). (For more information on these materials, as well as other innovations such as aerogel and movable insulation, see Appendix H.)

Additional Material Considerations

Additional considerations for energy efficient materials to be used in Antarctic stations include the following:

1) All materials exposed to the elements should pass endurance for extreme cold, temperature swings, and other harsh conditions. For example, the glass sealant used in

the windows at Princess Elisabeth was chosen for its strengths in resisting these extreme conditions as a silicone, which also exhibit " …high tensile and tear strength, long-term flexibility, resistance to harsh, weather, temperature extremes and ultraviolet light and excellent adhesion [to] building materials" (Dow Corning, 2010).

2) Antistatic interior finishes should be considered, especially on floors and door handles. In the dry Antarctic environment, the repeated experience of small electric shocks to the hands can become a tiresome recurrence. Additionally these finishes can reduce the risk to sensitive electronic equipment in laboratory or communications equipment. Safety measures are already in place at McMurdo's "gasoline station," where a grounding device is provided to protect people and vehicles during the refueling process.

3) Ergonomic shapes will not only provide a more pleasant experience but can sometimes be a matter of safety; for example, door and door handle design. Many buildings have doors that are essentially refrigerated building doors, heavy and with large push-activated deadbolts or long-handled releases. Other buildings and many interior rooms rely on door knobs, which can be difficult to grip with gloves and nearly impossible to manipulate with mittens. These should be avoided. Railings near steps are a similar problem –not their absence but the distance to them and the feel of the grip. In the same vein, interior circulation patterns should be considered as matter of designing for a human scale. The width of major hallways should be addressed in section to ensure easy passage of 2-3 people of American proportions wearing "Big Red," the large winter parka ubiquitous during the Winter and Win-fly seasons.

4) Sensory reactions, such as sounds, sights (colors) and smells should also be considered as part of the health and well-being of the station inhabitants. With so much time spent indoors, especially during the Winter and Winfly seasons, the interior design should not be left as a final thought. The designers of Halley VI incorporated these ideas early on in their design, keeping sleeping areas away from nosier pods (e.g., social areas and plant areas) and using designs and materials that limited noise transmission (see Section 4.3.2). Colors were used to designate different areas, and those colors were chosen to fit the program, being either more energetic in social areas or soothing in private, quiet areas. While there are very few natural smells in the Antarctic and the human body tends to sweat less in the arid environment, there are still smells from food preparation, engine exhaust, and (eventually) body odor.

4.5 Summary and Recommendations

Almost as much as the climate, the remote location of McMurdo Station drives up fuel costs and shapes the way the station looks. Structural systems, especially in the early Navy days, tended towards the lightweight and portable. Today buildings are heavier and more permanent with HVAC systems in the ceilings or attic space above conditioned space. Since there is no need to address a shifting ice shelf, McMurdo Station enjoys the luxury of permanence, although this brings with it the burden of being slower to change. Therefore, construction techniques should stress easy, on-site assembly with high-precision building connections to reduce infiltration of cold air and snow around building joints. Foundation systems should allow for the unobstructed passage of air below the buildings and should be kept uncluttered for easy maintenance access. Easy maintenance and long-term life expectancy should also be emphasized for building and their systems.

There are also several design and construction recommendations for buildings in very cold climates that enable the structures to remain comfortable but that also maximize energy efficiency. Some of these are hidden within the structure (e.g., layers of insulation) while others are within the building and manipulated by occupants (e.g., daylighting and mechanical systems) and so must be designed with users in mind. Some may only be visible from the bird's eye view, such as site selection and layout of buildings. All play a part in the design of a functioning, energy efficient, maintainable, healthy and comfortable remote research station. McMurdo faces the challenge of having a legacy of older, high maintenance, energy inefficient buildings, and a haphazard layout. While it may not be feasible to replace the entire station, the NSF should work towards its long-term redevelopment (i.e., away from the mistakes of the past) and design future structures with all of these factors in mind.

4.5.1 Long Range Development Plan

A master plan for McMurdo Station should: 1) plan for future growth of the station while minimizing site footprint, 2) minimize energy use, 3) maximize human comfort, 4) maximize productivity of scientific and support personnel, 5) increase the flexibility of the station, 6) improve the aerodynamic design of individual buildings that minimize snow drift patterns, 7) incorporate zoning and functional organization of the station's buildings (e.g., dormitories, heavy machinery shops, science and science support buildings, galley and recreational areas), 8) provide access by large vehicles between or around buildings, 9) minimize risk from fire, 10) minimize maintenance, and 11) provide redundancy of essential services.

4.5.2 McMurdo Station as a Community

It is important to remember that this station is a home to hundreds of people each year for a long time without much possibility of change. Even with the varied and dynamic makeup of the population, the overriding sense of community remains season after season. While scientists and support staff may all come from very different backgrounds, "…McMurdo effectively operates as a successful 'ideological community,' in which the members have a conscious, elaborated understanding of themselves as a group and to which individual members feel an emotional connection and investment" (Offen, 1994, p. 383). The group works towards a common goal (i.e., science and continued upkeep of the station) in the face of harsh, volatile weather conditions and ever-aging infrastructure. They do not lack the ability to poke occasional fun at contradictions in the huge bureaucracy that governs the station (and access to the continent), but those who are seen shirking responsibility or disrespecting others are not tolerated (Offen, 1994). All of this should be considered when proposing designs for the station.

5. REVIEW OF SOURCES OF ENERGY FOR MCMURDO STATION

To put Antarctic logistics into perspective, it is useful to look at the financial costs. The 2013 annual Office of Polar Programs (OPP) budget[130] was about $477 million (just under 7%) of NSF's $7 billion budget (OPP, 2012). Of the $477 million, roughly $357 million went to the Antarctic program (versus Arctic or other programs). Of this amount, approximately 20% was allocated to direct science support (i.e., grants to science projects and the sharing of information) and the remaining 80% for infrastructure, and logistics. Since 2002 the ratio of funding for science versus support has not changed significantly, but the total amount spent on support and logistics is trending upwards (Augustine, et al., 2012, p. 7). Some costs are unavoidable given the remote location and dearth of natural resources; others can be managed with increased efficiency and planning. Energy, one main driver of increased costs in recent years, is one area that can be contained though improved efficiency, which helps to reduce environmental footprint and pollution.

McMurdo Station requires a large quantity of fuel every year for approximately 550,000 ft^2 of heated space: 521,000 gallons (65,138 MMBtu) for building heat and 1,161,000 gallons (145,153 MMBtu) for electrical generation (13,182,536 kWh

[130] NSF's Office of Polar Program (OPP) has budgeted $477.41 million for 2012 fiscal budget plan, with Antarctic sciences to receive $76.65 million, and Arctic sciences nearly $113 million. Antarctic Infrastructure and Logistics will receive $280 million (Rejcek, 2011a). For comparison, the national defense budget for 2011 was $738 billion, with the same amount going to Social Security.

generated in 2007).[131] This represents 25% and 48%, respectively, of the station's annual fuel allotment (not to mention the station backup supply).[132] Part of the power plant output goes towards processing the 15 million gallons of potable water required by the station, which it desalinates (and later processes out the waste) on site.[133]

For an expanded discussion of Section 5, see Appendix M.

5.1 Non-Renewable Energy Options

Traditional, non-renewable forms of energy have dominated McMurdo's history: diesel (jet propellant), heating oil, "mogas," and even a brief period of nuclear power. Because of technological restraints, including the ability to store renewable energy, it is unlikely that a place as extreme and remote as McMurdo Station will be able to switch entirely to renewable energy (e.g., wind, solar) any time soon; diesel generators will always be necessary as a safety backup. However, transporting petroleum products from the New Zealand or the U.S. incurs very high costs; storing 2-3 years of fuel on-site requires infrastructure, maintenance, and environmental monitoring. Therefore, it is very likely that much effort will continue to go into the development of more extensive renewable energy systems for McMurdo Station (and its neighbor) that will allow the operation to rely less on non-renewable (carbon-based) forms of energy.

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131 Heating value of the fuel (JP-5) is 125,000 BTU/gallon. See Appendix M for more information.

132 Recently it has become necessary to install more fuel tanks so the station can store at least two years' of fuel. This became necessary because the U.S. does not have icebreakers and can no longer rely on other countries for icebreaker support, which is essential to the delivery of fuel and other supplies by sea.

133 Finding data on the energy required for this process is not readily available. Even the 2005 NREL study noted that it did not have good baseline data from the water plant (Baring-Gould, Robichaud, & McLain, 2005, p. 3, 14).

Doing so has multiple benefits. Less fuel demand means less fuel to purchase and transport, and less need for multiple million-gallon storage tanks, which also reduces the footprint of the station (Figure 29, Figure 30). Less fuel on site in turn lowers the risk of undetected or catastrophic fuel spills, another positive step towards reducing the environmental impact on Ross Island. Fuel spills are also potential fire safety hazards. Lastly, if generators can turn off during lower periods of energy demand, it is not only quieter, but also means less wear and tear on the machines.

McMurdo Station's generators were recently upgraded and provided with a new enclosure, increasing their efficiency from 11.4 kWh/gallon to 12.5 kWh/gallon, an improvement of 9.6% (RSA, 2008, p.18). Their presence is likely to remain in McMurdo, even if one day the station incorporates more wind power into its systems (Figure 32). Even at Mawson station,[134] with its three large turbines providing the majority of the station's power needs, diesel generators are necessary as a safety backup. Wind-diesel hybrid systems allow the station to enjoy peace of mind when it comes to continuous power. At McMurdo Station –and anywhere in the Antarctic– the goal of course would be to be able to rely on diesel generators only during extraordinary circumstances.

As far as nuclear power is concerned, its use in Antarctica is highly unlikely. However, at one time it was considered the energy source of the future on this remote, frozen continent. In the 1950s nuclear power was considered a safer,[135] more reliable

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[134] See Appendix F.
[135] This is because electric heat has a reduced risk of fire when compared with oil-burning devices.

source of energy, and provided enough power to allow heated water pipes and the possibility of a desalination center for potable water (Tyree, 1962, p. 273).[136] During a brief period the nuclear power plant also reduced the need for bulk fuel to be delivered by ship to McMurdo, saving pilots and crew from hundreds of dangerous flights to the Antarctic (Dufek, 1962, p. 712). The plan called for nuclear waste to be shipped back to the U.S., with only a small shipment of radioactive material imported every three years. In theory, it seemed like the perfect fuel source for remote stations like McMurdo, with its high power needs; in reality, the results were mixed.

Although the advantages of nuclear power seem to make it a good fit for a remote location like McMurdo Station, the burden of intensive maintenance (Figure 31) and lingering risks of nuclear meltdown (with limited means for station evacuation) in the end outweighed the "endless" supply of clean energy.[137]

5.2 Renewable Energy Options

Although there has been recent progress increasing the use of alternative forms of energy in Antarctica, there is still much room for improvement on Ross Island. There are potentially great cost savings from the integration of wind power into McMurdo's power grid and perhaps some smaller savings from small-scale solar power. Other energy sources such as expanded solar power and battery banks may one day prove feasible, but today they are not financially or logistically viable. Exploring renewable

[136] The current water plant would not be built until 1993.
[137] Although the loss was great when the station no longer had a source of nuclear-generated steam for desalinating seawater (see also Section 5.2.4).

energy options is important to the long-term success of McMurdo Station not only because of rising costs of crude oil, but because of the need for reduced station footprint under the Antarctic Treaty. The scientific program also benefits from the preservation of the pristine nature of the location.[138] Reducing the risk of environmental contamination (from oil or fuel spills, nuclear contamination, or habitat disruption) is not only required by the Antarctic Treaty, but is also crucial to the long-term viability of the station as a place of scientific research.

Wind power and a combined power grid (the Ross Island Wind Energy Project, (RIWE)) are two recent achievements. From 2009-2011, three Enercon 330-kW wind turbines erected between Scott Base and McMurdo Station by the New Zealand Antarctic program (Antarctica NZ; see sections 1.4.4 and 4.2.1) successfully demonstrated the potential for wind energy on Ross Island (Figure 34). These wind turbines provided a strong proof of concept of the potential of local wind power as well as the advantages of a shared power grid between the two stations. "Since January 2010 when the facility first became operational, approximately, 20 per cent of McMurdo's and 86 percent of Scott Base's electricity demand have been supplied by the wind turbines. This equates to a savings of approximately [118,877 gallons] of diesel fuel per year" (Colston, 2010, p.29).[139] This project has laid the groundwork for future turbine installations.

[138] In many places in and around McMurdo Station, any sense of the pristine has long since vanished.
[139] This figure may not even include the fuel saved by not having to transport more fuel to the station.

One estimate concluded that additional turbines could theoretically meet 90% of the electrical demand for McMurdo Station (Colston, 2010, p. 29). While the power generated for Scott Base was substantial and the benefit to McMurdo welcome, simply adding more turbines without addressing the inefficient design and maintenance of the station's existing buildings should not be considered an adequate solution. Furthermore, there are limited sites available for wind turbines,[140] with some of the best locations already set aside for science projects (e.g., Arrival Heights, Figure 33). The question of electromagnetic interference from the turbines confounding these ongoing projects has yet to be resolved.

Another renewable power system that does not have these problems is active solar. However, during the long night of winter, there would be no usable solar radiation, making it more difficult for a quick return on investment.[141] While summer days offer unending sunshine, the high latitude also reduces the potential solar radiation. Because of this, the potential for active solar powered systems in McMurdo has been addressed mostly at the small scale for remote camps (prevalent during the sunny summer months). It may also be possible to integrate active solar panels into the station buildings, or to make room for an array.

If operable only during the summer, panels used at the station may not need to withstand temperatures of -40^{o}F, but then they might have to be removed or winterized

[140] NREL considered the minimum spacing of wind turbines to be two rotor diameters. This varies depending on the wind rose for the site. (Baring-Gould, Robichaud, & McLain, 2005, p. 11).
[141] Even during the periods of 24-hour daylight, the sun at this high latitude would be at a low altitude and does provide much radiation on a stationary panel. During these times, the panels would need to capture more solar radiation by tracking the sun.

from April–September. At all times they would need to be able to withstand storm-force winds and deflect blowing snow and other debris. The solar panels ideally would track the low sun altitude (mostly from the southeast to the west). Here again, it would be necessary to include a battery bank to provide a more even power supply.

Finally, drilling for the purposes of obtaining heat and power from geothermal reservoirs may run contrary to the Antarctic Treaty (Article 7) (Alvine, 2010). However, the possibility of a geothermal system (i.e., Ross Island is volcanic) was considered in the early 1970s, but exploratory drilling showed little promise of such a system being economically viable at the time.

5.3 Water

Antarctica is a cold desert with almost no sources of fresh water beyond snow melt, an energy intensive and non-renewable solution.[142] Any discussion about water is actually about water conservation. McMurdo Station uses about 15 million gallons of potable water each year.[143] Currently this water is produced by an effective yet energy intensive reverse osmosis (RO) system using sea water (RSA, 2008) that desalinates millions of gallons of sea water each year. About 9 million gallons are consumed by station residents[144] (RSA, 2008).

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[142] On exposed land, once snow is scraped away it does not return sufficiently to be considered renewable; in fact, scraping the land for snow creates a negative environmental impact.

[143] Average per-capita water consumption: Summer 69.1 gallons/day/person, Winter 156.9 gallons/day/person, Annual average 125.9 gallons/day/person (RSA, 2008). While the per capita use goes up in winter, the overall population is greatly decreased. This may indicate people's behavior changes when the urgent need to conserve water goes away.

[144] As opposed to being used for operations such as the ice runway.

A reverse osmosis (RO) facility located near the sea-ice transition desalinates up to 80,000 gallons of sea water per day for drinking and other needs (e.g., food preparation, dish washing, laundry, personal hygiene, etc.). However, this is sometimes inadequate during the mid-summer period when the population approaches 1,200 people, and water rationing is sometimes required (e.g., for showers and laundry). It is also an energy intensive process, previously only feasible with the use of nuclear power on Ross Island (Tyree, 1962, p.273).

In addition to drinking water, it is necessary to create a reserve of water for fire safety purposes. With structural fires being a high risk in this low-humidity, desert climate, it is essential to have a reserve of water for use in an extensive building sprinkler system. To provide this, 100,000 gallons (about half the station's capacity) are kept in reserve in two of the four 50,000 gallon tanks located in the same building as the RO system and then piped through insulated and heated above-ground pipes.

With the option for collecting snow for melt water no longer practical or desirable,[145] the only way to reduce the energy and cost of fresh water production is to reduce daily consumption through behavioral changes and by installing water-saving fixtures, such as water-less urinals, dual-flush toilets, low-flow shower heads, and automatic faucets. Some of these changes have already been implemented per the recommendations of the 2003 LRDP (DMJM, 2003).

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[145] Melting snow takes too long for a large station, and scraping the ground for snow alters the environment. Both methods are relatively energy intensive, including the current solution: sea water desalination. In the early 1960s, nuclear power was supposed to solve this problem, providing enough energy for the desalination plant. When the nuclear power experiment failed, so did the hopes for the plant. It was not until the 1990s that the plant was finally installed, the benefit to the environment outweighing the cost of running the plant.

5.4 Summary of Energy and Water Recommendations

The first step towards choosing and sizing the best power delivery system is to reduce energy demand, in part by making the buildings as efficient as possible. Long-term goals for the station include provisions that will require fewer people to run the station. But even if the population peaks at around 1,000, it is still the single largest group of people living together on the continent. Therefore, the following are recommended:

1) As with Mawson Station, a varied energy supply is safer than relying on one type of fuel or system. Creating a hybrid system may be more complicated, but in this case, redundancy trumps simplicity. McMurdo Station is already on this path, with its combined power grid and emerging wind farm.
2) Active solar should be pursued, even on the small scale (i.e., near and remote camps, buildings used mostly in the summer). Large roof areas or long walls with few or no windows provide opportunities, if the buildings are well placed and the panels very well protected from the forces of the wind and ensuing airborne debris.
3) As much as is safely possible, move away from transporting and storing diesel fuel for building heat, power, vehicles, etc. Eventually, provide more electrical hook-ups around the station for vehicles. Currently there is nothing to be gained from an exploration of geothermal heat or power to the station.

4) Desalination is better than snow scraping, and the plant currently in place is held back only by its age and capacity. Increasing the storage capacity will help with supply during peak times.
5) The current trend to install water-saving fixtures should be continued, especially for showers and laundry facilities. As long as necessary, continue the scheduled laundry days and rationing of showers. Include clocks in shower rooms, visible to those showering, so they may better track their time under running water.
6) If possible, make saunas available all year for the benefit of occupants (e.g., relaxation and hydration).
7) Water for hydroponic plant growing should be considered beyond just a limited basis during the winter season.
8) Wastewater should continue to be treated before being returned to the ocean. It may be possible to reuse gray water for the purposes of hydronic heating, but this would require and entirely separate waterline system.

6. SUMMARY OF LITERATURE REVIEW AND DESCRIPTION OF IDEAL STATION

6.1 Summary of Recommendations From the Literature Review

Categorizing the lessons learned from the Literature Review is complicated because so many of them are related to or affect each other. Rather than simply listing all of them, here they are presented under three headings, that come from themes that emerged during the research for this study. The first, "Fire Safety and Occupant Health," highlights the need for nearly every design decision to comply with fire prevention/detection and occupant safety rules/guidelines. The second, "Flexibility vs. Simplicity," includes lessons and recommendations that must be balanced against each other, including many energy-saving measures for cold climates. The third, "Quality of the Interior Environment," consists mostly of lessons and recommendations that provide a sense of control for station occupants, who must spend much of their time indoors and nearly all of their time in Antarctica within the few square miles of the station.

6.1.1 Fire Safety and Occupant Health

Fire Safety

As previously stated, the specter of a structure fire in Antarctica drives many decisions in the design and layout of the station; the magnitude of the loss to fire of an entire structure –be it at the height of the season or the dead of winter– is eclipsed only by the loss of multiple buildings should the fire spread. Therefore systems must be able to produce, store, and deliver enough water to contain any fire as much as possible within one area of a single building. If buildings are connected, the connection must prevent fire from spreading. If the station is a composite design and fire breaks out in the main building, the materials, structure, and fire prevention systems must work at an even higher level. In all cases, fire detection/prevention systems should be both automated and manual, with redundancies built in for extra protection. It may make the system more complex, but it is necessary to have both types of responses.

Occupant Health

Beyond fire safety, indoor air quality as a health concern is should be considered as both a matter of comfort and productivity. With so much time spend indoors, and with outside air needing so much treatment before it can be distributed within a building, it is imperative to keep that air as free of pathogens as possible. Ways to limit VOCs and other harmful chemicals are well known (although they may run counter to high-rated fire-resistant materials), and lessons from hospital design provide insight into how HVAC systems can limit the spread of disease, which is a big problem in high density areas like dorm buildings and communal dining facilities. IAQ (including monitoring) adds another level of complexity and maintenance, but it is well justified.

6.1.2 Flexibility and Simplicity

Cold Regions Best Practices (CRBP) and Building Lifespan

For an operation as large as McMurdo Station, one of the biggest challenges is the balance between flexible systems which can accommodate changes (e.g., in weather, occupancy, available sunlight, and scientific program), and simple systems which are easy to understand and maintain, and that allow the station to be easily constructed and managed over time. The advantage of having smaller stations with shorter life expectancies is that there are fewer problems with legacy buildings.[146] In McMurdo, buildings need to be designed to keep out the unconditioned air and keep in the conditioned air under very harsh conditions, but it is likely that after 20-25 years they will become obsolete or age to the point they no longer function optimally. Buildings should be able to be upgraded, renovated, or completely replaced, a feature that does not lend itself to simplicity (in the planning phase) but does increase the station's flexibility.[147]

Cold Regions Best Practices (CRBP) (as described in Chapter 4) therefore should current guidelines and recommendations. However, with an eye to the future; it is likely that windows will need to be replaced after 20 years and the technology[148] will likely have advanced as well. There is no room for standard construction techniques in Antarctica, but no building system should be so complicated that construction errors return to hinder the building's performance (this is an advantage of prefabricated parts). Balance is key. The simplicity of the Quonset hut was its beauty, but also its downfall when it could not accommodate new demands,[149] and it fell victim to the harsh environmental conditions.

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[146] That is, buildings that no longer serve their purpose and have become energy inefficient because of their age.
[147] The great embodied energy of replacing a building versus renovating it should be acknowledged, but it is beyond the scope of this work.
[148] That is, thinner, clearer glazing that has a higher R-value, or window systems previously too expensive or technologically untested to use in McMurdo.
[149] For example, the needs of a high-tech, modern science lab.

Station Layout

As always, CRBP must be subservient to fire safety decisions. This also affects the decision to make the station a composite or multi-building station. The former is simpler, the latter more flexible. Both face challenges from fire safety, energy efficiency, and the quality of the interior environment. While it may be argued that no matter the technology, a single-building structure is simply too big a risk to take, other criticisms (e.g., the composite station's lack of connection to the outside) may be mitigated with thoughtful design.

Room Design and Functional Segregation

"Room style" is another clash of flexibility vs. simplicity. Fewer rooms with more people in each room is much easier, but overall must be considered the wrong path. Private rooms have long been considered the gold standard; they allow occupants to control their personal space, including the room temperature. The ability to "get away" or "turn off" for a few hours every day is recognized in many articles on small, confined spaces (see Section 3).

Room style extends to the question of functional segregation, or creating residential areas for people who work different shifts. It also includes the segregation of upper-level administrators and other VIPs. This hold-over from the USN days (and even back to the Heroic Age) is easily criticized but has its benefits. The rub comes with the question of flexibility: some people change shifts over the course of their stay. Does this mean that a worker must then move rooms (or buildings) to be in a designated quiet area during the day shift when he or she sleeps? It is much simpler to keep everyone in one general residential area; with single rooms and well-executed acoustical treatments, it may not be necessary to sequester night shift workers to designated floors (although including lounges in residential areas for semi-noisy activities is still an issue).

Energy Source

The flexible-simple balance also covers energy source. It is likely that a hybrid system that relies on renewable energy (probably wind) but which can fall back on a well-known source like diesel generators will be required. Smaller contributions from active solar or other future sources will also need to be accommodated in the delivery and/or storage system. The Ross Island Grid, incorporating Scott Base and its 240 voltage/50 cycle AC (see Chapter 5), further complicates the system, but for the sake of the environment, shipping costs, and fire risk, a system that reduces the need for diesel, mogas, and stove oil is worth it.

6.1.3 Quality of the Interior Environment

Sense of Control

The quality of the interior environment becomes almost as important as in a space station. Crucial to understanding this is the idea of providing occupants with a sense of control; in fact, this idea nearly becomes the main theme of this category. Living in close quarters (even in private rooms) and working with the same people daily for 8-12 months with very few ways of leaving can be stressful. In a place where work hours and food do not vary much, where the interior environment is often dull and with few outside views, where the weather sometimes dictates the day's activities, and where life in general is highly institutionalized, maintaining a sense of control over one's personal space can make a big difference in morale. Factors closely related to this include access to privacy and sensory control.

Access to Private and Social Settings

Privacy, as discussed in the previous section, provides a huge change in the way the station feels. Private rooms, if thoughtfully designed, can be comfortable places that provide a refuge for occupants at the end of the day. Occupants have control over stimuli, especially when it comes to sleep (a booster for productivity).

Recreational options also add variety to daily life, as well as promoting positive health choices in a place where one can become surprisingly sedentary. During the winter it is imperative that recreational options are not cut off by weather, or that a remote location (i.e., having to go outside) discourages people from getting some exercise. These places should be located in or close to dorms, or connected by protected passageways.

Connection to Place

The final factor in this category could be considered the most difficult to define- perhaps the most architectural (in a disparaging sort of way): connection to place, including views. Being in the Antarctic is one of the main reasons people decide to work as a janitor or cook in Antarctica. While keeping people safe, sheltered, and comfortable is obviously the priority, providing them with the ability to experience the outside environment is also very important for morale (and possibly job retention). Provide lots of view and opportunities (i.e., choice) to go outside. This goes against the principle of simplicity as well as CRBP (in terms of heat loss through windows or opening doors).

6.2 Synthesis of Recommendations: the Ideal Station

A description of the ideal station housing begins with a brief description of the station overall. The ideal station is compact and well organized, with a clear wayfinding system and zoning (e.g., loud industrial areas are away from housing; waste storage is separate from food storage). Buildings are spaced for fire safety and laid out so they are parallel with the prevailing winds; however, local topography sometimes breaks up the straight lines. An aerodynamic study of the buildings and their layout highlights any problem areas. Drainage studies determine where problems may arise during the summer melt, which makes certain areas muddy or difficult to access.

Buildings of similar or related functions are grouped and often linked by elevated walkways. For example, dormitories are linked with each other and to certain recreational areas so residents can access them no matter the weather conditions, and without having to don cold weather gear. Only related functions are connected, such as dormitories with recreational facilities, and science labs with science support buildings. High risk buildings (e.g., hazardous waste storage, vehicle maintenance) or buildings that must remain isolated for safety reasons (e.g., power houses, medical, waste and wastewater treatment) should remain physically isolated. The walkways are high enough off the ground to allow the passage of heavy vehicles, emergency vehicles, or fuel trucks. Ground-level entryways (with large vestibules) offer the option to walk outside. LED lighting below the walkways illuminates pathways during the dark, winter days and nights. Some walkways end close to buildings for easier access, but are not attached to them, for reasons of fire safety. Naturally, the structure and materials of connecting corridors is of fire-resistant and non-combustible materials that singe but do not burn, and the structures are fitted with automatic and manual fire suppression systems.

Roads and pedestrian areas are not crossed by fuel or water pipes; some of these run below buildings or walkways, but emergency water lines minimize their proximity to structures. Pedestrian bridges or a building walkway cross any areas in which pipes had to be placed in an otherwise pedestrian area (i.e., when there was no better option).

Moving on to dormitories specifically, these buildings are designed primarily to be quiet places for sleeping or contemplation, but living room-type lounges are still present. In-house recreational facilities are acoustically isolated, and there is protected access to off-site recreational facilities. All building-borne noises are dampened or muffled. This is emphasized for mechanical noise and traffic on stairs/doors slamming, especially for rooms closer to these functions. Most floorplans do not put personnel rooms next to such functions. Bedrooms are acoustically insulated from neighbors and those in the hallway.[150] There is complete control of the window in each room to allow for daylight or views and an LED system should be provided to simulate daylight in the winter, should the room occupant choose to use it as a sleep/wake aid. Windows are

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[150] Vacuum cleaners are the silent type, enabling them to pass by without disturbing the nightshift "day sleepers."

operable for emergencies only, and they are glazed with aerogel or a quadruple pane system.

Gang-style toilet and shower rooms balance out private (single) rooms. On-site laundry facilities are still provided for convenience. Hallways are long, but not straight, softened with slight turns and pocket alcoves. There are windows along the side of the hallways in some areas, but never at the exposed end of the hallway (this reduces glare). Vestibules not only keep out drafts and icy slush on boots, but they keep in the warm air and provide a large space for people coming in from the cold to slow down and remove the most outer layer of garments (e.g., unzip jacket, roll down face covering, pull off hat and gloves). This means they are quite spacious, which also cuts down on the amount of time both doors are open.

Rooms are compact but efficiently organized, with lots of features that perform double duty (as seen in very small homes). There are no interior single-bed rooms, and nearly all over-flow bunk rooms and lounges have windows.[151] Rooms are simply designed but able to be modified by occupants. Warm, wood tones and textures, along with task lighting, set the rooms apart from other parts of the station which remain more industrial looking (out of necessity). The dorm interiors are in general different from the rest of the station, looking not like offices or institutional areas, but more residential (i.e., homier) utilizing color, natural-looking materials,[152] and furniture type. Floors are anti-

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[151] As the number of required staff decreases it is hoped the need for over-flow rooms will be as emergency spaces only.
[152] Low-quality materials should be avoided, as they only emphasize the fact they are not real, and may tend to degrade faster.

static, as are door handles, which are also ergonomic (easy to open while carrying something or while gloved). Adjustable overhead and task lighting is available in all rooms.

Hallways have motion sense lighting as well as a "night (i.e., low light) setting." Room sensors also react to occupancy to revert to an "away setting" that allows the temperature in the room to drop. Scheduling can also play a role, but if buildings house people on multiple shifts, this becomes more complicated. If it becomes reasonable[153] to house different shifts on different floors (e.g., night shift on the top floors) or in a separate building, scheduling could play more of a part. Otherwise, sensors will be needed to monitor each room separately. Modular heating systems (such as the modular boilers already used) and a VAV air handler help ramp up or scale back the amount of fuel used to heat the buildings, depending on occupancy and outside temperature.

The building itself is well sealed and protected against the outside elements. As prescribed in all literature on *cold regions best practices* (CRBP), the air barrier is continuous and robust, and is located on the warm side of the envelope so that any moisture that does become trapped has a chance to exit (see Section 4.2). The buildings –which rest well above the ground to prevent negative interaction[154] with the permafrost and to provide easier access for maintenance– are essentially boxes sitting inside the structure. The insulation and sheet membrane are not penetrated by the services.

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[153] People may change shifts multiple times over the course of their stay, making segregation by shift difficult. If people are certain they are going to stay on one shift, they may choose to be housed in a specific area or areas.
[154] That is, a melting of the permafrost and the resulting destabilization of the soil.

Factory-made parts or sections of wall are used when feasible (i.e., they are not too large or delicate to transport). This also aids in the reduction of on-site waste, which must also be shipped back to CONUS.

Building form for the dorms should allow each room to have a window. This also goes for lounges. Placing sensitive areas like showers and restrooms in the core of the building may help protect water pipes. It may even be possible to maintain small hydroponic gardens on the ground floors that double as building lounges. On top, the roof should not be completely flat, but there is little need for it to pitch steeply. Attic space has previously been used to store air-handling equipment. Attics used for this purpose are insulated but not heated, allowing the roof to remain "cold." Any connections between buildings (most likely on the second floor) should double as public space, but should also be treated as a potential fire hazard.

Fire safety in the dorms is already helped by a ban on smoking, candles, and most cooking. In the idealized building, materials are also chosen for their non-toxic, anti-flammable qualities. As at South Pole Station, the interior wall structure known as Type X provides a one-hour fire resistance rating. Exterior walls are similar, if not even stronger. Insulation such as polystyrene, which offers very good R-values, is also valuable for its ability to singe but not combust. This kind of quality should be exhibited in all parts of the building, including furniture and bedding. Building connection, as previously stated, are potential weak points for limiting fire spread, and should not only feature detectors, alarms, sprinklers, and non-combustible materials, but be behind firewalls. If possible, these systems could even be detached. Walkways that do not connect buildings should be similarly protected, although their distance from other buildings should provide a great deal of safety.

Mechanical systems, as previously mentioned, include a modular heating and air-handling system that allows the building to be more flexible. Integrated in the HVAC is a pathogen control system that uses HEPA filters and UV lights to control the spread of disease within the dorms. Shower rooms and toilets are cleaned daily and supplemented with a UV treatment usually found in hospitals. Anti-microbial surfaces are used when feasible (e.g., counters, faucets, door handles), and touchless or foot-activated sinks and toilets aid in curbing cross contamination. Finally, air intakes for buildings are located in areas that are not subject to pollutants, such as idling vehicles.[155]

In summary, the dormitory is a comfortable place for station employees to relax and gain a restful night's sleep no matter what time of year or day. The building design promotes health and well-being, and rather than being a cookie-cutter institutional building, exhibits some characteristics of hominess by providing single rooms that allow for privacy, customization, and a pleasant view outdoors. At the same time, the building employs every energy-saving measure possible, in part by being flexible in the amount of fresh air and heat it delivers. That it is well insulated and constructed using CRBP goes without saying; that it pairs this with occupant comfort would make it an exceptional building in McMurdo Station.

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[155] It is hoped that soon vehicles will have more places to plug in so drivers are able to keep the engines warm; it may also be possible to switch the fleet over to electric-hybrid cars, greatly cutting down on the emissions fog that can hang over the station (Figure 26).

7. METHODOLOGY

7.1 Overview of Methods

The basis for this methods used in this dissertation (Figure 5) lies in the literature review, which informed not only the history and helped define the conditions, considerations, and complexities of architectural design in the Antarctic, but also other methods, which included the site visits and surveys (Section 7.2 and Appendix P), and the energy model and design matrix themselves. In turn, the site visits and surveys also informed the design matrix (Sections 7.3-7.5) and energy model (Section 7.6). The literature review is compiled in Chapters 2-5.

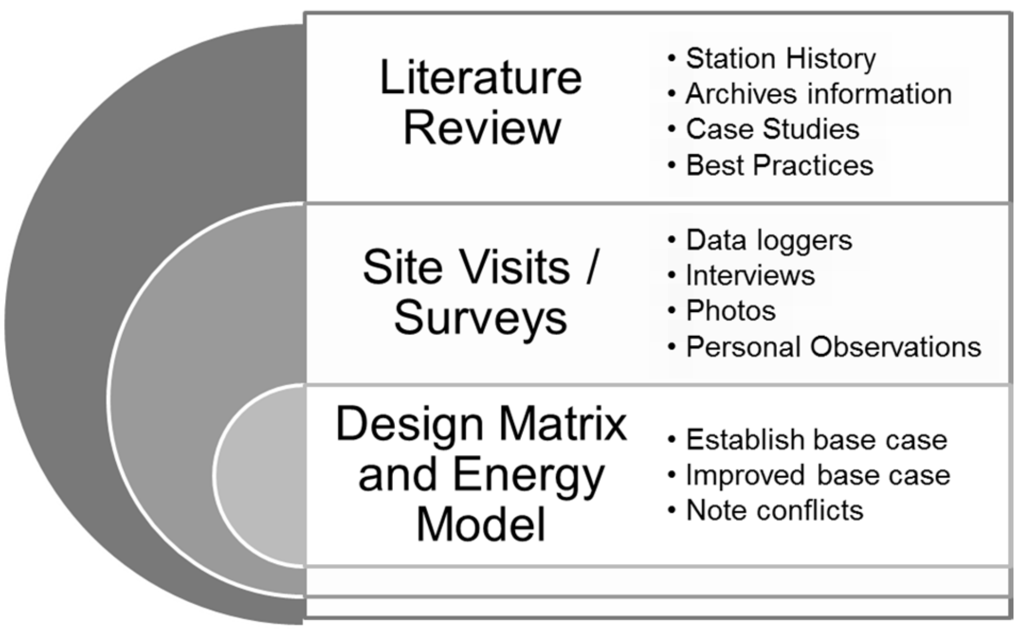

Figure 5: Graphic representation of the methods.

7.2 Site Visits and Surveys

I made two site visits to the station during the Winfly seasons of 2009 and 2010. Numerous photographs from these visits appear as figures in this dissertation, along with observations about daily life, building operations, station operations, and recreation options. Site visits have been a part of past LRDP and energy studies, but not since the early naval reports has one been from the point of view of someone working there, and never from someone working concurrently on a scientific project based at the station.[156] This position allowed me access to the station for over 60 days per season. I lived in a dormitory, worked in the Crary Lab, ate in the Galley, and made use of the station's recreational offers (e.g., gym facilities, volunteer-organized activities, and hangouts like the Coffee House). I also had access to areas off-station, a privilege denied to most contract workers.[157]

Surveys were distributed in 2009 and 2010 (mid-August – October) after approval by the IRB.[158] A full version of each survey (based on the recipients' time of stay, is included in Appendix P, along with the complete results. In the next section is a partial list of the questions asked in the surveys, of which there were two versions based on time of stay (i.e., those who had just over-wintered, and those who had just arrived at WinFly). Full versions are included in Appendix P.

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[156] The GreenPlay survey (See Appendix P) is an example of occupant opinions, but it is not clear how that survey information was used to inform any future station design.
[157] With the exception of organized "boondoggles" to the historic sites or other nearby attractions.
[158] In accordance with IRB approval IRB2010-0437 and 2009-0552.

Demographic Questions

Sex/ Age

Job/role at station

Shift worked

Is this your first deployment to McMurdo?

If not, how many times have you been here before, and at what time of year?

Is this your first time in Antarctica?

If not, where else have you worked, and for how long?

Is this your first time to be here at for Mainbody/Winter/Winfly

Built Environment

Do you feel the built environment (the buildings that comprise the station) provides a comfortable environment that promoted a sense of physical and emotional well-being?

Rate your ability to find comfortable places to socialize since you have arrived.

Rate your ability to find comfortable places for privacy since you have arrived.

Rate your difficulty sleeping since you have arrived.

Rate difficulty encountered when moving between buildings since you have arrived.

If there are problems, please describe them.

How often does the low relative humidity keep you from feeling comfortable?

If there are problems, please describe them.

How often does the low temperature keep you from feeling comfortable?

If there are problems, please describe them.

Work and Free Time

Since you have arrived, do you feel you get adequate physical exercise each day?

Do you feel there are there enough opportunities for physical exercise in McMurdo?

If you do exercise, where do you go and what activities do you engage in?

Do you feel you have adequate access to recreational equipment in McMurdo?

Do you feel there are there enough opportunities for excursions off-base?

Have you taken one of the provided hiking trails near McMurdo Station?

If you have taken one of the provided hiking trails, how satisfied were you?

Does your daily routine require that you spend time outside?

Do you like or dislike being outdoors in McMurdo Station?

Do you like or dislike going outside to travel between buildings?

Do you like or dislike being outdoors away from McMurdo Station?

What percentage of your work day is spent outside?

What percentage of this time is spent off the base (on the sea ice or elsewhere)?

What percentage of your free time is spent outside?

What percentage of this time is outdoors in town and how much is spent off the base (on the sea ice or elsewhere)?

Describe your place of work:

What is the building name?

Where is this building located?

How conveniently located is this building, relative to other buildings you frequent on a typical day?

Is there any natural daylighting (through windows or skylights)?

In general, what is the noise level like?

Does there seem to be adequate ventilation?

Is the temperature generally comfortable to you?

How important is occasional access to Scott Base?

When it is open, about how many times per month do you go there?

Does the ship's store (in Building 155) provide most of what you need?

If not, what would you like to see changed?

How important is the Internet to your daily life here in McMurdo?

How satisfied are you with your Internet access?

Are you satisfied with your voice/telephone access?

If not, what would you like to see changed?

Do you miss a normal light cycle (periods of daylight and darkness)?

Have you done anything to simulate a day/night cycle? If so, what?

Do you miss green vegetation?

Have you done anything to simulate having vegetation? If so, what?

Are you able to work flexible hours to accomplish your job?

Is having flexible work hours important to you?

Would flexible hours make you feel more comfortable in your job?

Room Conditions

Do you or will you have a roommate?

Is this by choice?

How many roommates do you have at the moment?

Did you know your roommate(s) before they arrived?

How important to you are private rooms in McMurdo during Win-Fly?

Do you have access to a private or semi-private shower/bathroom?

How important do you think private or semi-private bathrooms are in McMurdo?

About how many hours per day do you spend in your room?

Aside from your room and your place of work, where do you spend the most time, and why?

Describe your room:

What is the building name?

What is this building's location?

How conveniently located is this building, relative to other buildings you frequent on a typical day?

How many windows are there?

What is the view out the window (if present)?

In general, what is the noise level?

Is the temperature comfortable to you?

If you had the means, how would you make your room more comfortable?

7.3 Basis for Matrix Framework[159]

In creating a design matrix it became apparent how many design criteria and factors are codependent. The goal of creating a design matrix is not only to rate each factor against set criteria, but to clarify the connections and understand the relationship between two (or more) factors, thus making it easier to make an informed decision. The matrix showed that achieving an optimal balance may mean accepting high upfront costs for long-term gains.[160] Specific factors that are highlighted are further discussed in Section 7.7. Here I discuss the criteria by which these factors are evaluated.

The matrix displays design factors in more detail than are described more generally in Section 6.1. Specifically, these factors focus on housing (although many could be applied to a variety of buildings in nearly any Antarctic Station). Again, it is not always easy to evaluate a successful design, since the successful ones can be described best using paradoxical terms: design that is simple yet flexible, redundant yet elegant, homey *and* energy efficient.

The range of considerations for a successful design spans not just safety and measures such as fire prevention and disease control, and not just basic protection from the extreme cold, but also a coherent design for simultaneous long-term energy savings and occupant comfort.[161] These characteristics must be present and balanced for McMurdo Station to be considered sustainable.

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[159] "Factors" are the horizontal headings in the design matrix.
[160] This should not be a surprise if one looks at the history of the station
[161] Goals regarding site protection –everything from improving waste management, reducing the potential for accidental spills, reducing carbon emissions, and limiting area of site disturbance– should be considered non-negotiable

In the matrix each design factor is rated by: 1) its ability to achieve the main objectives of the design while meeting or exceeding 2) fire safety guidelines; 3) energy/water conservation through HVAC and structural cold regions best practices (CRBP); 4) expectations of limited environmental impact; and 5) occupant comfort recommendations for isolated, remote regions.

Ideally the design criteria should receive top ratings under all five factors; however, a condition in one category may be required at the expense of another. This should raise a flag that extra attention in required so that both criteria are rated as highly as reasonably possible.

7.3.1 Health and Safety

Criterion 1: The design reinforces/provides protection from the environment.

Discussion: Buildings provide the artificial environment necessary for survival in the Antarctic, like a fortress protecting occupants from the very cold temperatures, potentially high winds, and prolonged darkness. In a space capsule this barrier is a matter of life and death; in the context of McMurdo Station it is less critical.[162] However, because of the extreme conditions, long-term occupation and the success of the scientific mission would be impossible without it.

The "lifeless" terrestrial environment in Antarctica makes the contrast between it and the warm, brightly-lit human habitats very striking. This overlaps with the need to address two other points: the importance of energy supply/storage and its impact on the local environment. The fortress would not stand long otherwise.

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[162] That is, there is a breathable atmosphere and no problems associated with living in microgravity.

The need for these two considerations to complement each other, as well as the design of the interior environment, becomes extremely important. While the design aspects of these structures that make them "fortresses" are significant, their thoughtful design as *habitats* allows people to work optimally and to rest comfortably for the long term. Only then do they become sustainable.

Criterion 2: The design meets or exceeds fire code regulations.

Discussion: Dry conditions, limited access to water, and a remote location make fire the boogey man of all Antarctic stations. Fire safety, prevention, and containment touch on several areas of building design; in addition to numerous code requirements for stairwells, one needs to consider windows, emergency lighting, signage, extinguishers, and alarm systems. Other concerns include: material choice, structural integrity, fire walls/barriers, means of egress, station layout,[163] system redundancy, water delivery (sprinklers), and emergency water reserves. For the feature to be rated highly, all benchmarks must be exceeded. Regarding fire safety, there is very little room for leeway in design; however, sometimes a little flexibility is necessary. Any deviation from accepted codes or standards must be adequately justified and documented. If it is not, the lowest score is assigned.

Criterion 3: The interior environment retards the spread of disease in a small, confined community.

Discussion: Neither air quality nor object surfaces should detract from the health and safety of station residents. With so much time spent inside, the interior environment

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[163] That is, adequate spacing between adjacent buildings.

again becomes very important to the health –and by extension, productivity– of the occupants. The design achieves the highest score when the control of bacterial and viral contamination protocols resemble those found is hospitals, where preventing the spread of disease is a major challenge.

Related areas: water supply, emergency water plumbing, materials choice (flammability rating and pathogen resistant), building layout, station layout, occupancy, mechanical systems (air purifiers).

7.3.2 Energy/Water Conservation Through Best Practices

Criterion 1: Everything from wall structure, ventilation, windows, appliances, and the HVAC system contributes to the overall energy efficiency and lifespan of the building.

Discussion: The remote location and constant, high energy demand have always meant that energy intensive buildings –on top of an already expensive logistics and science program– are significant burdens on those operating (i.e., funding) the station. The underlying goal of efficient HVAC design and cold regions best practices (CRBP) is not just interior comfort and building integrity but overall energy efficiency. These practices are well known, but with the added complications of the extreme climate, more must be done for a design to achieve a high ranting in this category. Therefore, designs that meet basic energy efficiency or water conservation guidelines receive moderate scores, while those designed according to CRBP receive the highest score.

Criterion 2: Plumbed fixtures are energy and water efficient, and encourage water-saving behavior.

Discussion: The desert climate means there is very little precipitation to collect for potable water. Water is highly rationed at inland stations, even more so than McMurdo Station, which benefits from its proximity to the ocean.[164] While the desalination plant provides enough water to supply the station, the science program, and fire reserve in two locations (main station and an airfield), the desalination process is energy intensive and as the population increases at the station, it is still possible to exceed the capability of the water plant and exhaust its reserves. Water saving fixtures and automatic sensors are an easy change to make. Continuing to encourage water-saving behavior is also positive, but people should still be able to enjoy a hot shower without fear of running out of water. Introducing a grey water system for toilet water is a possible future upgrade, one in which the cost-benefit would have to be carefully considered.

Related areas: fire safety, emergency water plumbing, energy source/demand, expanded footprint (e.g., more buildings and pipes for storing/distributing water), occupant comfort (e.g., ability to shower, access to saunas).

7.3.3 Environmental Impact

Criterion 1: The design meets or exceeds expectations for the reduction of environmental impact by reducing or limiting the station footprint;

Criterion 2: reduces or eliminating the risk of environmental contamination;

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[164] Personal laundry days are staggered, and people are encouraged not to shower every day (in the dry climate body odor is less of a problem). Nevertheless, people are encouraged to hydrate themselves since dehydration can cause other health problems.

Criterion 3: preserves the natural landscape (that has not already been heavily disturbed).

Discussion: Many of these goals are described in the Antarctic Treaty and its subsequent environmental protocols, but McMurdo Station has more than what is stated in the treaty. Much has changed since the old days of open pit burning, ocean dumping of raw sewage, and the Greenpeace protests of the 1980s. The station is generally on the right path toward site remediation, foot print containment, waste processing, and low-impact energy sources.

Mostly it is the size of the station that keeps it from making progress towards footprint consolidation and reduced demand of fossil-fuel based energy (e.g., relying mostly on wind-generated electricity). Significant reduction in the demand for oil or mogas (gasoline) means fewer million-gallon holding tanks, and less of a chance for a catastrophic spill (see Section 5). Keeping environmental risk low also precludes a future with nuclear power (and probably geothermal as well).

High scores were awarded to designs that move the station away from past mistakes. There should be no reason to reverse gains or expand the size of the station, with the one exception made for the presence of more wind turbines.

Related areas: fire safety, station layout, redundancy

7.3.4 Occupant Health and Comfort

Criterion: The interior environment supports the physical/psychological needs of occupants.

Discussion: Every effort should be made to address the needs of contract employees and scientists. It may even be prudent to think of the station of the future, which could potentially one day host entire families. Occupant health and safety should be paramount, while comfort may be trumped by energy conservation and environmental impact. However, these potential conflicts should also be resolved early in the design phase, since occupant comfort (and hence, productivity) can be considered a type of energy efficiency (see Section 3).

Without the existence of any post-occupancy evaluations (POE) it is sometimes necessary to rely on historical assessments, case studies, analogue environments, surveys, and personal observation to judge this category. *Were steps take to incorporate designs that address the needs of the current occupants based on their expressed opinions?* Since the composition of the station has changed so much since the 1950s, moving away from being a male-dominated military outpost to a diversely populated research station run by private civilian contractors, the design of the building interiors – especially the living quarters– should change as well.[165]

Related areas: materials, energy demand, IAQ, windows

[165] There are also a considerable number of instances of occupant-initiated designs and design changes in the face of something lacking. Beside the temporary examples of dormitory room design, other examples include the creation of the first Chapel of the Snows, the interior design of the various bars and coffee house, and nearly every piece of artwork on display.

7.4 Selection of Design Factors[166]

The factors included in the McMurdo Station matrix are organized under categories from frameworks used by several sources, which in turn credit information from other previous studies. The categories are reorganized here for the purpose of this project based on the author's firsthand experience working at McMurdo Station and on the need to condense the points of view from many and varied sources on designing, building, and working in Antarctica.[167] The most prominently used sources for the construction of the matrix include an evaluation system for hospital satisfaction (Harris, et al., 2002) and proposed frameworks by which to evaluate a space habitat[168] (Vogler & Jørgensen, 2005; Preiser 1983; Preiser, 1991). For cold-climate, structural and mechanical information, there are various studies, articles, and reports that detail general guidelines and best practices (e.g., Lstiburek, 2009; Freitag & McFadden, 1997) which provide information; design factors are taken from the Unified Facilities Criteria for Arctic and Subarctic Construction (DOD, 2004) and are (again) reconfigured or combined to fit within the new matrix.

Combing the research and references from these seemingly disparate sources allows a multi-dimensional approach for the evaluation of such an unusual place; indeed

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[166] These are the vertical elements in the Matrix.
[167] Not all categories fit the current matrix or complement each other since they originate from such different sources. In addition, there is much overlap of similar ideas:, i.e., sources use different terms for certain topics, e.g., the UFC framework (DOD, 2004) considered cold attics and window construction "architectural"; while Harris (2002) describes architectural features as problems with wayfinding, the size and shape of rooms, and window views; and Vogler & Jørgensen, (2005) and Preiser (1991) do not include "architecture" as a category, but do cover several aspects of what the author considers architecture, e.g., spatial distribution and the need for privacy.
[168] Certain ideas for the evaluation of the space habitat appear earlier in a more general article on a "habitability framework," an approach to linking human behavior and the physical environment (Preiser, 1983).

several sources advocate a wide brush, multi-dimensional approach to the design of comfortable spaces. Each source includes considerations that are applicable to McMurdo Station's remote location and population, the latter being largely confined to an artificial, interior environment and exposed to extraordinary environmental conditions. Occupants of the station may not be as vulnerable as hospital patients, or work as astronauts outside the Earth's atmosphere, but the characteristics of the Antarctic environment create similar conditions and thus benefit from a similar response.[169]

For example, modern satisfaction ratings for hospitals include a number of room design characteristics and HVAC regulations that focus on occupant health and well-being. While occupants staying in McMurdo have passed a physical exam,[170] they are still largely bound to the confines of the interior environment and the rules of the remote authority governing the station. Issues of privacy and stress-relief are common to both hospitals and remote, confined environments. Additionally, the spread of infection is a problem in the confined interior environment; efforts to control the spread of disease contribute to morale and increase productivity (in terms of days lost to sick leave).

The comparison with a space station has been well established (see Section 3.1 and Harrison, Clearwater, & McKay, 1991; Suedfeld & Weiss, 2000; Rivolier, Bachelard, & Cazes, 1991; Bluth, 1985), making Preiser's (1991) attempt at creating a framework for the design of an extraterrestrial habitat for humans a *natural analogue* for

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[169] The argument that Antarctica is an analogue environment for outer space is made in several locations, including Harrison, Clearwater, & McKay, 1989; Suedfeld & Weiss, 2000; Suedfeld & Steel, 2000.
[170] Those wishing to winter over must also pass a psychological evaluation.

a matrix of McMurdo Station design guidelines. People living in Antarctica are still earth bound, but their view is of a land of ice, rock, and lifelessness (unless they can see the ocean). They can still travel outside, but never very far and almost always donning heavy clothing; sometimes they must abandon outside activities for those in the protected interior environment ("a capsule environment," see Section 3). Thus, many suggestions for space stations that deal with sensory stimulation and physical activity translate well to a remote station in a very cold climate. For these reasons, some pre-existing frameworks can be adapted to McMurdo Station to address the habitability of a design for the station.

That the design of the interior environment is often considered a soft (qualitative) undertaking should not mean it has no place in the programming of a building, or in its ultimate evaluation. Ultimately the success of a building it is assessed in a post-occupancy evaluation (POE), which goes beyond "… descriptive studies [and use] criteria standards, objective or threshold values to evaluate the performance of a building…" (Preiser, 1983, p. 89-90). Before that can happen, certain criteria must be established.

This process has been well described and tested in hospital design, especially with the advent of evidence-based design (e.g., Harris, et al., 2002; Marcus and Barnes, 1999; see Section 3.2.3). While many architectural and building HVAC design measures overlap both hospitals and "capsule environments," it is more useful to choose criteria other than patient outcomes to judge the success of a remote research station. To describe how well the interior environment supports the goals of the station and needs of the people who operate it, we can turn again to Preiser, who chooses the term "habitability," which he defines as "…the degree of fit between human goals and cultural characteristics … and the performance characteristics of the environment that is to support them. … [It is] environmental quality as perceived by the facility's occupants" (Preiser, 1991, p. 150). Without the benefit of a POE, the next best undertaking is to understand who is living and working at the station, and take into account a history of the station's past design decisions, both good and bad (i.e., the Literature Review, Sections 2-5).

Preiser (1991) points out differences in how groups, such as the USN, the U.S. Army Corp of Engineers, and NASA, define "habitability." Unlike the first two groups –of whom it may be said operate under a more traditional definition (quality of the environment for humans) – NASA looks to productivity and well-being as markers of the habitability of a space. Because McMurdo's primary mission is as an international research station, it is fitting to follow NASA's example for McMurdo Station.

Preiser (1991) continues his discussion of habitability, writing that building on NASA's motivations of improved *performance* of the users, the term "performance" should also indicate "…characteristics of an occupied facility that support human activities in terms of individual, group, or organizational goals"[171] (Preiser, 1991,p. 151). The matrix I have proposed begins with three categories of performance named by

[171] Preiser also notes that performance is not an absolute measure, but one that may be perceived by different groups occupying the space. We must therefore take into account the needs of these different groups, be they (in the case of McMurdo Station) individuals or groups; administration, science, or contract; and short or long term residents.

Preiser and compared with the oft-cited Vitruvian triad: health/safety, function/productivity, and psychological comfort/satisfaction.

7.5 Matrix Walk-Through

The following is an abridged description of the design categories in the matrix, including how they are judged. It is meant to be an overview of the matrix, not specific to any one scenario. See Section 8.1 for a discussion of every element in regards to the three scenarios (McMurdo As-Is, the OZ proposal, and the Idealized Station).

7.5.1 Security, Health, and Safety

These factors fall under the heading of measures generally covered by codes or standards since they regulate health and public safety. Recommendations therefore rarely deviate from code and standards found in other (U.S.) locations; however, some may carry extra weight because of the extreme climate or remote environment.

Protection from Elements: Building (Shelter), Connections

Main Objectives: Buildings provide the artificial environment necessary for survival in the Antarctic, like a fortress protecting occupants from the negative effects very cold temperatures, potentially high winds, and prolonged darkness. Of the four space categories mentioned by Vogler and Jørgensen (2005), "Physiological space" fits this category closest, as it "… needs to provide structural integrity and protection against the external environment and to maintain an interior environment within a certain comfort zone" (Vogler & Jørgensen, 2005, p. 392). The need for these issues to complement each other as well as the design of the interior environment becomes extremely important. While the design aspects of these structures that make them "fortresses" are extremely important, their thoughtful design as *habitats* allows people to work optimally and to rest comfortably for the long term, thus achieving a higher level of sustainability.

This idea can be expanded from individual buildings to the transitional spaces between them. Connections between buildings (e.g., semi-heated walkways) featuring glazed openings allow people to pass between buildings protected from cold, wind, or low visibility while providing some break –if only visual– from being in an artificial environment the rest of the day.

Criteria: Buildings that accomplish meet the most recent standards (i.e., ASHRAE 90.1-2013) and CRBP meet the minimum requirements and therefore receive higher scores than those which fall below these recommended levels and/or do not show adequate attention to occupant comfort. Those which go beyond these standards and demonstrate extensive energy efficiency practices and attention to occupant comfort receive higher ratings.

Fire Safety: General precautions, Detection/Prevention, and Structure/Materials

Main Objectives: As was discussed in Section 4.1.5, it is difficult to overstress the need for fire safety. Everything from smoking policy to fire suppression systems is covered. Many basic fire safety measures come down to general precautions, i.e., behavior (and how the built environment can influence it). These criteria are generally covered by codes or standards since they regulate health and safety. Recommendations rarely deviate from code and standards found in other (U.S.) locations; however, some may be found to carry extra weight because of the extreme climate or remote environment.

Spread of Disease: IAQ and Maintainability

Main Objectives: Keep the air healthy and comfortable to breathe while limiting the spread of disease through the ventilation system. It is also necessary to curb the spread of disease by keeping public areas clean; one way is by making them easy to keep clean, and the other is to install anti-microbial surfaces when possible and appropriate.[172]

Criteria: Systems which very effectively preheat and heat outside air but do not include ways to reduce pathogens are rated lower than those which address air quality through filters, pressurization, or UV-lights. Surfaces and materials which are durable and easy to maintain are rated highly, even more so if they go farther and stress anti-microbial surfaces and easy-to clean rooms. Note that none of these solutions can cause problems by being too noisy or difficult to service.

7.5.2 Psychological Comfort and Satisfaction

These factors are design elements that pertain to psychological health and well-being. The need to address these in remote habitat design is prevalent in studies of space habitats, but also extends to most ICE environments. One may argue that in space, where humans are uprooted from all that is familiar, these criteria are even more important.

Architectural Features: Occupancy, Hallways, Shower Rooms, Lounges, and Windows

Main Objectives: These factors include permanent or semi-permanent features of

[172] E.g., anti-microbial counters and door handles.

the building environment, as described by Harris, et al. 2002 (p. 1278-1279), which includes hallways, wayfinding, and building layout, and on a smaller scale, bedroom size and windows. For this study, shower rooms, and lounges are also included.[173]

Private/single rooms have long been a top request by station workers. Most rooms at the station accommodate two people (i.e., there is space for two sets of furniture) but there are no notable features of the rooms (i.e., built-in features) with the exception of a window (if any) that help demarcate personal space. Single rooms provide privacy and greater control over one's environment. However, if one includes more single rooms into existing spaces solely by shrinking their size, there are a few points to consider. By code, rooms cannot be smaller than 7 ft. in any plan dimension, no less than 7ft. 6-in from floor to ceiling, and each habitable room must have a net floor area of greater than 70 ft^2 (International Code Council [ICC], 2009, "Section 404 Occupancy Limitations").

Criteria: Design decisions that eliminate crowded living conditions are rated highly, while those that emphasize space-saving efficiency while disregarding occupant needs are rated lower. Well-balanced access to privacy and social areas is rated well; designs that eschew and institutional feel while being energy efficient are rated highly. There should be very little leeway regarding fire safety.

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[173] Vestibules are included in the section on Building Form.

Ambient Features: Thermal Comfort, IAQ, Sound, the Luminous Environment

Main Objectives: This category focuses on the occupants' senses, emphasizing control over stimulation and relaxation. Specifically, rooms should be areas where a single occupant may control the temperature and lighting to their desire, and very little unwanted noise should ever enter the room.

Criteria: Design decisions that give occupants more control over their environment are rated higher than those which do not, or which even deny certain sensory opportunities (e.g., windowless rooms). Energy efficiency should still be considered (e.g., occupancy sensors for lights); there should be little interference with fire code in this category.

Interior Design Features: Furniture, Artwork, Greenery, Lighting, Balance of Private and Social Spaces, Hominess, Boundaries, Proxemics

Main Objectives: This sub-category includes factors that are still related to the senses but are a bit more tangible. They should again focus on the needs of the occupants, including their spatial requirements, sense of personal space, and desire to engage in social interactions (if they desire). Availability of lighting that promotes diurnal rhythms and access to greenery –an idea highly related to sensory stimulation- is also included.

Criteria: Much like the previous sub-category, designs that grant greater control and present more opportunities for expression are rated higher than those which do not. Ideas like "hominess" and "furniture," both of which are closely related, should not interfere with maintainability. Providing enough space in a single bedroom must include proxemics and furniture; access to greenery may run counter to water and energy conservation recommendations, but its positive impact makes it worth pursuing.

7.5.3 Functional and Task Performance

Building Structure: Form, Floor and Foundation, Walls, Glazing and Frames

Main Objectives: The immediate objective of all factors in this category is to meet and exceed *Cold Regions Best Practices* guidelines to give the buildings their best chance at performing optimally for the longest time. This in turn affects their energy demand and occupant comfort.

Criteria: Building designs that achieve high levels of energy efficiency and demonstrate a commitment to high quality construction techniques and materials receive higher marks than those which do not.

HVAC: Power and Distribution, Heating, Ventilation, Water

Main Objectives: This category is similar to the last but puts more emphasis on the special demands that the *remote* quality of the site puts on building systems. Conservation is key, from power source and distribution to how individual buildings receive and store water.

Criteria: These may not be conventional solutions, but they are the best for this remote site, with its high energy demands and on-site power and water generation. At the same time waste is rated poorly, and a lack of redundancy for safety reasons is also rated low.

Logistics: Transportability, Construction Time, Scarcity of Materials/Facilities

Main Objectives: Again, the remote, extreme nature of the site comes into play, and every building and building part must be able to make the journey to the site and then either be used immediately or stored for up to a year before being used. Once a building is finished, its purpose may change over its lifetime.

Criteria: It may seem that time moves more slowly in the Antarctic, but when it comes to construction, there is never enough time. After a long journey and offloading, the amount of time to finish a project (or a stage) is limited. Yet the finished building needs to be strong enough to withstand the elements and heavy traffic, and built well enough that it does not age too prematurely. Designs that can accomplish this while retaining some flexibility are rated higher than ones which do not. It goes without saying that fire safety remains paramount.

7.6 Introduction to Energy Model

The following is a condensed discussion of what was needed to create a base case model for DOE-2.1E. It can be found in its entirety in Appendix O. This process does not seem to have been previously documented in reports about McMurdo Station using weather data for McMurdo Station specifically; therefore, there were several challenges caused by gaps in information that had to be overcome through research, trial and error, and informed assumption.

7.6.1 Documentation

Locating Building Documents

Aside from basic building plans obtained while working in McMurdo Station I had no ready source of building documents. Previous Antarctic contract holders had worked with a number of architecture and engineering (A&E) firms, and before that the USN had employed its own A&E department. With most of the previous contract holders dissolved, there was no source of historical building documents online or a company to contact. One fruitful source of information was the National Archives Branch in College Park, Maryland, which had building documents and boxes of official USN photographs.

Locating Building Data

Buildings at McMurdo Station are monitored for their energy consumption and records are kept for the purposes of refueling and budgeting, but those data are not made public. An exhaustive internet search (e.g., Google, Google Scholar) was fruitless. The only data available were totals representing the entire station, not just one building (i.e., a three-story dorm) (DMJM, 2003). Building documents (from the National Archives) provided no numerical information. It was not until 2014 that a source of data was found. A request to station managers was finally accepted, and a year's worth of dormitory fuel usage was released.

The Weather File

A custom weather file had to be created for this dissertation since no reliable source of weather data existed for McMurdo Station in a useful format. See Appendix N for a full discussion.

Age of the Base Case Building

Built during the 1988/1989 season, the three story dormitories replaced the last of the older T-5 huts and Jamesway quarters (see Appendices A-C).[174] Thus it might have been necessary to refer to older building standards (e.g., ASHRAE Standard 62.1-1981 or Std. 62.1-1989), assuming they were followed at the time. If this were the case, it would also necessary to determine relevant differences between the older standards and those which would be referenced today (e.g., ASHRAE Std. 90.1-2013, Std. 62.1-2013, or even Std. 189.1-2011).

However, because comparing models based on two different codes would create difficulties with the comparison, all measurements for building ventilation rates are based on minimums and equations laid out in Std. 62.1-2013.

7.6.2 Description of the Base Case .INP File (Appendix T)

The components of the base case are based on Building 209 in McMurdo Station, a dormitory from the late1980s (Figure 6). Information from the McMurdo Station Intranet describes the building as "Type II, 1-Hour, non-combustible; steel-framed structure with 2-1/2" thick foam-insulated metal siding and roofing, steel-framed heavy timber first floor, steel-framed metal second and third floors. Steel-stud gypsum board

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[174] About ten years after the 203 series two-story dorms.

interior partitions." Through documents obtained from the U.S. National Archives and other sources (e.g., Hoffman, 1974), and from personal observation, I assumed that the metal siding for the building (and roof) was Robertson Versawall panels (see Appendix J).

The building is a long rectangle, 48' wide and 168' long (Figure 36, Figure 37). The first floor is slightly different than floors 2 and 3 because it has fewer rooms (instead including a laundry room, mechanical room, sauna, public restroom, and vestibules), but each floor is 8,064 ft^2 for a total of 24,192 ft^2 (there is a typo in the information from the Intranet). Each floor has a lounge which faces south towards Winter Quarters Bay (Figure 24). The rest of the floor is taken up by double-occupancy rooms connected by a shared shower and toilet. Floors two and three are essentially

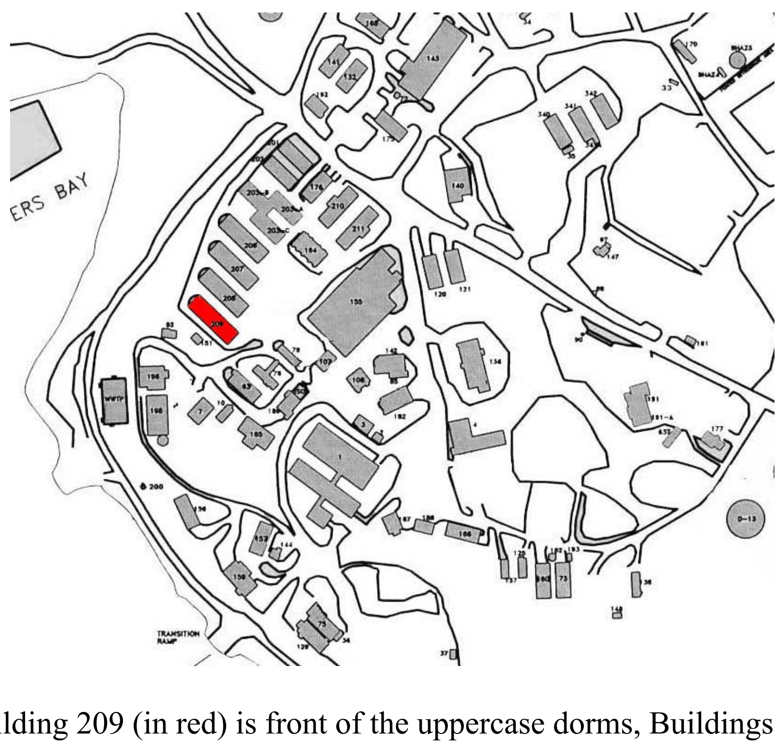

Figure 6: Building 209 (in red) is front of the uppercase dorms, Buildings 206-209.

identical. A single hallway runs through the middle of each floor and connects to a staircase on either end of the building. The roof is slightly pitched, with no overhang (contrary to construction documents). Beneath the roof is an attic space that houses two air-handling units.[175]

A 2,500 gallon tank holds heating fuel for the building and is located just outside the north wall, making it accessible to fuel trucks (aka, "gas hoppers," Figure 25). The mechanical room, with exterior access only, is also located close to the tank. Prior to 1999 the building was heated by a York Shipley oil-fired glycol boiler. It now features three 330,000 Btu/hr. input, oil-fired, cast iron, Hydrotherm glycol boilers which are staged in order to adjust the amount of heat supplied.

The boilers are connected to a heat exchanger which also serves the potable hot water with a primary and secondary reverse-return configuration. According to information from the station intranet, "[t]he temperature set point for the primary loop is 180^{o}F. The secondary loop provides heat to the baseboard radiators [in] six different zones and to the two air handling units [in] one zone. The temperature set point for the secondary zone varies with the outdoor temperature. The range is approximately 100^{o}F to 180^{o}F. Heat is supplied from the primary loop to the secondary loop by means of a diverting valve." Potable water is stored in a 440 gallon tank, which is often inadequate at certain times of the day during the summer.

Although the layout of the rooms plays no part in the energy model, each has two beds, a window, and outlets for appliances such as small refrigerators, radios, clocks,

[175] The Trane "Climate Changer" units supply fresh air at 60^{o}F only.

lamps, and personal devices (e.g., phone, camera, tablet) (these affect the energy load of the building, which does appear in the model). Four people share a shower and toilet, with a sink in each room. Each room is supplied with fresh air from a VAV box located over the sink; baseboards below the windows provide extra heat (Figure 37). Exhaust fans in the shower and toilet room remove stale air, but it is not clear if there is any recirculation.

In the input file, the building is divided into several zones (Appendix T). Each of the three main levels has one hallway and one living zone; the first floor also has a laundry room. Two staircases on either end of the building form one zone that is three stories tall. The attic is an unconditioned space. A building shade representing Building 208 is on the north side (Figure 38). The hallways are created by two long interior walls that terminate at the staircase zones.

Three modifications were made to the base case: 1) the walls, roof, and floors were given a higher R-value (from R-24 to R-60)[176], 2) the windows were given an R-value closer to that of aerogel (from R-8.5 to R-20), and 3) the boiler was made more efficient (from 75% to 90%).[177] Each of these improvements was tested separately, but the results will focus on the effects of the combination of all three improvements (see Section 8.2).

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[176] R-60 is more standard for this climate, but still less than the R-70 SIP panels found at the South Pole Station.

[177] That is, the ratio of fuel input (Btu) to heat energy output at full load. The range in DOE-2.1E is 0-3. A value of 1.33 for HW-BOILER-HIR means 1/1.33 = 75% efficiency, and 1/1.10 = 90% efficiency.

8. RESULTS

8.1 Matrix Results

The goal of assembling the matrix (Tables 1-6) was to quantitatively evaluate three major design categories (Health and Safety; Psychological Comfort and Satisfaction; Functional and Task Performance) for three scenarios: McMurdo Station as it currently exists (McM), the proposed design by the OZ architectural firm (OZ), and an ideal design that was explained in Section 6.2 (Ideal). Each category was divided into a number of subcategories and scored for five factors: 1) Achieves main objectives, 2) Fire Environmental Impact and 5) Occupant Comfort Recommendations. Each factor was numerically ranked from 0-2 using criteria described in Sections 7.3 - 7.5. A ranking of 0 meant that a scenario failed to meet or achieve current standards, whereas a ranking of 1 meant the standards have been achieved. Only when a standard had been exceeded did a factor receive a ranking of 2. Each subcategory was summed for the five factors for the three scenarios, and then the subcategories were summed to give a category subtotal and percentage of total possible points. The subtotals for each category were summed to give a final total and percentage. In this analysis, a category and overall percentage of 0-33% meant that a scenario failed to meet or achieve modern standards, while a percentage of 34-66% meant that standards had been achieved. A percentage of 67-100% meant that a category exceeded minimum standards. Final scores were 1) McMurdo as-is 45%, 2) OZ proposal 64%, and 3) Ideal Design 85%.

8.1.1 Security, Health, and Safety (Table 1)

Protection from Elements

Building (Shelter)

McMurdo Station – Score: 2/10. Although the station accomplishes its goals, it does so at the expense of high energy demand, with the age of the buildings presenting severe limitations on energy efficiency. The legacy of the station leaves an environmental footprint which, while vastly improved over the last few decades, is still large and in need of remediation. The age of the station also presents limitations for occupant comfort, in part because of the changing demographics and evolving expectations of the occupants (e.g., private rooms, access to recreation).

OZ Master Plan– Score: 7/10. Positively, the reduction of multiple station functions into a single, large building is a bold step that offers maximum protection from the elements while achieving the decades-long goal of reducing station's environmental footprint. With certain precautions regarding fire safety, this single, large facility *could* receive higher marks. Although it is yet unclear how well this proposed building will exceed energy conservation goals through CRBP, because it is probably influenced by the design of the hyper-conservative South Pole Station, it can be given high marks at present. Additionally, it receives high marks for its effort to limit site footprint.

On the down side, its mass presents problems with snow drifting and maintenance. The single, large building could also present problems in the "occupant comfort" category. Dormitories attached to the main building will have to be

Table 1: Results for the matrix that was used to evaluate four major design categories (Health and Safety; Psychological Comfort and Satisfaction; Functional and Task Performance) for three scenarios: McMurdo Station currently (McM), the proposed design by OZ architectural firm (OZ), and an ideal design that was explained in Appendix O (Ideal). *Health and Safety* section. Each category was divided into a number of subcategories and given scores of 1-3 for five factors (column headings): 1) Achieves main objectives, 2) Fire and Safety standards/guidelines, 3) ; Energy/Water Conservation based on CRBP, 4) ; Environmental Impact and 5) Occupant Comfort Recommendations. The numerical rankings for each factor were: 0 = Failed to meet or achieve standards, 1 = Met or achieved standards and 2 = Exceeded standards. Each subcategory was summed for the five factors for the three scenarios (right side of Table), and then the subcategories were summed to give a category subtotal and percentage of total possible points. The subtotals for each category were summed to give a final total and percentage. In this analysis, a category and overall percentage of: 0-33% = Failed to meet or achieve standards; 34-66% = Met or achieved standards; 67-100% = Exceeded standards.

Health and Safety

Protection from Elements								
buildings								
McM As-Is	1	1	0	0	0	2		
OZ	1	2	2	1	1		7	
Ideal	2	2	1	2	2			9
connections								
McM As-Is	1	1	1	0	1	4		
OZ	1	2	2	1	1		7	
Ideal	1	1	2	2	2			8
category subtotal						*6*	*14*	*17*
percentage						*30%*	*70%*	*85%*
Fire								
general precautions								
McM As-Is	2	1	1	1	2	7		
OZ	2	2	2	1	2		9	
Ideal	2	2	1	1	2			8
detection/prevention								
McM As-Is	2	2	1	1	2	8		
OZ	2	2	1	1	2		8	
Ideal	2	2	1	1	2			8
structure/materials								
McM As-Is	1	2	1	1	2	7		
OZ	2	2	1	1	2		8	
Ideal	2	2	2	1	2			9
category subtotal						*22*	*25*	*25*
percentage						*73%*	*83%*	*83%*
Spread of Disease								
IAQ								
McM As-Is	1	1	2	0	1	5		
OZ	1	1	1	1	1		5	
Ideal	2	2	1	2	2			9
maintainability								
McM As-Is	1	1	1	1	1	5		
OZ	1	2	2	1	1		7	
Ideal	2	2	2	2	2			10
category subtotal						*10*	*12*	*19*
percentage						*50%*	*60%*	*95%*

thoughtfully designed so that the small, single rooms do not feel cramped and do not suffer from building noise. Although well intentioned, the interior (windowless) rooms and lounges are a negative to many people because they lack a connection to the outside.

Idealized Station– Score: 9/10. The ideal station for McMurdo shelters occupants while acknowledging that 50% of contract workers ranked "experience the Antarctic environment" as "essential" to their decision to work in Antarctica (NRC, 2010). In other words, while their job may not allow them much time outdoors –let alone away from "town"– the design of the station provides a balance of shelter and exposure that allows them to experience their unique location and not feel as if they were in an office anywhere in the world. This includes providing a connection to the outside, be it actually going outside or passing between buildings through protected connections that afford a view.

At the same time, fire prevention precautions (including redundancy) are fully implemented, as are health and safety measures. Therefore, these buildings are the energy efficient "fortresses" that are also productive work environments and comfortable dwellings. Environmental protection and site containment remain high priorities, but the layout is more spread out than the OZ proposal, and it also calls for wind turbines, meaning a larger (but well planned) footprint.

Connections

McMurdo Station– Score: 4/10. Distance between buildings[178] ranks very highly for fire safety. Currently McMurdo Station has no inter-building connections.[179] Therefore it receives low marks for all categories except fire safety, in which it receives the highest mark. Similarly, people who live in Building 155 need not don a coat for a trip to the galley, and if they also work there, they have very little need to go outside at all (a potential 'psychological comfort' pitfall). The station's organic (i.e., haphazard) layout makes the possibility of adding corridors challenging, but as the station begins to reorder itself and consolidate its footprint, natural places for efficient, safe connections could become clearer.

OZ Master Plan– Score: 7/10. Rather than connect buildings, the OZ plan combines many of them into a single structure, with a few walkways between the main building and other functions, like the Crary Lab. Doing so saves on construction costs and exposes fewer walls to the outside (an energy saving measure). However, it requires strict attention to the already hyper-vigilant approach to fire prevention and fire spread. Since these have not yet been specified, the plan receives middle marks for fire safety.

The "composite" design also represents a near-complete interior environment, with few reasons for people to go outside. For many, a typical day will be spent completely inside, which can be positive during inclement weather, but it comes at a

[178] An adequate distance depends somewhat on the resistance of the building exterior, but Scott Base keeps in buildings 25 ft. apart, and currently most buildings in McMurdo are the same way.
[179] One exception to the "no connections" design in McMurdo is the one between three dormitories added in the 1980s, resulting in a single building (the 203 dorm series).

cost. During periods of very cold or otherwise dangerous weather, being able to stay inside is an obvious plus, especially if conditions prevent people from moving between separate buildings. However, for people with no means to move beyond the station, being kept inside all the time may be a serious psychological negative, which is why this design receives a low mark for occupant comfort, even as it achieves the highest marks for energy efficiency and site impact.

Idealized Station– Score: 8/10. Rather than consolidate buildings, the idealized approach brings buildings close together but not juxtaposed, grouping them in loose zones and increasing access through carefully designed corridor connections. While less exposed to fire than a single building, the corridor connections still would only receive the highest fire marks with high ratings in other design factors (e.g., materials, structure).

The connections rate highly for comfort because they provide protected access between certain buildings while acting as extra public space (mostly in the links between dormitories) as well as a visual break from the interior environment. Dorms are close or connected to recreational areas, especially places people use for physical activities (e.g., gym, yoga, climbing wall, indoor sports), making it easier to motivate oneself to visit one of these places. In some instances, the connections deposit pedestrians close to buildings, so some outside travel is still necessary. Connections are designed to be energy efficient, but it is acknowledged that they represent a higher number of exposed walls than in a single structure like that in the OZ proposal; therefore, they receive lower energy efficiency and site impact marks.

Fire

General precautions

McMurdo Station– Score: 7/10. Most precautions are in place (see Appendix J). Because historically buildings were spaced fire safety,[180] the station receives high marks for fire safety but lower marks for limiting site footprint. Unheated shelters for smokers draw them away from building entrances.

OZ Master Plan– Score: 9/10. There is no current information, but I assumed that the same general precautions would persist and mimic those at South Pole Station, especially since both are single, large buildings. Until this is made clear, the plan receives some middle marks. It is unclear if there are plans for protected outdoor smoking areas, but none are indicated in the currently available proposal.

Idealized Station– Score: 8/10. All general precautions are carried over. Smoking is discouraged but smokers are provided shelters away from building entrances.[181] In dormitories, each room above the ground floor has a window large enough to act as an emergency exit (5.7 ft^2),[182] even though the increased area of glazing is a potential energy loss (the losses are mitigated by well-constructed windows that minimize heat loss). Exterior doors also have viewing windows so one may see what (or who) is on the other side before opening.

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[180] Building separation was a method to prevent fire from spreading between buildings.
[181] Until possibly they are no longer needed.
[182] Minimum width 20 inches, minimum height 24 inches.

Detection and Prevention[183]

McMurdo Station– Score: 8/10. McMurdo's large dormitories are equipped with dual-action sprinklers (see Appendix J). It is unknown why a dry pipe system is only in place for older dormitories, but it may be for maintenance reasons, making it a choice of simplicity.[184] Dust sometimes interferes with the alarm system, triggering false alarms which can interfere with sleeping schedules. Overall the system gets the job done, even though some exceptions must be made when it comes to following the fire code strictly.

OZ Master Plan– Score: 8/10. While there is no detailed information about a fire protection system, it is clear that this building will feature comprehensive fire suppression system technology. Increased access to central water pumps will also help provide adequate water to the system, although there is always the possibility that any water supply for fire suppression could be exhausted. In this worst-case scenario, the safety of the building would be completely reliant on its fire-resistant structure and materials to keep it from being destroyed or from the fire spreading to other parts of the building; therefore it is marked down overall, while receiving highest marks for meeting fire code.

Idealized Station– Score: 8/10. Dormitories are equipped with simple yet effective sprinkler systems (i.e., dual-action sprinklers) to prevent damage from false

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[183] "Environmental impact" and "occupant comfort" are not included for this sub-category.
[184] One possible explanation is that while dry pipe systems allow a building to freeze without the environmental hazard of antifreeze in the "wet standpipe," they are also more complicated to maintain because they require an air compressor to be available to charge the system, which is an additional system maintenance requirement.

alarms. Multiple pump houses for these sprinklers are located far enough away to be spared from the spread of fire. Pipes are well protected and heat-traced so that they do not fail to provide enough pressure for fighting fire, or become damaged during the time they are needed most. Pipe systems are laid out so they do not interfere with pedestrian or vehicle access.

Structure and Materials for Fire Safety

McMurdo Station– Score: 7/10: Even McMurdo Station's legacy buildings are constructed of fire-resistant materials, though older and smaller structures sometimes have wood frames and heavy timber floors, making them more vulnerable. Robertson panels (see Appendix C and J) line the steel frame of the larger dorms; it is not known if these are the same as the galbestos-lined Robertson panels from the 1970s (the dorms in question were completed in the late 1980s).[185] Newer buildings (e.g., the Crary Lab) take advantage of more fire-resistant materials, just as they do fire suppression systems.

OZ Master Plan– Score: 8/10. OZ: Proposed dormitories would be built with steel-frames and fire walls, connected to each other and to a single, station hub. The design decision to create fewer, larger buildings also brings with it the need to include more fire walls, fire exits, and means of egress. It is not necessarily a bad decision, but extra care should be taken (see Appendix J). The initial floor plan design shows a large structure separated by several fire walls, thus compartmentalizing the building, as is currently the case for parts of Building 155. In the OZ plan, the dormitory "offshoots"

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[185] Construction documents from the 1980s label the cladding "Robertson Panels" (Figure 39). The 1974 NCEL Engineering Manual includes an illustrated section that identifies the panels as galbestos, and a description that indicates they are from the H.H. Robertson Company.

are on the other side of a fire wall (the image may not indicate this), which are in turn divided in half by another fire wall. However, no construction details are available. It is reasonable to assume that no toxic materials would be specified, and that precautions similar to those taken at the South Pole station would be taken.

Idealized Station– Score: 9/10. Building structure meets and exceeds code; individual buildings are separate so the use of fire walls is not necessary except where the buildings meet the corridor connections, when present. The utmost care is taken to ensure any vulnerability is well protected. Table 602 in the IBC 2012, which shows the fire-resistance rating requirements for exterior walls based on fire separation distance, would need to be consulted.[186] If this distance is greater than 30 ft., no extra precautions are needed. Once buildings are connected or moved closer, the fire resistance rating needs to be increased. This will affect the design of corridor connections that span less than 30 ft.

Spread of Disease

Indoor Air Quality (IAQ)[187]

McMurdo Station– Score: 5/10. It is unclear what measures (if any) are currently in place, except for the use of pressure differences to help keep warm air inside. Pressure differences may help keep energy costs down, but since many vestibule areas are not designed well, the savings are mitigated (see Section 4.2.1). On the

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[186] Code determines that the "fire separation distance" is the distance measured from the building face to the closest interior lot line, to the centerline of a street, alley, or public way, or to an assumed imaginary line between two buildings on the same lot.
[187] "Environmental impact" and "fire safety" are not included for this sub-category.

positive side, the hospital is completely separate from the rest of the station; however, anecdotally, the IAQ there is poor. Convenient shelters for outdoor smoking[188] do not exist, but there are two unheated enclosed shelters located away from buildings.[189]

OZ Master Plan– Score: 5/10. This design has not yet been identified in the OZ Master Plan, so for the moment this category receives middle marks. IAQ will be controlled by mechanical means (i.e., filters, fans, humidification, and pressurized spaces). It is likely that South Pole Station will again serve as a guide. The medical complex is not attached to or included in the main building, so isolating it mechanically will not be an issue, but oddly it is part of the same complex as some administrative spaces, so care will have to be taken there. There is no mention of a smoking policy.

Idealized Station– Score: 9/10. The station generally has sufficient ventilation and excellent air filters, especially in high-risk areas like Medical, the Galley, and the dormitories. Pressure differences help keep warm air inside the dormitories and also keep air from escaping from certain areas (e.g., mechanical rooms, toilet rooms, and medical). Dorm rooms are kept at a negative pressure to limit airflow from one room to the next; this includes the showers/toilets rooms. Outside the dorms, the hospital remains a separate structure but also maintains a high rate of fresh air. The boiler room is also separately ventilated.

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[188] All indoor smoking areas (smoking lounges) except one bar (Southern Exposure) have now been removed. All smokers must venture outside and away from entranceways, although the distance is often fudged for the sake of remaining in the lee of a building.

[189] This used to lead some to huddle close to an exterior door, despite rules and signs, putting the interior air quality at risk, as well as people who must pass through the smoke cloud to enter the building. The distance rule is now enforced.

Use of pressure differences and air filters do not necessitate larger fans (the way HEPA filters would), so very little additional burden is placed on energy demand. However, taking the further step of using UVGI lamps would increase energy demand. The lights, about 100 watts each, mean a bank of them could represent between 500-700 watts.[190] Their use is limited, used only during transitional seasons or times of high station occupancy (during winter they remain off).

Maintainability

McMurdo Station– Score: 5/10. Gang-style bathrooms are in place for all dormitories except the three-story dorms (Buildings 206-209), which have a shared shower and toilet between two two-person rooms (each room has a sink). Gang-style facilities are cleaned daily by a janitorial staff, while en suite facilities are cleaned at the discretion of the four people sharing it (with variable results for cleaning). They are relatively easy to clean, most with a janitor's closet with floor sink for mops) but could be better (e.g., seamless counters and anti-microbial surfaces). Showers include a curtained-off dry area for hanging and changing clothes before entering the glass-door stall. There is no indication of the use of anti-microbial surfaces, and it has only been recently that some sinks have been upgraded to a hands-free model.[191]

OZ Master Plan– Score: 7/10. The OZ Master Plan indicates that the dormitories will rely solely on gang-style bathrooms, located at the juncture of the main

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[190] It would also be necessary to specify a UV-resistant coating for the inside of the ducts to keep them from degrading so quickly; any unprotected plastic would have to be stabilized or painted.
[191] It was observed by the author in 2010 that the motion-sense sinks make it irritatingly difficult to brush one's teeth because the water stops running and takes several seconds (and some hand shaking) to restart.

building to the dorm. With two bathrooms for each sex serving 100 people (in 100 rooms), these rooms will probably be larger than the three showers/three stalls shower rooms in the 203 series and more like the larger gang-style rooms in Dorms 210 and 211. Daily cleaning schedules will be very important, especially at the height of the season. Because details are unknown, this category receives a 1 for achieving main objectives. From the current drawings, it is not clear how these spaces will be organized.

If the dormitories are reduced to a single wing for Winter quarters (as happens at Pole), it is possible that an entire floor would be dominated by one sex and the "extra" shower rooms would be converted for convenience of the most represented sex (probably men, as sometimes happens during the Winter in smaller dorms like Building 203).

Idealized Station– Score: 10/10. Dormitories feature hands-free fixtures and easy-to-clean surfaces finished with anti-microbial materials (e.g., copper oxides) when possible.[192] As far as shower/toilet room styles, frequently-cleaned gang-style bathrooms are the best compromise, since private toilets and showers would place an undue burden on the dormitories in terms of square footage and plumbing; it is also unlikely that those spaces would be cleaned very often.

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[192] This is coupled with the upgrading of the hand washing station outside the Galley.

Table 2: “Architectectual Features” subset of the Psychological Comfort section of the design matrix; see Table 1 for detailed description.

Psychological Comfort and Satisfaction									
Architectural Features									
occupancy									
	McM As-Is	**2**	**1**	**2**	**0**	**0**	5		
	OZ	**2**	**1**	**2**	**1**	**1**		7	
	Ideal	**2**	**1**	**1**	**2**	**2**			8
hallways/ circulation									
	McM As-Is	**2**	**1**	**0**	**0**	**1**	4		
	OZ	**2**	**1**	**2**	**0**	**1**		6	
	Ideal	**2**	**1**	**1**	**2**	**2**			8
showers/ restrooms									
	McM As-Is	**1**	**1**	**2**	**2**	**1**	7		
	OZ	**2**	**2**	**2**	**1**	**2**		9	
	Ideal	**2**	**2**	**2**	**1**	**2**			9
lounges									
	McM As-Is	**2**	**1**	**0**	**0**	**0**	3		
	OZ	**2**	**2**	**0**	**0**	**0**		4	
	Ideal	**2**	**1**	**0**	**2**	**2**			7
windows									
	McM As-Is	**1**	**0**	**0**	**0**	**0**	1		
	OZ	**1**	**2**	**2**	**1**	**0**		6	
	Ideal	**2**	**1**	**1**	**2**	**2**			8
category subtotal							*20*	*32*	*40*
percentage							*40%*	*64%*	*80%*

While a highly efficient use of space, these large restrooms showers should large enough to prevent overcrowding. Grouping them close together will allow easier access without becoming a plumbing challenge. Measures that limit the spread of disease (lid-activated auto-flush toilets, hand-free appliances) are widely used. There is no effect on site impact or fire safety, but occupant comfort remains high.

8.1.2 Psychological Comfort and Satisfaction[193] (Table 2)

Architectural Features[194]

Occupancy (Spatial Distribution)[195]

McMurdo Station– Score: 5/10. Dormitories featuring single rooms have been in demand at McMurdo for some time (DMJM, 2003; OPP 2003; USAP, 2010). Unfortunately, after the winter season is over, very few people are granted private rooms during the crowded summer conditions. At times certain groups of people are housed in dorm lounges converted to bunk rooms. Currently it may not be possible to provide a single room for every person in McMurdo Station.[196]

Any spatial demarcation in the rooms comes from the use of bulky dorm furniture to create temporary barriers (Figure 40, Figure 41). In a small room this system is not space efficient, and of course it does little to provide auditory privacy for conversations, phone calls, or during sleep. Sleep can also be disturbed by other sources, such as a roommate snoring or opening the door to a lit hallway, turning on overhead lights, or other distractions. The station therefore receives a low rating in this category, although it rates highly for energy efficiency and site impact because nearly every room houses two-five people.

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[193] Category title taken from Preiser, 1983.
[194] Adapted from Harris, et al., 2002 (content of category expanded for this study).
[195] Adapted from Preiser, 1991 (originally "spatial distribution and density of occupants," p. 156).
[196] The main reasons this may not be possible or desirable involve budget, station footprint, and the needs of different people at the station, i.e., some people are only at the station for a few days or weeks before moving to another station; some science groups may stay for just a few months, and others may spend most of their time (after orientation and field training) away from the station in a field camp, coming back every two weeks to resupply, or maybe even less often.

OZ Master Plan– Score: 7/10. After decades of winter-only single rooms in McMurdo, the inclusion of single rooms for everyone but transients is a huge step forward. This is accomplished by decreasing room size and creating two rows of interior (windowless) rooms. Each floor will house about 100 people, about twice as many as a typical floor in one of the 206-209 series dorms.

If the design of the rooms at South Pole Station is an indication of the OZ plan, rooms could be as small as 9ft. by x 8ft. (winter quarters at Pole) or 9ft. by x 7ft. (summer quarters).[197] At McMurdo, it will be important to make these single rooms feel as large and private as possible –if they are noisy and ill-planned, they run the risk of feeling cramped. This may be especially true for the windowless rooms which may feel claustrophobic. Providing large, open public areas with pleasing views may provide some relief from the tiny rooms, but it appears that the main lounges are windowless. Rooms that face the adjacent building effectively make the outside view meaningless. Aside from this, there is no further information on the design of the rooms, so they are given middle marks.

Idealized Station– Score: 8/10. The Ideal station includes dorms with a variety of rooms, with single rooms reserved for those staying the longest (or those who do not wish to room with someone). Double rooms accommodate couples or two roommates staying less than three months. Finally, in the Idealized station, four-person rooms or bunk areas would be available to accommodate people only staying a few days or weeks

[197] This number is below the minimum square footage indicated in ICC, 2009, "Section 404 Occupancy Limitations."

before heading to their final destinations, which frees up space for more single rooms. The scenario receives a lower mark for environmental impact because of the extra area needed for single rooms.

The privacy of a single room is in part paid for by its reduced square footage, but it should not feel cramped. Since these rooms are the most likely to be used by long-term occupants, they have a small but thermally efficient window. Increased privacy through greater control over one's environment offsets the smaller room size, and the increased number of rooms per floor that is a result of the private rooms.

Hallways and Circulation

McMurdo Station– Score: 4/10. Typical double-loaded hallways dominate the station. These straight-line corridors have an institutional feel, much like an old college dormitory, and provide no protection against hallway noise. Current housing garners high marks for limited site impact but low ones for occupant comfort.

OZ Master Plan– Score: 6/10. This plan lays out not one but three double-loaded hallways per floor, a highly efficient design that runs the risk of feeling quite cramped and anonymous unless special care is taken to distinguish floors, hallways, and direction. Rooms in the middle of the hallway are windowless, which is considered a plus be the designers but viewed negatively here. Therefore, this design receives less than full marks for overall objective and occupant comfort. Because there are single rooms for everyone, the marks for energy efficiency and environmental impact are also lessened.

Idealized Station– Score: 8/10. The idealized dormitory features hallways designed not to feel cramped or "institutional." The Ideal design would eschew long, straight corridors with bright windows at either end. The layout is broken up by alcoves, side lighting, sky lighting, and a subtle directional changes to make it feel homier. Doors and stories are distinguished by more than just numbers, using colors or themes to break the monotony. Again, because there are single rooms for everyone, the marks for energy efficiency and environmental impact are also lessened; however in this case, the rating for comfort is the highest.

Showers and Restrooms

McMurdo Station– Score: 7/10. The three-story dormitories feature semi-private bathrooms, allowing its 1-4 users to leave some or most of their toiletries there. Every other dormitory is outfitted with gang-style showers and toilets which are cleaned by a staff of janitors (lifting the burden off the occupants). There are few places to hang or place toiletries or clothing, leaving most to fling articles of clothing over the curtain rod and place shampoo and soap on the floor of the shower. A person in the shower is vulnerable to blackout conditions during power outages, or hyper-vigilant people who turn the lights off if they think they shower room is vacant (or who simply turn lights off as a matter of habit).

OZ Master Plan– Score: 9/10. Gang-style showers are continued. There is no definite information about the design of these areas, but they appear to be located at the beginning of the hallway, between the lounge area and the private rooms. This is a positive move when it comes to water delivery but has no bearing in this section.

Because of the lack of detail, the design is ranked in the middle for comfort, but gets high marks for efficiency.

Idealized Station– Score: 9/10. Besides being easy to clean (see section on "Maintainability") these areas are well lit, spacious, and homey (without being hard to clean or precious). If the station converts to single rooms it is unlikely that there will also be private showers and toilets. The total square footage of the gang-style bathrooms should be large enough to accommodate peak traffic, but is not consolidated into two large rooms.[198] The smaller size will create a more comfortable feel and allow people to keep some articles in cubes or lockers in "their" bathroom, rather than carry everything down the hallway every shower day like a college freshman.

The shower area is physically separate from the toilet area. Motion sensors and emergency lighting eliminate problems associated with manual lights. Showers still have a changing area with plenty of opportunities for hanging clothing or temporarily stowing personal items. Saunas are also provided, and are well maintained and accessible throughout the year.

Lounges

McMurdo Station– Score: 3/10. Lounges sometimes have the best views in the building, and often feature more windows.[199] They are the size of two to three rooms (with two means of egress) and are a single large open space, which causes a problem

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[198] Unless there are upgrades to the water delivery system and hot water heater it is likely that short, non-daily showers will continue to be the rule.

[199] Unfortunately, these windows are often boarded up during the winter because they are too drafty. See Section 2.1.5 in this Appendix for more information.

with noise. Some lounges have a folding wall to divide the rooms, but this does little to block out any noise. If just a small group wants to watch a movie, the rest of the space is essentially useless to other groups. The furniture provided is adequate but dated, and not always sufficient. These rooms are often empty but are sometimes used for small parties, causing problems with those trying to sleep next door (Figure 42, Figure 43).

OZ Master Plan– Score: 4/10. The lounges are moved out of the dorms completely, now located between the showers and the main building corridor. This frees them from being stuck in quiet hallways, surrounded by rooms. An unfortunate downside from this arrangement is that each lounge serves 100 people even though they appear to be no larger than the lounges that are currently accommodate approximately 30-50 people/floor. Additionally, these lounges are also passageways between the main building corridor and the dormitory wings. This may cause some traffic and noise problems if, for instance, a group of people are watching a movie in the lounge when another group moves through the lounge.

Although these spaces do not have windows, the corridor areas adjacent to them do. The thought may be that people prefer the lounges to be darkened anyway, for movie viewing. However, it would be an unfortunate loss not having windows in the lounge areas. For a view, it seems people will now have to linger in the main corridor.

Idealized Station– Score: 7/10. Lounge areas would be attractive and inviting, providing space for the occupants to gather with friends without disturbing other people in the building. Sound dampening in the ceiling, floors, and walls help contain the noise (similar to a karaoke room). Windows provide pleasant daylight during the summer months and views of the station, Hut Point, or the ocean and mountains beyond.

The room itself can be customized to users' needs; for example, they can be arranged for several small groups or a single large group; seating around the TV or seating pushed to the walls. Windows can be blocked if light interferes with activities (e.g., watching a movie). Loud activities like aerobics groups, pool games, and big parties should be discouraged (space for these activities should be provided elsewhere). If night shift workers do not have their own wing, floor, or building, they should at least have the ability to use the lounges without disturbing others.

Windows

McMurdo Station– Score: 1/10. Because most windows are operable (making them highly rated for fire safety), they are also drafty. They also lack daylighting systems more sophisticated than a piece of canvas and some two-sided Velcro. Spindrift and icing are problems, and most windows end up covered with makeshift, movable insulation or lined in foil wrap. Between the old or inefficient windows and their subsequent "fixes," the presence of windows is probably a bad investment.

Newer buildings (not housing) such as the Crary Lab show how window design can be more positive. The top-floor lounge and library feature a ribbon of windows that runs nearly the length of the space. Set in thick walls with a beveled sill, these windows take advantage of one of the best interior views at the station and even feature daylighting control (i.e., conventional blinds).

OZ Master Plan– Score: 6/10. Perhaps the first thing noticeable in the OZ plan is that two-thirds of dorm rooms have no windows. The reasoning behind this is that windows only can cause problems and provide very little real view (R. Petersen, personal communication, November 12, 2013). Most of the time it is either too cold or too dark, and when it is sunny outside, the windows have to be covered part of the time in order to sleep in darkened conditions. Going on the premise that windows in rooms for sleeping at South Pole Station are not missed, most rooms in each dormitory wing in the OZ plan for McMurdo do not have windows.[200] Rather, windows in public areas are emphasized, with large areas of glazing indicated for the galley and corridor.

Because of their placement, approximately the same number of people as there are today will have a view that is not a neighboring building. This layout once again sets up a hierarchy of rooms: those with windows and views will still be more highly prized than those completely boxed in or with a view of the neighboring dormitory wing. One positive (hopefully) aspect from the new building is that no room will be more desirable than another because one is too drafty.

Idealized Station– Score: 8/10. Windows are placed very carefully throughout the station. Set inside thick walls, these windows may not be enough to keep the chill out completely on the coldest days, but they will have daylighting controls that minimize

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[200] At South Pole during the winter, all windows are permanently covered in order to make the building Dark Sky compliant. Dark Sky compliance is not currently a necessity during the winter at McMurdo Station, but the egregious light pollution prevents anyone in town from enjoying one of the last places on earth with access to a truly dark sky.

glare, are able to block light completely for sleeping. Inoperable, they will still be able to be pushed out in the event of an emergency.

These systems will work well in conjunction with the design that keeps excessive frost from accumulating on the inside of the windows, as was done at South Pole. Glazing should be transparent where there are views and translucent (indicating aerogel) where light is required but there are not views; large glazed areas also feature aerogel, as in the main pod at Halley VI (see Appendix F).

Ambient Features (Table 3)

Thermal Comfort and Control

McMurdo Station– Score: 4/10. In-room radiators provide some control of room temperature, but if the building temperature is set too low or too high, this control will not perform adequately. There is no easy way to tell what the actual in-room temperature is. In the survey 61% of respondents wished they could change the temperature of their room, it being either too warm or too cold. In lounges or the Galley, one may sit farther from windows if they feel chilled; in offices and rooms there are generally fewer choices, with some opting to open the windows and other choosing to line them with foil. It is acknowledged that heating buildings in this climate is difficult, so this feature receives low scores for energy efficiency practices but middle scores for occupant comfort.

OZ Master Plan– Score: 7/10. There is no definite information on this at the moment. If the system at South Pole Station is an indication of what will be done in in the OZ plan, the use of radiation heating and hydronic heating will provide even

Table 3: “Ambient Features” subset of the *Psychological Comfort* section of the design matrix; see Table 1 for detailed description.

Ambient Features									
thermal comfort									
	McM As-Is	2	0	0	1	1	4		
	OZ	2	1	1	1	2		7	
	Ideal	2	2	2	2	2			10
IAQ									
	McM As-Is	1	1	2	0	1	5		
	OZ	1	1	1	1	1		5	
	Ideal	2	2	1	2	2			9
sound									
	McM As-Is	1	0	2	0	0	3		
	OZ	1	1	2	1	1		6	
	Ideal	2	2	1	2	2			9
quality luminous environment									
	McM As-Is	1	1	1	1	0	4		
	OZ	1	1	1	1	1		5	
	Ideal	2	2	1	2	2			9
absence of natural day/night cycles									
	McM As-Is	1	1	1	1	0	4		
	OZ	0	1	0	0	1		2	
	Ideal	2	1	1	2	2			8
category subtotal							*20*	*25*	*45*
percentage							*40%*	*50%*	*90%*

temperature coverage with “…gentle temperature changes, and reducing the need for ventilation airflow” (Ferraro & Brooks, 2002, p. 239). This system is aided by the design of the station as one large building, with few weak points such as open doors, windows, or poorly planned vestibules to upset the balance of the indoor temperature.

Idealized Station– Score: 10/10. Individual room heaters would have set-points instead of a range of 1-5 on the radiator dial. Thermostats show the desired room temperature and help people decide if they want to increase the heat or not. Occupancy censors and set points help adjust the temperature in each room while conserving energy. Occupants will be able to adjust their room temperature without having to open a window.

IAQ

McMurdo Station– Score: 5/10. Because the dormitories are nearly completely free of cooking amenities, they do not have much need of protection from cooking odors. At the most it is necessary to keep any smell from the toilet area from becoming a problem. People tend to self-police bringing contaminated work clothing into domestic areas, but during the day (e.g., for lunch) it is sometimes necessary for some to change outerwear before they enter the galley.

Cleaning agents are a potential source of indoor air contaminants, but it is minor. Fresh air intakes are at risk of being exposed to idling vehicles if not properly marked. Buildings are all old enough to be mostly free of VOCs, but it is unclear whether or not these were taken into consideration when they were new (it is unlikely). Carpet, adhesives, furniture, and paint would all have had to have been cleaned.

During the summer, dirt, dust, and mud from the exposed volcanic soil have the potential to lower IAQ when they are brought in on people's shoes. This is already a problem year-round in the gyms, where the fine dust interferes with the workout equipment.[201] The biggest problem is the control of the spread of pathogens, which is in the IAQ category previously discussed (under "Spread of Disease").

OZ Master Plan– Score: 5/10. Because this is now one large building, extra ventilation is required in the galley/kitchen to keep food smells from wafting into other parts of the single building. If this plan draws ideas from South Pole Station, it will also restrict smoking and VOC emitting materials and finishes, and contain indoor pollutants. Materials such as "…loose-laid, interlocking modular athletic flooring system and free-laid carpet tile" will not push indoor VOC levels above prescribed limits (Ferraro & Brooks, 2002, p. 238). At South Pole, smokers are not shut outside, but rather provided

[201] A sign asks people to dedicate a pair of sneakers to the gym (i.e., not wear them outside).

a “smoking room” with an independent ventilation system. The current OZ floor plan, however, does not show a smoking area.

At South Pole Station, people entering the main pods from work areas that contain fuel, oil, or other unpleasant-smelling substances must pass through a special entry way with walk-off mats and store their contaminated outer layers in an area with a separate ventilation system. Additionally, ventilation system distribution points are well placed and kept running at a low velocity, limiting discomfort from drafts.

Idealized Station– Score: 9/10. IAQ would meet LEED guidelines for IAQ in mechanically ventilated spaces, which requires the minimum attainment of Sections 4-7 of ASHRAE 62.1-2013, *Ventilation for Acceptable Indoor Air Quality*. Distinct buildings keep ventilation systems separate, and the galley kitchen is on its own ventilation system. Fresh air supply in dormitories supplements filtered recycled (preheated) air, and is preheated with recaptured heat.

Sound

McMurdo Station– Score: 3/10. The dormitories are generally quiet, but do experience some noise from wind coming through cracks in the window frames and under doors. In the 203 series dorms it is known that the rooms at southwest end of the hallway have the best views but are plagued with mechanical vibrations from the boiler room below. Outside sources of noise like large or idling vehicles can be a problem, but that is more of a question of location (next to a parking area).

People create the most noise in dorms. In general, rooms adjacent to lounges are not well protected from the noise generated when a few people get together. If it becomes too much they must call the fire house operator, who then calls the lounge and asks people to tone it down. Noise from the single, long hallways can also be a problem, especially for those who try to sleep when the rest of the station is awake and working. For any nightshift workers, vacuums are the enemy. In certain older dorms, slamming doors and pedestrian traffic are also sources of annoyance.

Lounges themselves are not well soundproofed. Some lounges can be divided by a folding wall, but this does very little to block noise from one side other the other (imagine a Ping-Pong game on one side and a group movie on the other).

OZ Master Plan– Score: 6/10. Moving the shower/toilet areas between rooms and the lounges acts as an extra buffer space against noise coming from the lounges and beyond. Lounges are completely removed from the "sleeping area," a deliberate act since lounges were viewed as sources of noise and rooms designated areas for sleeping *only*. Whether this holds true remains to be seen, but without enough public places for people to gather, the only other space they have is individual rooms.

The plan for South Pole Station recognized the need to protect rooms from sound, especially since there would be mechanical systems within the main building. Close inspection of the construction documents shows isolation of equipment and details of acoustically absorptive materials in mechanical rooms and other places like the galley and the gymnasium; the gym itself is a double height area with no rooms above or below it. It is likely that the OZ plan will follow this closely (the gym, in this case, is on the far side of the building from the three dorm wings).

Idealized Station– Score: 9/10. Protection from noise is not only a part of being able to control one's environment, and it is seen as a major obstacle towards getting a good night's sleep. In the idealized station, the dormitories remain a mix of private (bedrooms) and semi-private (lounges), but with ample physical distance and acoustical isolation between them. Mechanical systems are placed on pads and are located in rooms that prevent sound and vibration from spreading throughout the building. Bedrooms have additional sound absorption insulation; rooms near high traffic may have a different design (e.g., to provide additional spatial separation) or additional sound protection. Rooms are never next to stair cases, which are instead flanked by lounges, shower rooms, or janitorial closets. If there is not a wing or floor dedicated to night shift workers, the use of quiet (non-motorized vacuums) does not interrupt their sleep.

Quality of the Luminous Environment

McMurdo Station– Score: 4/10. Most rooms have windows, but not all of them. There is very little in the way of effective daylighting control, and the main options for artificial lighting are overhead room lights and small desk lamps. Hallways are lit but also have windows at each end, often resulting in glare.[202] Daylighting is not

[202] Many older buildings have very small –or just a few– windows and some offices are interior locations with no windows. Large garage areas sometimes have clerestory windows. Some buildings take full advantage of their views (e.g., the Chalet and Crary Lab library). During the winter these views are nearly non-existent, and with the exception of the tiny greenhouse, there are no other way to access a view that is not an artificial interior (or a magazine cut-out). At least one area –the galley in 155- has skylights, which are covered in the winter.

heavily relied on in dorms, although other buildings are sometimes able to operate with fewer artificial lights (e.g., the Crary Lab hallway).[203]

It should be noted that some locations, like the Coffee House, benefit from dim lighting and small lamps, especially when coupled with a wood panel interior (Figure 44, Figure 45). In contrast, the Galley, with its bright overhead lights and white walls is a good, high-ceilinged place where lots of people (too many, at times) can sit down with coworkers for a meal. It is not, however, a place many people choose to linger or hangout after dinner.[204] Most dorm rooms and lounges have the same feeling: institutional, a little worn, and not very warm (i.e., welcoming).

Color has been used to a limited extent in McMurdo Station; most recently, Building 155 was painted a vibrant dark blue, replacing the former drab brown. With the exception of vehicles and parkas, which are often bright red (U.S.) or orange (NZ), there are very few interior or exterior colors that stand out in McMurdo.[205] The one positive here is that there are often many opportunities to go outside where one may be able to see a blue sky, or possibly an unusual meteorological event.

Because there are few options for controlling lighting and they are in dire need of replacement with more efficient systems, and because few buildings were designed to take advantage of the (admittedly) difficult daylight conditions, McMurdo As-Is receives low scores for efficiency an occupant comfort.

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[203] This area has been identified as a definite energy efficiency measure by previous reports (RSA, 2008; DMJM, 2003).
[204] The ban on alcohol in the galley (bring-your-own) except on Saturday nights is partly to discourage people from lingering, so that more people can sit in the seating area.
[205] Scott Base is uniformly painted what some may call Kiwi Green, but is actually called "Chelsea Cucumber." (See Appendix F.)

OZ Master Plan– Score: 5/10. There is no currently available information about lighting, simulated daylighting, or color for the OZ plan, although they may take a page out of the plan for South Pole Station, which indicated that "[a]ppropriate use of color and variation of finishes helps to prevent interior sameness and monotony" (Ferraro & Brooks, 2002, p. 238). This idea was also used in the design of Halley VI (see Appendix F), which uses color to indicate the pod segment a person is in (breaks monotony). There, the designers also provided windows in the pod connections so people could see outside as they walk from pod to pod. One factor that is known is that many rooms in the dorm interior corridor will never have to worry about darkening their rooms, as they will not have a window. For this reason, the plan scores well, except in the occupant comfort category.

Idealized Station– Score: 9/10. The design of the Ideal station balances energy efficiency and protection from the elements with the provision of natural and artificial views. Variations in color, texture, and interior finishes that have a more organic feel keep building interiors (and some exteriors) from looking all the same. Walkways with windows provide an alternative route between buildings, although on "warm" days people may also choose to walk outside. Views are provided in nearly every room and are always present in common areas.[206]

Absence of Natural Day/Night Cycles

McMurdo Station– Score: 4/10. While all but one dorm in McMurdo Station provides at least one window per room, there are only a few crude ways to control the

[206] With the exception of dedicated movie rooms and the greenhouse.

Table 4: “Interior Design Features” subset of the *Psychological Comfort* section of the design matrix; see Table 1 for detailed description.

Interior Design Features								
furniture								
McM As-Is	1	1	1	1	1	5		
OZ	1	1	1	1	2		6	
Ideal	2	2	2	2	2			10
artwork and materials/color								
McM As-Is	1	1	1	1	2	6		
OZ	1	1	1	1	1		5	
Ideal	2	1	1	2	2			8
access to greenery								
McM As-Is	1	0	0	0	0	1		
OZ	2	1	0	1	1		5	
Ideal	2	1	0	2	2			7
privacy/social								
McM As-Is	2	1	0	0	1	4		
OZ	2	2	1	1	1		7	
Ideal	2	2	1	2	2			9
hominess								
McM As-Is	1	1	2	0	1	5		
OZ	2	2	1	1	1		7	
Ideal	2	2	1	2	2			9
distances maintained								
McM As-Is	0	1	2	0	0	3		
OZ	1	1	1	1	1		5	
Ideal	2	1	1	2	2			8
category subtotal						*24*	*35*	*51*
percentage						*40%*	*58%*	*85%*

amount of daylight coming in and when. Drafty windows aside, people use anything from foil wrap to thin curtains to canvass and Velcro to block the daylight once the sun starts to rise too far above the horizon. In lounges it is largely the same story. Some people have learned to bring their own sun clocks, providing a better way to fall asleep and wake up.

OZ Master Plan– Score: 2/10. There is no current information on this topic. Rooms are seen as places for sleeping only, with windows small and sometimes completely absent. There is no information about any built-in features that helps the occupant tell what time of day (or night) it; especially in the interior rooms, a feature like this could help establish a healthy sleep cycle.

Idealized Station– Score: 8/10. Natural daylighting controls include blackout features, especially in bedrooms, where sleeping in the priority. Rooms feature allow occupants to block out light and alternatively slowly brighten them at a certain time (a full night's sleep). Each room would have its own control, making it easier for day and night shift workers to be neighbors (assuming everyone has a private room).

Interior Design Features **(**Table 4**)**

Furniture

McMurdo Station– Score: 5/10. The furniture is large and bulky and adds nothing to the design of the room. Currently most furniture is used to create a visual barrier between roommates. Many roommates use their heavy –but movable– furniture to cordon off their own "space" within the shared room. Makeshift curtains, walls created by tall dressers, and personal decorations define visual boundaries and personal space.

Most lounges have big couches, a common area bookshelf, and large televisions. If enough people pool their resources, other items appear in the lounges, such as fake plants, pool tables, cardio equipment, and Ping-Pong tables. Because of scavenging, other lounges are often striped clean of their best furniture and entertainment equipment

OZ Master Plan– Score: 6/10. There is no current information on this topic. If rooms at South Pole Station are a cue, the same approach is attempted but not yet perfected. Space is tight and the custom furniture helps take advantage of the narrow room, but it is not as efficient as it could be. Hopefully the OZ plan will soon show a very well-planned room where no square inch of space is wasted.

Idealized Station– Score: 10/10. Rooms for two-to-four people exhibit clear demarcations for personal space, offering visual –if not total acoustic– privacy from roommates (if any). At the same time, the rooms are able to be customized by occupants if desired. Since furniture is still likely to be shifted, it is easy to move or reconfigure so that it does not become damaged (or damage walls and carpet). Built-in features provide extra privacy (e.g., walls, nooks). For most rooms, single occupancy means less space and an even greater need for double-duty furniture, but it does not infringe on the perception of space or feel like a sterile cell.

Artwork

McMurdo Station– Score: 6/10. The station is full of artwork by "artists in residence" and by people working at the station. There is even an unofficial art gallery. The large canvases in the galley feature landscapes from all over the continent. Public art can be found around town: signs, sculptures, paintings, interior murals, spray-painted stencils, informal sketches. In a way these also reaffirm people's sense of individuality in a place that is highly institutionalized and regulated. Less formally, people tape bright, colorful images of living things and landscapes in shower rooms, toilet stalls, and on their room walls (as a way to combat wintertime blues).

OZ Master Plan– Score: 5/10. There is no information on this topic yet. In other stations it is often the occupants who put up artwork at their own discretion, but sometimes it is a more deliberate decision (e.g., large canvasses in the McMurdo Galley; a large landscape image in the Scott Base dining area).

Idealized Station– Score: 8/10. The tradition of artwork around the station is maintained and better exhibited. Dorm areas are accented with murals and there are places to post more artwork.

Access to Greenery

McMurdo Station– Score: 1/10. The small, unofficial greenhouse is only open during the winter because it has such a high energy demand, and because it is not large enough to provide enough fresh food during Mainbody. It can only accommodate a few people at a time, so its usefulness as a lounge is limited. It is such a small, non-descript building (volunteer-built, like the original Chapel of the Snows) that its presence is almost hidden (especially when the snow drifts are high). Therefore there is a low mark for energy efficiency and occupant comfort.

OZ Master Plan– Score: 5/10. There is an area marked “growing lab” on the floor plan for the new building, but it is not yet clear if this will in fact be a hydroponic green house, and whether or not this room would double as a lounge. Containing the greenhouse within a building will help keep the room warm, but as a lounge it may falter if it is not well insulated from the noise of the adjacent rooms. Centralizing it is also energy efficient, but it does lose its feeling of being “away” from the hubbub of the rest of the station if it is just steps away from offices, cafes, and the galley.

Idealized Station– Score: 7/10. Ideally each dorm has its own hydroponic greenhouse lounge, providing a quite reprieve in a setting filled with lush, green life. Additionally (or in place of if necessary) there would be access to a single, large greenhouse/lounge, probably attached to the kitchens (for easier access), with other greenhouse areas open to the general population. It should be noted that the inclusion of a greenhouse in Antarctica is an immediate energy sink, and a feature that takes up more square footage; however, if designed well, its psychological benefits make it a worthwhile endeavor. For this reason, all three plans assign a middle mark for "limited environmental impact." It is assumed that any greenhouse would be hydroponic and not violate the terms of the Antarctic Treaty regarding the introduction of foreign soils (or illegal plants).

Private and Social Settings

McMurdo Station– Score: 4/10. Currently only Air National Guard (ANG), special guests, and upper management reside in single rooms. Their dedicated dorm also has a private lounge and unofficial bar. There have been plans to upgrade station housing to include more single rooms for years, but very little has actually changed. During the peak of the season there is sometimes a housing shortage, with lounges and gyms transformed into overflow bunk houses. Dorms with gang-style bathrooms may be easier to convert to single bed rooms than those where two 2-person rooms share a shower/toilet.

During periods of lower occupancy people at the station have more room to spread out, and community areas are not very crowded. Once the Mainbody season begins, however, the galley, bars, lounges, and other "public" areas can be quite crowded. With not even a private room to retreat to, it can be a stressful situation.

OZ Master Plan– Score: 7/10. The plan shows a single-bed room for every person, even if that room does not have a window. No details for the rooms are currently available. Lounges are provided, one per floor per wing, but they seem on the small side, and are bisected by the main hallway entrance into the dorms. Because there are no details about this configuration, mostly middle marks are given.

Idealized Station– Score: 9/10. There would be private rooms for every long-term individual, with double rooms for medium-length stays and a few bunk rooms for transients. Light and noise control measures would preclude the need for a separate building/wing for night-shift workers, although some general zoning could also exist. Rooms are at least 9’x10’ and most have a window large enough to be used as emergency escape (operable only during emergencies).

Hominess

McMurdo Station– Score: 5/10. The dormitories are unremarkable places. When enough people scavenge enough furniture, lounges can begin to feel homey, but this is generally not the case. Rooms can be personalized with some effort, but this is limited by hard walls and large, bulky furniture.

People are in Antarctica to work, and they are housed and fed by a government agency while they are there. The massive bureaucracy and logistical support complex that oversees contract workers is often viewed as a “Big Brother” type. Dangerous activities should be discouraged, but harmless means of self-expression, including the personalization of a room, should be encouraged.

Places in McMurdo Station that have gradually cultivated a non-institutional feel are some of the more desirable areas (e.g., the Coffee House). Therefore, places not used for work or official business should have a more relaxed, homier feel.

OZ Master Plan– Score: 7/10. There is no current information on this topic, and so this sub-category is assigned mostly middle marks. It is given a low mark for occupant comfort because of the high density, two double-loaded, straight hallways with two-thirds windowless rooms.

Idealized Station– Score: 9/10. The combination of furniture, lighting control, color, materials, proportion, single-occupancy, and hallway design all contribute to a homier dormitory setting. These buildings are designed to feel different from the office, laboratory, or workshop settings found in the rest of the work settings in McMurdo.

Distances Maintained in Private, Social, and Public Interactions

McMurdo Station– Score: 3/10. The station is sized according to an American/Western sense of personal, semi-personal, and public space, but there are a few areas that could improve. Bulky gear requires slightly larger hallways, and a large peak population can create bottlenecks at the height of the season, mostly in common areas like the galley. Bars can also be packed at the end of the day, reversing any good done by going somewhere to "unwind after work." Above all, the lack of single rooms is the biggest violator.

OZ Master Plan– Score: 5/10. The inclusion of single rooms is a huge improvement over past designs or policy changes. While more details are required to judge this category effectively, the building shows a promising start in laying out what appear to be specific rooms for socializing along the south side of the building. There is also the Coffee House, which is converted from the NSF Chalet. It is not clear if these will be enough room to accommodate everyone. It should, however, signal the end of these recreational spaces closing during the winter because of high energy costs.

Idealized Station– Score: 8/10. Most occupants in McMurdo dormitories are accustomed to Western ideas of privacy and have a Western sense of personal space. Rooms should be designed with space saving design solutions, maximizing their efficiency. Limits on room size should not go as far as a capsule hotel "pod," but should be outfitted with several pieces of multi-purpose furniture or built-in designs. The idea of making some rooms convertible to double rooms in the OZ proposal is also a good idea, one that offers greater flexibility. Socialization areas should offer a range of classic bars, homey lounges (e.g., a Coffee House), and quieter places (e.g., the library).

8.1.3 Functional and Task Performance (Table 5)

Building Structure: Cold Regions Best Practices (CRBP)

Building Form

McMurdo Station– Score: 5/10. McMurdo Station may seem to be the ultimate "winter city," but its layout does little to accommodate inter-building travel, as Pressman (1998) recommends (see Section 4.1.1). The idea of connections has already been discussed, but here in "building form" it once again appears. Building form also includes the shape of the building when it comes to heat loss and snow drifting.

Table 5: The *Functional and Task Performance* section of the design matrix; see Table 1 for detailed description.

Functional and Task Performance									
Building Structure: Cold Regions Best Practices									
building form									
	McM As-Is	2	1	0	1	1	5		
	OZ	1	1	2	1	1		6	
	Ideal	2	2	1	2	2			9
floor & foundation									
	McM As-Is	1	1	0	1	1	4		
	OZ	1	1	2	2	0		6	
	Ideal	2	2	2	2	2			10
walls/roof assembly									
	McM As-Is	1	1	0	1	1	4		
	OZ	2	2	2	2	2		10	
	Ideal	2	2	1	2	2			9
glazing & frames									
	McM As-Is	1	0	0	1	0	2		
	OZ	1	1	2	1	1		6	
	Ideal	2	2	1	2	2			9
category subtotal							*15*	*28*	*37*
percentage							*38%*	*70%*	*93%*
Building HVAC: Cold Regions Best Practices									
power/distribution									
	McM As-Is	2	1	0	1	1	5		
	OZ	1	2	1	1	1		6	
	Ideal	2	1	0	1	1			5
heat provision									
	McM As-Is	1	0	0	0	1	2		
	OZ	1	1	2	1	1		6	
	Ideal	2	2	1	2	2			9
ventilation									
	McM As-Is	1	0	1	1	1	4		
	OZ	1	1	2	1	1		6	
	Ideal	2	2	2	2	2			10
potable water									
	McM As-Is	1	1	1	1	1	5		
	OZ	1	2	1	1	1		6	
	Ideal	2	2	1	2	1			8
category subtotal							*16*	*24*	*32*
percentage							*40%*	*60%*	*80%*
Logistics: Remote Regions Best Practices									
transportability									
	McM As-Is	1	1	0	1	1	4		
	OZ	1	1	1	2	1		6	
	Ideal	2	1	1	2	1			7
construction time									
	McM As-Is	2	1	2	2	1	8		
	OZ	2	1	2	2	2		9	
	Ideal	2	1	2	2	2			9
relative scarcity bldg. materials									
	McM As-Is	2	1	1	2	2	8		
	OZ	1	2	2	1	1		7	
	Ideal	1	2	1	1	2			7
category subtotal							*20*	*22*	*23*
percentage							*67%*	*73%*	*77%*
Total							**153**	**217**	**289**

Most McMurdo buildings have a low surface-to-volume ratio, but with so many individual buildings, the number of exposed walls adds up. With a few exceptions, these buildings cannot be called aerodynamic,[207] and while snow accumulation in not as drastic as in other locations, it does require maintenance. Aside from there being no trace of the original layout which was parallel to prevailing winds, most buildings are boxy and experience low-to-moderate snow drifting, even Quonset huts with their arced roofs. Scheduled road scraping is an adequate remedy –except when it comes to exposed staircases– but this is also an additional source of carbon emissions.

With the exception of keeping roads clear for emergency vehicles and doorways clear for emergency egress –which is very important– most accumulations area allowed to develop into semi-permanent features or are pushed off to the side of a building (see Section 4.1.2). Some buildings were designed to allow snow to pass below, while others are skirted; it is not entirely clear why there is a distinction. For these reasons, McMurdo station receives mixed scores for building form. Because it is a multi-building station –and a sprawling one at that– it gets a low score for environmental footprint.

A subset or offshoot of building form is its entrance: the vestibule. McMurdo Station has vestibules or "staging areas" in nearly every building, but they are often too

[207] The design of the Crary Lab is one exception. It was subjected to aerodynamic studies (water flume) which resulted in a modification to part of the design (Ferraro, 2010, Ch. 10). There is some snow drifting between the phases of the building, and snow accumulation on stair cases is as much of an issue as anywhere on the station, but there is little or no accumulation beneath the structure.

small for people to clear one door before the second is pushed open, or are awkward for more than one person to enter at a time.

OZ Master Plan– Score: 6/10. The OZ plan for consolidating the station buildings ranks highly under energy efficiency since it limits the number of exposed walls and the amount of building materials, and because it creates a (nearly) entirely indoor "winter city." Fire safety is another matter, with the risk being much higher and the need for extra fire prevention measures extremely important. There are few details of fire prevention methods in the OZ proposal, but looking to South Pole Station may offer some insight.

Vestibules are not specified; the image in the OZ Master Plan seems to show an undersized vestibule as the Main Entrance, but this design may still be modified before the final design is set. One large building *would* require fewer vestibules since there would be fewer points of entry, something bound to limit the amount of heated air escaping through open doors. However, snow drifting may be a problem, especially if the large structure does not allow snow to pass beneath it; the building could potentially require additional snow management (i.e., drift removal).

Idealized Station– Score: 9/10. The station's buildings are designed to allow snow to pass beneath and around them, with pedestrian walkways moved up one floor (the corridor connections), making an ideal winter city. Vestibules are adequately sized for traffic flow and room size, and are laid out so that at least one set of doors is closed at all times. Like the floor in a mud room, vestibule flooring needs to be able to absorb snow from shoes and be non-slippery. It should also be able to tolerate snow that comes through the door (either while open or as spindrift) (see Section 4.1.2). Vestibules should be well designed and limit the amount of air infiltrating the building from foot traffic passing through entrances. A variation on the OZ consolidated building would be to have the interior space feel more spread out (i.e., less like a single building), giving people the feeling of traveling between buildings rather than staying inside a single location all day.

Floor and Foundation

McMurdo Station– Score: 4/10. Historically, permanent buildings in McMurdo were raised four feet off the ground to provide good air circulation; however, this was not high enough to allow snow to pass completely under the building, meaning that over time this distance decreased, causing problems for the foundation and for pipe maintenance (Hofmann, 1974, p. 5-2). Today there is evidence that the underside insulation in older buildings (i.e., dormitories) is not performing optimally, and pipe accessibility continues to be important. This deteriorating state is most likely because of the age of the building, but there is also evidence that newer buildings (e.g., the Crary Lab) may have problems keeping escaping heat form affecting the permafrost. Some buildings are not raised off the ground enough for easy maintenance (Figure 47). This undoubtedly creates complications when underfloor piping needs to be accessed.

Some buildings in McMurdo feature a skirt around their exposed foundation. Skirting buildings in McMurdo has been shown to be effective in keeping snow from collecting underneath structures[208] (e.g., Medical), without trapping enough heat to melt the permafrost (Hofmann, 1974, p. 5-2 – 5-3). However, it means months of snow accumulation on one or more side of the building.

OZ Master Plan– Score: 6/10. There is no definitive information on this topic, but it is known that the massive structure *must* be elevated enough that the frozen ground does not melt. The few renderings available indicate that the structure may be raised only slightly off the ground, enough to accomplish this, but perhaps not enough to allow easy maintenance, or to allow snow to pass below the building. From the renderings, it also appears that the building is skirted, but this has also yet to be confirmed.

A new cargo building will feature a concrete floor, which is very important for the supply or vehicle maintenance buildings. How the concrete will be poured onto the frozen ground has not yet been specified; nevertheless, having a non-timber floor is a positive for fire prevention and the lifespan of a building that will probably accommodate heavy vehicles.

Idealized Station– Score: 10/10. Like the walls and roof, the floors are very well insulated and raised several feet off the ground. South Pole Station seems to have accomplished this, resembling quite closely recommendations provided by Lstiburek (2009) and the existing structure of South Pole Station. This keeps the interior floor warm and protects the frozen ground below the building from thawing.

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[208] However, it will still be pushed against long walls on the windward side or be deposited on the leeward side, depending on the circumstance.

Certain buildings such as those with payload bays or garage (vehicle maintenance) areas, or that house heavy equipment like generators, water tanks, or utility vehicles may have different foundations (i.e., very carefully poured concrete), perhaps on a pier and beam configuration.[209]

Wall and Roof

McMurdo Station– Score: 4/10. Construction type and age vary greatly across the station; even dormitories exhibit three distinct building "series," along with the rooms in Building 155 and two other buildings from the late 1960s. Regarding the 206-209 series, the wall and roof assemblies are relatively successful, but suffer from age and the slow march towards obsolescence. In at least one instance, storm winds have managed to separate sections of the metal panels from the frame, a good argument for the smooth, precision walls of buildings like the Princess Elisabeth base (see Appendix F). The exterior walls of dorms 210 and 211 exhibit some icing problems (Figure 46) but it is unclear whether that is a problem inherent with the structure or simply a matter of harsh conditions resulting in a shorted useful lifespan. It appears the same materials should not be used again because there are improved insulative options available, providing an opportunity to make the most of CRBP for airtight construction.

The 206-209 dormitories feature Robertson Versawall panels (see Section 4.1.5 and Appendix J). These are not structural panels, like SIPs, but are affixed to a steel studs. They combine insulation with an exterior finish in modular, snap-together pieces.

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[209] See (Hofmann, 1974, p. 5-7 – 5-26).

OZ Master Plan– Score: 10/10. There is no definitive information on this topic, but it is clear that composite wall panels (or SIPs) will be used again, probably similar to those used at South Pole Station. Those SIPs are composed of expanded polystyrene (EPS)[210] wrapped in Tyvek and sandwiched between 3/8" OSB. Walls are 10" thick (R-50), while roof and soffit panels were 14" thick (R-70). They have a vapor resistance of 0.007 perms (Ferraro & Brooks, 2002, p. 238), more than satisfying the recommended maximum of 0.1 perms (Lstiburek, 2009, p. 56). Rated alone, this category does very well, even in terms of fire safety; however, it is important to remember the form of the building (composite, single structure) means that elsewhere the design ranks low for fire safety.

Idealized Station– Score: 9/10. The walls and roofs follow CRBP very closely, utilizing a sandwich panel structure (SIP) for ease in site transportation, quick assembly, and quality assurance.[211] VIP insulation may make this wall even more insulated, but now there are too many unresolved complications with VIP insulation, including fragility and the added cost when compared with SIP construction. All feasible CRBP techniques are applied to the construction of walls for idealized McMurdo buildings (see Section 4).

[210] EPS with density of 2lbs.
[211] If the insulation is flammable it should be treated with a non-toxic fire retardant.

Glazing and Frames

McMurdo Station– Score: 2/10. Natural daylighting systems in McMurdo are very few and most have very little control over the amount of daylight coming in.[212] Crude systems mostly intended to keep out drafts totally block daylight when in use. Window assembly is an obvious area for improvement in McMurdo's dormitories. Age is a huge factor in the performance of these assemblies, but so are craftsmanship and the fact that most dorm windows are operable. Interior ice formation, drafts, noises, and spindrift are not uncommon, turning the presence of a window into a waste. Windows in rooms and lounges are often "plugged up" with extra insulation or covered by heavy curtains, which causes problems when the ice melts.

OZ Master Plan– Score: 6/10. If the design of the windows at South Pole Station is any indication, the windows for rooms (and presumably the entire building) will be high quality, constructed in a way that limits the formation of condensation on the interior. CRREL did extensive laboratory testing on commercial window assemblies for the South Pole Station before choosing a final design (Dutta, 1999; Dutta & Clark, 2001). The station features small, triple-paned windows (R-6.66) fitted with translucent blinds to protect from glare; during the long winter these windows are covered with

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[212] McMurdo Station enjoys more days of twilight or full sun than South Pole Station. New or recently renovated areas are noticeably well lit and somewhat sterile, but often with more windows. Older areas tend to have fewer or smaller windows and are not as evenly or brightly lit. The recently refurbished Galley, on the other hand, features a long strip of windows, sky lights, and extensive overhead fluorescent lights. The lighting is appropriate for its purpose: it is not intended to be an after-hours hangout. Older locations like the Coffee House rely mostly on localized task and accent lighting which, combined with the wood paneled walls, creates the sense of a warm, homey place, even without a single window. It is important to recognize the need for both of these kinds of spaces

interior insulation to protect from the cold and to create Dark Sky conditions for science observations made during the winter (Ferraro & Brooks, 2002, p. 238).

Idealized Station– Score: 9/10. Windows should feature high performance, multi-pane glass or aerogel (R-10–R-20). The assemblies should be precision crafted (probably pre-fabricated) to reduce spindrift infiltration. Frames are insulated and contain a thermal break and are operable only when the window needs to be used as an emergency exit. Room windows are small, but every single-and double bed room has a window. Sleeping rooms that do not have windows are generally larger rooms for groups of transients. These rooms should be located close to emergency exits.

Makeshift protection from drafts (e.g., sheets of foil) would not be necessary; rather, a room darkening system acts as a draft inhibitor. The daylighting control is located inside the window assembly and is controlled by the room occupant. The windows are sturdy enough (not iced over or leaky) that covering windows is limited to room darkening for sleeping during the continuous summer days. As previously mentioned, between-the-glass shades or blinds (windows with shading sandwiched between the glass panes) provide an efficient way to darken rooms without becoming a maintenance burden.

Building HVAC: Cold Regions Best Practices (CRBP) **(**Table 5**)**

Power and Distribution

McMurdo Station– Score: 5/10. McMurdo's power grid just received a major overhaul, not only in the form of new generators and a new power house (with waste heat capture), it is now also a part of the wind-diesel hybrid Ross Island power grid, shared with New Zealand's Scott base (see Section 5). With increased building efficiency and more wind turbines, McMurdo's demand for diesel fuel and heating oil could decrease significantly. Until then the station is faced with a legacy distribution system and a scattered station layout.

OZ Master Plan– Score: 6/10. There is not enough information on this topic to draw many conclusions, but it is generally accepted that building efficiency will increase and if possible the number of turbines on Ross Island will someday grow.

Idealized Station– Score: 5/10. A well-organized station with energy efficient buildings makes power distribution more effective (in terms of transmission losses). More land is set aside for turbines.

Heat Provision

McMurdo Station– Score: 2/10. Unfortunately under current conditions, on very cold and windy days, certain rooms in the dormitories do not receive adequate heat. I experienced this in 2009 during a cold snap in early September. This condition is not usual, however, and most of the time the heating system is adequate. It was also noted by some living on the first floor of the dormitories that conditions in the rooms on the first floor were significantly colder (uncomfortably so) than conditions in rooms on the second and third floors.[213] Some survey responses indicated they would prefer better control of their room temperature.[214]

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[213] This condition may be due to a stack effect that pressurized the upper floors and deprives the lower floors. It is asked of all residents not to open their operable windows if their room feels too hot, as this only exacerbates the colder conditions on the first floor. This rule is not always followed.
[214] The Winfly surveys showed 62% of the respondents felt at least some dissatisfaction with their room temperature (the room was comfortable "sometimes" or "never").

While the current system consisting of a single generator house and dozens of oil-fired boilers seems outdated, a station-wide, centralized, all-electric system would be more vulnerable to station-wide blackouts, unless there were multiple redundant electric systems with their own set of generators. It would also require a complete utility redesign of the station's utility lines. However, as the station moves towards greater wind-generated energy capacity, it may be possible that boilers, like diesel generators in selected locations, will be present as backup systems only.

OZ Master Plan– Score: 6/10. There has been no specific conversation about this yet, but clearly the single building will make heat delivery easier. However, since the dormitory wings are still exposed on three sides and are quite large (300 people/wing), it will be necessary to ensure that the rooms farthest from the heat source are still adequately heated and comfortable.

If the design of South Pole Station is any indication, the system will continue to rely on a "… forced water/glycol heat transfer system [that] circulates recovered waste heat from the power generation plant heat recovery system…" (Ferraro & Brooks, 2002, p. 238). Since there are no definitive plans regarding new sources of energy to provide the heat, I assume that oil-fired boilers or diesel-electric (supplemented with the waste heat) will continue. Finally, if the three wings are to be scaled-back to one during winter, the heating systems will have to be able to be controlled accordingly.

Idealized Station– Score: 9/10. Building heat, specifically dormitory heat, that remains independent of a central supply allows each building to be heated if occupied and left cold (i.e., slightly above freezing) if not. If boilers are maintained, boiler rooms need to be well-ventilated and protected from the cold, but they may not need to be kept as warm as the living areas. The system should be easily accessible, probably via a separate utility entrance that is close to the fuel tank, which can be approached by a fuel truck for resupply purposes (this is generally the status quo). Modular boilers add a level of redundancy and flexibility if the occupancy level in the dorm changes, or when temperatures are less severe.[215]

Ventilation

McMurdo Station– Score: 4/10. Ventilation in dorms is generally good, as evidenced by the numerous leaky windows. Ventilation in recreational areas is also quite good, erring on the side of being too drafty. However, older buildings like the Coffee House experience both drafty and stuffy conditions, as seen in the temperature/relative humidity/carbon dioxide readings. Here it is clear that during peak occupancy (between 20:00 and 23:00), the CO_2 peaks at undesirable levels, then quickly drops off once the Coffee House closes for the night. This type of condition could be avoided with tighter sealing of the buildings and a well-sized ventilation system.

OZ Master Plan– Score: 6/10. There is no information about the ventilation system yet, but if the plan follows the measures taken at South Pole Station, a VAV system will provide adequate air flow in spaces based on demand (determined by CO_2 occupancy/air quality sensors), and OA will be preheated using a heart recovery from exhaust systems (Ferraro & Brooks, 2002, p. 238). There is no information about humidification units, but it is likely that they will also be a part of the HVAC system.

[215] Temperatures can reach as high as 40^{o}F, but not for very long.

Idealized Station– Score: 10/10. The Ideal station should circulate clean, fresh air, providing healthy conditions for station occupants. Buildings are not reliant on infiltration for fresh air; rather, the buildings are mechanically ventilated with preheated, slightly humidified air (no more than 30%) (see Section 4.2.4). The South Pole Station system is a good model to follow.

Potable Water

McMurdo Station– Score: 5/10. In dormitories there has been a recent effort to upgrade appliances to be more efficient or low-flow. Automatic sinks are now more common –a good water saving feature, even if it makes it difficult to brush one's teeth. Water-saving behavior is already prevalent, with designated (i.e., staggered) laundry days and short showers encouraged. Glycol heat exchangers located on the ground floor of the 209 dormitory heat the water and store as much as 440 gallons a time, although they are often depleted as the population grows. People are reminded to take short showers and only do laundry on assigned days, but even this does not completely solve the problem.

OZ Master Plan– Score: 6/10. Gang-style showers (as found at South Pole Station) are located at the intersection of the dorm rooms and the main buildings; this allows the piping to be contained to one area of each dorm wing, a very good idea, especially if each wing is going to have the potential to be "cold soaked" to 46^{o}F each year, as they are at the South Pole.[216] Much like South Pole Station, the "laterally" nested layout (as opposed to a radially nested building like Princess Elisabeth) of the toilet/shower areas at the ends of each dormitory wing shown in the OZ master plan will provide extra protection to the water pipes.

What is not shown in the available drawings is the demarcation between the main building and the dorm wings. This is important since the showers/toilets should be on the "warm side," i.e., that part of the main building to stay continuously heated, not the dorm wing that could potentially be "closed" for the winter (as at Pole). Dorm laundry facilities (and any dormitory area that uses water) should also follow this layout. Doing so provides great flexibility for when the dorms are vacated and "cold soaked," if not completely winterized.

In the single, raised building that is South Pole Station, these pipes are also protected by the building, located in a chase between the first floor and the SIPs that form the underside of the building envelope. "Localized boilers … [accommodate] on-demand domestic hot water requirements" (Ferraro & Brooks, 2002, p. 238). This means that pipes are not an afterthought, installed wherever there is room and denied the extra protection provided by the insulation of the building. However, it should be noted that this can be a source of increased fire risk if the combustion system pipes and water tanks are located in the same location. It is important that pump houses be located away

[216] This term is used at South Pole for the two summer berthing wings which are emptied during the summer and not heated as much as the rest of the structure. Anecdotally, they remain good places to chill beverages.

from the structures they service because pipes and pumps within the building should be protected from fire if the building and/or structure collapse.

Idealized Station– Score: 8/10. Pipes are protected as much as possible by being laid within the protected insulation of the building, but not at the expense of fire safety. Doing this also provides easier maintenance for the pipes, since they can be accessed from inside the building instead of underneath. In dormitories, water-saving appliances should be installed and used where possible: automatic sinks, dual-flush toilets, and waterless urinals. Another water-saving feature is a timing device that helps people showering keep track of the time. As a nod to occupant comfort, however, ice machines are still available in each dorm.

Logistics: Remote Regions Best Practices (Table 5)

Transportability

McMurdo Station– Score: 4/10. The beginning of Operation Deep Freeze in the 1950s was essentially a huge test in optimal logistics for Antarctica. Since it was run by the USN, all buildings, systems, tool, construction techniques, etc., were all based on naval tests and tradition. Between the annual supply ship and the military cargo flights, it is safe to say that building material transport is well understood, and the information is there for those who seek it. The Chalet, with its wood exterior and shingled roof, is unique for a reason.

McMurdo Station also has an advantage over stations farther from air and sea access which must go to even greater extremes as the cost of transporting those materials and supplies skyrockets. The same can be said of construction waste, which must also be packaged for shipping and must return by overland traverse or by air to the coast and then by ship to its final destination. Once again, looking at South Pole station provides a good idea of what might be considered the extreme end –or ideal– of practical logistics.

OZ Master Plan– Score: 6/10. If the OZ plan mimics the practice at South Pole Station, building parts will be lightweight, factory cut, and assembled only so far that they can still be transported on a standard-size palate. Some leeway is possible since McMurdo has access to an ice pier; in fact, it is more likely that almost every building part, tool, and material will arrive on the ship, not by plane. SIP panels are an obvious choice, as are lightweight steel frames. Lumber should be reserved for interior finishes. The use of concrete – impossible at Pole- is still to be reserved only for certain types of building in McMurdo: those that must support great weight such as heavy vehicles. Concrete footings may be poured on site, and of course concrete blocks may be pre-cast and imported (undesirable because of the weight and bulk). Because these specifics have not been presented, the plan receives a middle score for "meets energy/water standards through CRBP."

Idealized Station– Score: 7/10. The design follows examples set by South Pole Station and Princess Elisabeth. These stations took advantage of high performance materials, very well insulated walls, and followed CRBP to create highly insulated structures with no penetrations, and all wiring and plumbing contained within the insulated envelope of the structure.

Construction Time

McMurdo Station– Score: 8/10. Large structures have sometimes taken years to complete. Because most programs in McMurdo are so large, larger buildings are also being required more often. In the past, these structures were closer in form to the early, modular, prefab USN buildings, and it was easy to add an addition to existing structures for more room, even if these changes were haphazard and sometimes increased fire hazards. Today, when a program outgrows a building, it must wait years before a new, larger structure can be funded. Until then, staff and scientists using the building simply must make do.

OZ Master Plan– Score: 9/10. The planed central building provides more room for station functions, but also operates under the assumption that peak population will no longer be the oft-cited 1,200 people of the past. For this reason, it should be able to accommodate the scientific mission of the station for decades to come. As long as the population of the station stays around these projected levels, there should be no need to plan for additional housing, labs, or storage.

Idealized Station– Score: 9/10. The station is returned to a compact form (as far as fire safety measures will allow), its program streamlined to reduce the total number of people required to run the station, but it is also given a path if future growth if necessary. Construction time for most structures is short and scheduled to allow interior work to continue through the winter until the next phase of exterior work commences the following summer. This allows future buildings to be completed in a timely fashion.

Scarcity of Natural Resources

McMurdo Station– Score: 8/10. Unfortunately many existing buildings are so out of date and so weather-worn that it makes more sense to rebuild. Future designs should include a certain amount of flexibility and parts-reuse, enabling buildings to be maintained and upgraded easily instead of falling into disrepair or obsolescence.

OZ Master Plan– Score: 7/10. There is only limited information on this topic in the OZ Master Plan. Specifically, at least one building is preserved in the OZ Master Plan: the NSF Chalet. This building is named as the replacement for the Coffee House, which, while loved, has only been kept open because there is no acceptable replacement and its presence is much appreciated.

Moving the Coffee House so far from the dormitories is not desirable, but the argument could be made that most of the trek could be made by passing through buildings and walkways, although somewhat awkwardly since the best route would take people through the Crary Lab. However, usually only scientists and support staff who work in the Crary Lab have door keys to enter the lab. Alternative pathways take people to the medical building, or simply go outside once the southeast edge of the main building is reached, somewhat defeating the purpose of have one large multi-purpose building.

Idealized Station– Score: 7/10. Over time as renovation becomes necessary, dormitories can be upgraded one building season –with any exterior changes made during the summer– and the interior finished during the winter if need be. Multiple buildings could be retrofitted in the way, which would mean less disruption for the program. Additionally, if there are problems with the interior insulation or vapor barrier, sections can be removed and replaced as needed. HVAC system renovations would be mostly straightforward since the systems are easy to access, allowing them to be replaced with newer, more efficient systems.

8.1.4 Building as Symbol

That the building is comfortable, that it is healthy, and functions properly should be a given. In extreme environments it requires more effort and money to implement, but even if the solution is not ideal, the architects and engineers designing the structure should address each issue lest they undermine the intent or mission of the structure (Tom, 2008). All of these features should fade into the background when one considers what the building symbolizes, what it "…communicates to its users" (Harris, et al., 2002). Occupants see the building as a reflection of who they are in this particular setting: vulnerable patients or numbers in a hospital, astronauts or lab rats in a space capsule, individuals or conformists in a college dorm, enthusiastic participants or hirelings in a remote research station.

Both Davis and Rozien (1970) and Harris, et al. (2002) indicate their belief in the importance of the building as symbol in terms of occupant satisfaction. In a study of occupant satisfaction in student dormitories, it was found that this was the best indicator of overall satisfaction, and that dorms that did not feel like dorms ranked highest. The overall impression that a student has of his housing is more important than his satisfaction with the individual environmental characteristics. What the building symbolizes to him is the deciding factor, not the complaints or gripes about specific detailed parts of his living experience (Davis & Rozien, 1970, p. 29). At the architect's expense is this overall impression left out of the design process.

It is still important to address individual features of the building –especially in a demanding environment with high fuel costs– because the symbolic meaning of a building is largely composed of the success or failure of these features (Harris, et al., 2002, p. 1281). Davis & Rozien (1970) concluded that the best design (of a student dorm) was to create an image that did not scream "institutional dormitory," but instead was a pleasant place to live, study, and allow the student occupants to express themselves as individuals. The design specifics laid out in this paper were later challenged by Devlin, et al. (2007), fortifying the statement in Harris, et al. (2002) that "[s]ymbolic meaning might be the most difficult of all of the features to study, primarily because the concept is so general and holistic" (p. 1281). There has been much progress in this type of approach in the healthcare industry but not much for student dormitories since the 1970 study. In McMurdo Station, it was only in the last few years that there was a housing survey, and very little has changed as a result.

Overall, it appears that every design feature that could increase occupant satisfaction will probably increase upfront costs and possibly challenge fire safety best-practices in the very cold, remote McMurdo Station. Smaller housing facilities, a less institutional feel, intimate settings, increased control over noise, access to greenery, windows, therapeutic winter lighting: all unnecessary to survival, but necessary to the long-term viability of the station.

The current dormitories represent the old style of housing people in climate controlled, efficient boxes. In their day these buildings (e.g., 201-203) were a huge improvement over the older structures (e.g., Hotel California) and a world away from the old naval barracks in T-5 huts and Quonset huts. Indoor showers and restrooms, private (two-person) rooms, and improved wall construction were another signal that the old way of doing things was ending. Today, these dorms and the “upper-case” dorms (i.e., 206-209), are an image that is not so bright. People in the industry are increasingly accustomed to private (single) rooms. The rows of identical buildings, stacked with identical hallways, now feel more like a return to college than a professional setting. On top of this, the buildings and systems are aged and mostly falling behind current technology and building practices for extremely cold climates.

If these criteria were in the matrix, McMurdo would receive a low score because it is aged, unorganized, and an unremarkable sight to find at the end of such a long journey. The new OZ plan would be improved –mostly with the “new paint” feeling. Overall its image is impressive (in that it is a very large building) and tidy, but the way the station is bundled into one indoor environment ranks low. The Ideal station should not only be visually striking –a symbol of the commitment to Antarctic science and the preservation of the environment– but afford occupants the healthy interior environment alongside access to the outside.

8.1.5 Summary of Matrix Results (Table 6)

Final scores in the matrix indicate a great need for improvement in the existing station (53%). The OZ proposed plan offers many good changes (71%), but still falls short of the ideal station (90%). While McMurdo Station in its current condition received a score of 0 for some factors, it never fell below a score of 45% for any subcategory. This is largely because most of the time other factors received higher scores. For instance, a low score for occupant comfort rarely affected the fire and safety score.

Because there was often not enough information for the OZ design factors, a score of 1 (i.e., achieves current standards) was assumed, especially if there was a highly ranked precedent set by the design of South Pole Station. Additionally, the matrix showed that the single, large building proposed by OZ ranked lower than McMurdo's sprawling layout and the Ideal design (i.e., condensed but multi-structure layout) because of fire safety concerns. From the information currently available, it is not clear if the building could survive a catastrophic fire, and if that were the case, there was no obvious building that could be used as a back-up shelter for so many people. Furthermore, with much of the cargo storage (including some food storage) in the main building, the risk was even higher if the station was largely consolidated into a single structure.

Table 6: Summary of matrix results; see Table 1 for detailed description.

	McM	OZ	Ideal
Health and Safety			
Protection from Elements			
category subtotal	*6*	*14*	*17*
percentage	*30%*	*70%*	*85%*
Fire			
category subtotal	*22*	*25*	*25*
percentage	*73%*	*83%*	*83%*
Spread of Disease			
category subtotal	*10*	*12*	*19*
percentage	*50%*	*60%*	*95%*
Psychological Comfort and Satisfaction			
Architectural Features			
category subtotal	*20*	*32*	*40*
percentage	*40%*	*64%*	*80%*
Ambient Features			
category subtotal	*20*	*25*	*45*
percentage	*40%*	*50%*	*90%*
Interior Design Features			
category subtotal	*24*	*35*	*51*
percentage	*40%*	*58%*	*85%*
Functional and Task Performance			
Building Structure: Cold Regions Best Practices			
category subtotal	*15*	*27*	*37*
percentage	*38%*	*68%*	*93%*
Building HVAC: Cold Regions Best Practices			
category subtotal	*16*	*24*	*32*
percentage	*40%*	*60%*	*80%*
Logistics: Remote Regions Best Practices			
category subtotal	*20*	*22*	*23*
percentage	*67%*	*73%*	*77%*
Total	**153**	**217**	**289**
percentage	*45%*	*64%*	*85%*

The OZ plan also received low marks for its condensed floor plan for the dormitories, with two rows of windowless interior rooms. This decision ranks low not only for occupant comfort and for some ambient features criteria, but also a when it comes to fire safety. Combined with the design decision that makes McMurdo Station rely heavily on a core building, the scenario receives a middle or low score four times.

Scores for the Ideal station are high, but there are a few areas that fell short because of conflicting design factors. For example, all buildings should be separated to lower the chances of a fire spreading, but the Ideal design proposed a few limited connections between buildings. Even though these connections would be constructed with multiple layers of fire safety, the matrix still scores this decision lower than the current station's completely disconnected buildings. However, the score for occupant comfort is higher for the Ideal station.

8.1.6 Additional Findings from the Design Matrix

When information from the design matrix (see Section 7.5) is combined with the energy analysis, the literature review, and the survey responses, the result is a more complete picture of the challenges facing the design of the station. What quickly become clear are the conflict areas. This includes challenges that arose in the process of this study (e.g., when ICE designs, EEMs, and survey responses clash or result in less-than-optimal best practices), as well as areas that are problematic because more data are needed. The following sections identify some of those areas.

Choosing an EEM Only on the Results of an Energy Model Misses Important Information and May Overstate the Energy Savings.

Recognition that an unbalanced analysis of design (especially one which affects a human habitation) creates an incomplete or disported view is not new, and has been discussed previously in this document.[217] Here we can see one example of this pitfall: rooms with no windows. This design choice can affect both interior rooms and those along an exterior wall (if windows are excluded completely). The absence of windows certainly decreases construction and materials costs, but the energy saved (through decreased heat loss) compared with safety and any negative psychological effects (see Section 3) are questionable.

Ten people (43%) mentioned windows in their survey responses, and two respondents indicated they were currently living in the windowless interior rooms in Building 155. Of those that had windows in their rooms, all mentioned either draftiness or the need to darken a room for sleeping. One respondent wished for larger windows; another wished for windows in his or her place of work as a way to cool the space (i.e., open the window). Just over half (56%) wrote that they simulate greenery in their lives, be it fake plants, photos of other places, or volunteering to work in the greenhouse (which provides access to grow lights and the only access to live plants). While no one wrote they wished their room had no windows,[218] these responses indicated a desire to bring elements of life in a lower latitude (i.e., back in the U.S.) into daily life, be it a diurnal light/dark cycle, thermal comfort, or a biophilic desire for sensory stimulation. The solution may be the ubiquitous installation of a smaller, tighter, better insulated, and

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[217] See Sections 3.2 and 7.3.1.
[218] This question was not directly posed.

more flexible aperture in the dorms.[219] Winter conditions[220] may also warrant the addition of LED lights (or other heliotherapy lights) to simulate dusk, dawn, and daylight.

The design matrix showed that the OZ proposed design is an improvement over the base case because the quality and younger age of the windows is improved. However, the OZ proposal does not receive full marks for safety or occupant comfort (as the ideal design does) because of the four rows of window-less rooms with no natural daylight or connection to the outside and the increased fire risk.[221] The argument that 'because some rooms at South Pole Station are windowless and occupants do not mind' falls short in McMurdo. Although the station currently resembles a combination mining town, military base, and college campus (DMJM, 2003, p.1-2), there are still views of hills, mountains, and ocean; up on the polar plateau the blue and white horizon is unrelenting.[222]

When looking at the energy models, the amount of energy saved for space heating by eliminating glazing completely is modest but significant and should not be discounted entirely. In the base case, removing the R-8.5 (U-0.117) windows provides a savings of slightly more than 10%; improving the windows alone (R-20 or U-0.05) and comparing it with a no-windows base case yields a savings of just under 9%; once the

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[219] That is, one which can be easily and neatly covered and uncovered. See also a discussion in Section 4.2.3 about using LED screen in place of windows.
[220] That is, months without daylight.
[221] The other ramifications of including windowless rooms are low marks for "quality of the luminous environment" and "hominess."
[222] During winter it is dark, but not without its share of astral phenomena. However, because of winter experiments, the station becomes Dark Sky Compliant, forcing all windows to be covered. This is not currently the case in McMurdo.

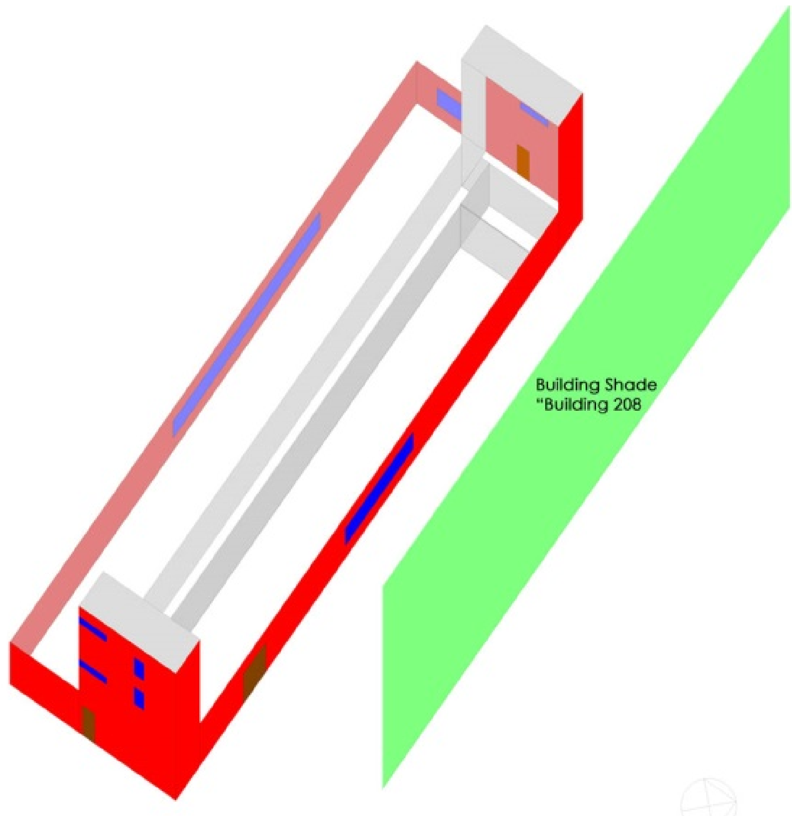

Figure 7: DrawBDL view of the energy model, first floor only with staircases, interior hallway walls, and building shade.

entire building and windows are improved the savings drop to below 7%. These savings must be weighed against the psychological effects of housing people in a completely enclosed environment (see Section 3), as we can see in the design matrix.

It is important to note that these savings are from EEMS applied to the dorm-as-is, Building 209. When looking for savings in the OZ proposed dorm wing, the calculations become more complicated. This brings us to a second reason why relying just on the energy model provides an incomplete picture.

The model of the base case dormitory shows a simplified building with two zones per floor. The circulation areas are separate from the living areas, which are

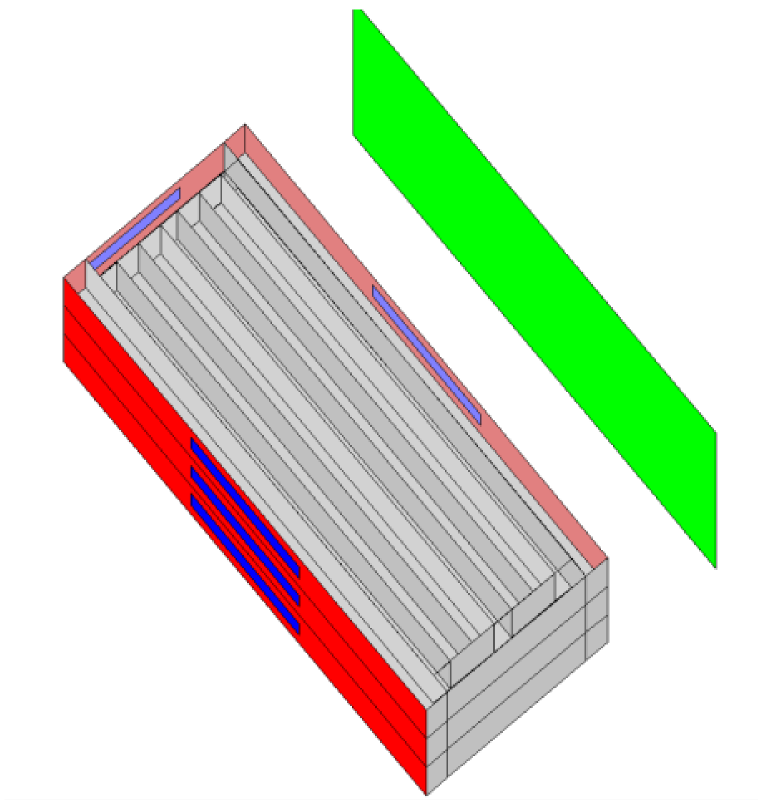

Figure 8: DrawBDL view of one of the proposed OZ dormitories, all floors, showing the layout of the rooms and hallways.

directly affected by the envelope of the building (Figure 7). This building is easily modeled in DOE-2.1E and, with a few caveats, yields a reasonable representation of the dormitory energy demand. A mock-up of the building proposed by OZ Architecture reveals a few problems if it were modeled using a building energy simulation program. For example, the proposed dorm design includes two double rows of interior, windowless rooms (Figure 8). These rooms would need to be designated as separate zones from the two rows of rooms along the exterior wall of the building. Additionally, the three interior hallways would need to be separated from the one that runs along the exterior wall (perpendicular to the others) as well as the hallways that also connect to the main building. This presents a much more complicated building energy simulation model that would be difficult –if not impossible– to model in DOE-2.1E. Therefore, proposed energy savings based off a simulation (which has not been discussed in the publicized information) should be closely inspected.

This is one example of how information from multiple sources provides a better foundation for making a design deciscion.

A Shift towards a Higher Winter Population Will Require More of a Focus on Design Temperature Differences of 106^{o}F.

Looking at differences in the results from the two Design Day energy simulations, it is clear that the main load during the summer is the occupants of the building, while the main load during winter comes from the low temperatures (Figure A-75). If the winter population increases, it will be an additional strain, not only for building systems, but also for the equipment electric demand, and this scenario has not yet been tested. More people working in McMurdo during the winter means more lights, more heating, more laundry, and a greater need to keep open (or somehow provide) socialization spaces that normally would be closed until the population and temperatures have increased during Mainbody.

A large winter population is so unusual that the energy model would have to be revised. For example, the base case schedules would be affected, mostly for occupancy. In the design matrix the ICE conditions would need to be refocused, as the long dark days and cold winter temperatures would still keep most people indoors for a majority of the time. The DMJM report from 2003 included engineering calculations from RSA

Engineering, Inc., which calculated a simple load tally for buildings (resizing a dorm to 60 ft. x24 ft.) with a 60°F *and* 106°F outside temperature difference. These calculations do not include laundry facilities or any equipment loads; they assume a full building in both instances, and was likely presumed only to apply to a low and stable winter population, not one that is larger (i.e., over 250) and variable (DMJM, 2003, p. 2-8). This kind of distinction is not made in the OZ proposal, which provides single rooms (mostly) for 900 people.

For comparison, the RSA calculated their conduction load for the winter design conditions (i.e., a 106°F temperature difference) at 30,274 Btu/hr. This study used an existing building that is larger and has more windows. It requires 58,560 Btu/hr., but when adjusted to be the same area, the number falls to 14,767 Btu/hr., a 52% improvement. If the opposite action is taken (i.e., the Design Dorm is given the RSA R-values), the number jumps to 112,180 Btu/hr., a 52% decline. This performance of the Design Dorm is to be expected, since the walls and windows are much better insulated.[223] It illustrates possible savings through better insulated walls, especially during the coldest time of the year.

[223] For ventilation and infiltration, RSA used a number higher than those calculated for the base case. Apparently referring to older standards (current for the time), the proposed dormitory receives outside air at the rate of 30 CFM/room, with a resulting heating load of 618,919 Btu/hr. If this rate were applied to the 209 dorm (65 rooms versus the RSA 18), the rate would jump from 1,578 CFM and 180,659 Btu/hr. to 1,950 CFM and 223,236 Btu/hr. However, these numbers are unclear, as it is not stated how many days per year this calculation (i.e., temperature difference) applies. The calculations could not be replicated with certainty.

Laundry Rooms in Dorms Represent a High Percentage of the Total Energy Demand.

To understand better the total energy demand of the base case dormitory, it was necessary to remove the laundry facility and model it separately. That the figures would be high was never in question, but how nine dryers would affect the power demand and the ventilation rate of the building was less clear. The totals were calculated assuming different rates during the three main seasons every year (see Appendix O). EEMs included more efficient washing machines, which use less water and therefore require less drying time. New dryers have also became more energy efficient, and with less water and drying time needed, pull less cold air into the building for a load of washed clothes.

In addition, it is not clear where the laundry facilities will be located in the OZ proposal,[224] as they are not labeled on any published drawing. Their location –be they in or close to the dorm wings or in the main building– will have a significant effect on the rest of the building. Locating them to take advantage of waste heat would also be advantageous. If it is necessary to locate this facility in a separate building, it should be connected to the dorms or at least to the main facility, making it easier for residents to transport and monitor their laundry.

In the design matrix, this design falls under the "multi-building vs. composite" heading in the Functional and Task Performance category, but also affects the entire

[224] A laundry is mentioned once in the list of initial observations as being a potential violation of life safety as it is included in the main building (Building 155 along with food service and living quarters). This is most likely a reference to the station laundry room, which has several commercial-sized machines reserved for station laundry or, in certain cases, for soiled gear (e.g., saturated with oil or fuel). Everyday laundry facilities in the other dorms are not mentioned in the OZ proposal.

building HVAC Best Practices sub-category (i.e., heat, ventilation, water). Fire safety is an important criterion for all of these categories. As there was no information regarding laundry facilities or location in the OZ proposal, it is not included in the rankings here, but its absence should be noted.

Work Shifts and Mixed Housing Make Ventilation and Thermostat Set-point Scheduling More Complicated, and Occupancy Sensors Will Only Solve Some of Those Problems.

Survey responses and temperature data loggers show that some dormitory rooms often become too hot, while others suffer from the cold when, as data from the temperature sensors shows, people on upper levels open their windows to let in some relief (Figure 27, Figure 28).[225] Therefore, there is a need for a way to manage room temperatures more precisely to avoid the desire to use such brute force tactics as opening windows.[226] With so many variables in the dormitory occupancy schedules, suggesting one or even two temperatures for the entire floor or building seems too inflexible. However, thermostatic control should not be so complicated that the systems are misunderstood, bypassed, and left underutilized (see the design matrix).

During the year there are up to 1) three different work shifts, 2) four seasonal changes that bring different weather and different population numbers, 3) one "weekend day" per week, 4) the constant threat of a weather event keeping people inside, 5) a transient population, 6) two extremes of a daylight cycle, and 7) a 40-110^{o}F indoor-outdoor temperature difference. Without more detailed data, it is difficult to determine a

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[225] Overheating was also noted in other buildings (e.g., the Crary lab offices).
[226] Removable windows should still be installed for emergency access only.

particular time of day when the building temperature could decrease to conserve energy. Occupancy sensors take away the guess work, so that room temperature can be adjusted based on need (CO_2 is a common indicator of occupancy) while never letting it drop below a certain temperature (e.g., 65^{o}F).

Complicating this is the status quo, in which a sizeable night shift is comingled with day shift (there is also a swing shift in some cases). The different shifts share the same buildings, floor, and even rooms. There is never one time of day when the entire building is empty or sleeping. Creating a building or even setting aside a floor in each building for the night shift is tempting but ultimately inefficient, since people will sometimes change shifts over the course of a few months and would need to be moved. Moving more than twice in a year would be undesirable. With the exception of power plant workers, there is no night shift in Winter.[227] During the height of the summer season, it is possible that a typical dorm (i.e., one housing contract workers) will be occupied all or most of the time.

One obvious solution –one that is already being pursued for many other reasons– is single-occupancy rooms. Single-occupancy rooms be unoccupied for part of the day and could be allowed to slip to a lower temperature without affecting a second occupant. Having single-bed rooms also begins to address noise complaints from "day sleepers," but does not solve the problem of general hallway noise or sources of noise outside the

[227] If the population of the station grows in Winter, this may change.

building.[228] As the matrix shows under the subcategory "ambient features," thermal comfort is joined with IAQ, sound control, control over artificial light, and access to daylight.

8.2 Energy Model Results

In this model, my goal was to quantify potential savings from a tighter building constructed with more modern (i.e., better insulating) materials and outfitted with energy saving appliances. Some of these changes were made in the model simulation (see Sections 7.1-7.3) and some improvements[229] were made external to the model (see Appendix O). Hourly loads were estimated based on two Design Days (Table 7, Table

Table 7: Building Peak Heating Load (LS-C) for the base case and improved building models for the Winter Design Day (July 8).

	Bldg Peak Heating Load SENSIBLE (KBTU/H)	(KW)	Bldg Peak Heating Load SENSIBLE (KBTU/H)	(KW)
	--------	--------	--------	--------
WALL CONDUCTION	-92.461	-27.091	-30.816	-9.029
ROOF CONDUCTION	0	0	0	0
WINDOW GLASS+FRM COND	-13.493	-3.953	-5.912	-1.732
WINDOW GLASS SOLAR	0	0	0	0
DOOR CONDUCTION	-2.094	-0.614	-0.406	-0.119
OCCUPANTS TO SPACE	1.709	0.501	1.728	0.506
LIGHT TO SPACE	2.072	0.607	0.663	0.194
EQUIPMENT TO SPACE	9.414	2.758	7.858	2.303
TOTAL	-94.853	-27.792	-26.885	-7.877
TOTAL/AREA	-0.002	-0.007	-0.001	-0.002
TOTAL LOAD	-94.853 KBTU/H	-27.792 KW	-26.885 KBTU/H	-7.877 KW
TOTAL LOAD/AREA	2.176 BTU/H.SQFT	6.863 W/M^2	0.617 BTU/H.SQFT	1.945 W/M^2

[228] It also does not address the need for more areas for dormitory socialization that do not cause noise problems for one shift or the other.

[229] That is, the domestic hot water (DHW) for both showers and laundry, and the infiltration loads from the building and specifically from the laundry dryers.

Table 8: Building Peak Heating Load (LS-C) for the base case and improved building models for the Summer Design Day (December 19).

	Base case Bldg Peak Heating Load SENSIBLE		**Improved Bldg Peak Heating Load SENSIBLE**	
	(KBTU/H)	**(KW)**	**(KBTU/H)**	**(KW)**
	--------	--------	--------	--------
WALL CONDUCTION	-33.816	-9.908	-2.152	-0.63
WINDOW GLASS+FRM COND	-2.227	-0.652	-0.185	-0.054
WINDOW GLASS SOLAR	4.771	1.398	0.329	0.096
DOOR CONDUCTION	-1.035	-0.303	-0.08	-0.024
OCCUPANTS TO SPACE	6.55	1.919	0	0
LIGHT TO SPACE	0.118	0.035	0.084	0.025
EQUIPMENT TO SPACE	6.834	2.002	0	0
TOTAL	-18.804	-5.51	-2.004	-0.587
TOTAL/AREA	0	-0.001	0.046	0
TOTAL LOAD	-18.804 KBTU/H	-5.510 KW	-2.004 KBTU/H	-0.587 KW
TOTAL LOAD/AREA	0.431 BTU/H.SQFT	1.361 W/M^2	0.46 BTU/H.SQFT	0.145 W/M^2

8), but a Yearly summary is also presented (Table 9).[230]

The results include a number of points. In the summer (Table 8), improvements to the envelope R-value (seen as “wall conduction”) and to the windows (i.e., “window glass+frm cond”) are result in a 90% improvement. Improved windows also reduce solar gain, which might be a negative in some buildings, but with reports of rooms being too hot some days, this is an interesting point to consider, and should inform window shade design. A tighter building would have to address this conflict, as it may likely require less heating to maintain a comfortable temperature.

The heating load for the Winter Design Day has a few significant differences (Table 7). Besides the much larger heat losses, there was no solar gain through the windows (“window glass solar”). Energy savings from improved walls and windows

[230] This dual approach was necessary because the program selected different days for the hourly “snapshot” changed days between the base case and improved design runs (i.e., the Building Peak Load LS-C). One day in the middle of the summer and winter seasons were chosen for their representative weather –not for any extreme winds or temperature.

were 55%-65%, less than those in the Summer Design Day (Table 8). With heat loss through the windows over 90% more than in the summer, it became clear why so many drafty dorm windows are plugged with makeshift insulation panels, lined with foil, or covered with cloth. These heat losses also showed why older, draftier buildings are often shuttered during the winter (e.g., the Coffee House).

The final analysis of the two dorm cases (Table 9) represents loads over the course of a "typical year." These results do not show heat loss but rather the loads requiring electricity (for power and some heating) and JP-5 (for heating). Here, the improved efficiency of the boiler finally appears. Lights and equipment do not change because those schedules are not affected by occupancy sensors or by fewer occupants. Space heating is reduced by a third, but it was not clear why the ventilation fans increased. Externally calculated EEMs, such as improved efficiency in the laundry and water demand, showed a marked improvement, with the power demand for laundry ("LAUND") reduced nearly by half.[231] DHW demand is reduced by one third, and the total building infiltration (includes laundry) is reduced by 20%. The improved case showed a 21% overall savings.

[231] See Appendix O for the details of these calculations.

Table 9: Summary of totals for energy consumption for the base case dorm and the improved version. These represent a yearly total. Numbers below the solid line were calculated separately and included for the total. The savings are 21%.

	BASECASE			**IMPROVED**		
	Electricity MMBTU	JP-5 MMBTU	Total MMBTU	Electricity MMBTU	JP-5 MMBTU	Total MMBTU
AREA LIGHTS	321	0	**321**	321	0	**321**
MISC EQUIPMT	493	0	**493**	493	0	**493**
SPACE HEAT	31	1,425	**1,456**	25	956	**980**
PUMPS & MISC	9	0	**9**	7	0	**7**
VENT FANS	34	0	**34**	41	0	**41**
SHWR DHW	0	68	**68**	0	54	**54**
WSHR DHW	0	85	**85**	0	48	**48**
LAUND	50	0	**50**	22	0	**22**
BLDG VENT	0	1,147	**1,147**	0	918	**918**
LAUND VENT	0	46	**46**	0	36	**36**
	----------	----------	----------	----------	----------	----------
TOTAL	937	2,771	**3,708**	907	2,012	**2,919**

In summary, the energy model validated the Ideal design process by providing another layer of detailed information. For design decisions that are affected by building occupancy rates, outside conditions, and appliance efficiency, the model was able to identify real and specific savings. Although additional detail could be added to the model, the information that was available for the base case was painstakingly gathered from a few disparate locations (See section 7.1). It used real information from the station documentation and from historic documents (i.e., original blueprints). Parts of the model were also compiled from my experience living in one of the dormitories for a few months. Consequently, the results from my energy model are unique.

9. CONCLUSIONS AND FUTURE WORK

What is normal in Antarctica is different than most other locations because of the extreme temperature range, remote location, and profiles of the occupants. As McMurdo begins the process of replacing old and poorly designed structures in the next 10 years, new emphasis should be placed on human comfort which will enhance occupant well-being, productivity, health, and retention.

For the first time, a multi-faceted approach, represented by the design matrix and supported by an hourly energy model, was used to analyze a base case dormitory at McMurdo Station. The matrix highlighted conflicting areas, alerting the designer that a low mark in one area requires extra attention there or elsewhere. This process enabled design decisions to proceed without factors being marginalized or overlooked.

9.1 Conclusions

This study achieved two significant accomplishments. First, it represents the first time a comprehensive architectural history of McMurdo Station has been presented in one volume. Most of the previous analyses and energy reports[232] of the station included a brief overview, but none of the reports assembled as much architectural detail or as many sources. These sources were obtained from several fields of study and represent

[232] For example, DMJM, 2003; Hoffmann, 1974; Ferraro, 2010; RSA, 2008.

both public and restricted[233] information. In addition, I included photographs and personal observations, as well as on-site data of building conditions and station occupant survey responses. These data were collected over two Winfly seasons, covering a time of year when personnel who have spent the winter overlap with new arrivals for the upcoming Mainbody season. The compilation of this information is significant because it is the first of its kind.

The second accomplishment was the creation of a design tool based on this expanded collection of information. The design matrix used here, which is also built on information from many sources across a number of fields of study, provides decision – makers with better insight on how changes to one area of design may affect others. While the matrix is not automated, I hope that one day it will be used as the basis for software that can be used for many design projects (see Section 10). It is significant because this kind of multi-faceted approach (see Section 7) has never been applied to the architectural design of McMurdo Station. A summary of the conclusions from Chapter 7 (Section 7.7) and 8 include:

1. The matrix provided a visual tool to evaluate quantitatively the design factors between a base case and two proposed scenarios (OZ and the Ideal). Final scores indicated a great need for improvement in the existing station (45%). The OZ

[233] For example, information not available online and only in one location, like the U.S. National Archives.

proposed plan offered many improvements (64%), but still fell short of the Ideal scenario (85%).[234]

2. The energy model provided another layer of detailed information that supported the design matrix. For design decisions affected by building occupancy rates, outside conditions, and appliance efficiency, the model was able to identify real and specific savings.
3. Choosing an EEM based solely on the results of an energy model missed important information and may overstate the importance of the energy savings. This resulted not only because of the limits of current energy modeling programs, but because many EEMs are better described from a combination of energy efficiency and human factors, provided in the design matrix.
4. A shift towards a higher winter population will require more design focus on the use of an indoor-outdoor design temperature difference of 106^{o}F. Should plans to increase the winter population come to fruition, there should be an emphasis on EEMs during the colder, dark months, station wide.
5. Laundry rooms in dorms represent a significant percentage of the total energy demand. Sealing these rooms from the rest of the building, or moving them to a separate (but possibly connected) structure may help reduce negative pressurization loads in the dormitories. Not including detailed laundry

[234] In this analysis, a category and overall percentage of: 0-33% = Failed to meet or achieve standards; 34-66% = Met or achieved standards; 67-100% = Exceeded standards.

calculations in a dormitory energy model or building description was a major shortcoming of previous studies.

6. Work shifts and mixed housing complicate ventilation and thermostat set-point scheduling, and occupancy sensors will only solve some of those problems. Further data are needed to understand how set-points could help save energy; these should be coupled with occupant surveys, real-time occupancy information, and occupant education.
7. A large-scale multi-building station makes well-insulated inter-structure connections desirable but also poses a potential safety/fire hazard. The push/pull between these two design approaches has been a challenge across the continent since people first arrived; finding the right balance may prove beneficial to the future of McMurdo.
8. Single rooms are worth the extra cost; however, their worth is diminished if they come at the expense of losing popular socialization and exercise areas. The implication is that large buildings with single rooms will have to be larger still if they include some or all “activity areas.” These areas cannot be reduced or sidelined.

9.1.1 Summary of Guidelines

The Ideal dorm meets the challenge of providing shelter in an inhospitable environment without completely cutting off its occupants from the outside environment. It does so despite dynamic forces like the changing weather seasons and population fluxes (3-4 times per year as well as daily).

1. Dorms –for safety's sake there should be more than one– should be distinct from other places at the station, such as offices, labs, and workshops. They should have a homier, less institutional feel, and be places for both isolation (i.e., privacy) and socialization. As much as possible, human senses should be positively engaged through artwork, color, room personalization, greenery (hydroponic greenhouse), and finish materials.
2. Fire-protected connections between certain structures will allow easier access during colder and darker months. These spaces are not dark and windowless tunnels, but a protected way for station occupants to connect visually with the outside without enduring the more negative effects of cold weather.
3. Small, private rooms should be primarily used for isolation and sleeping, and so should be kept acoustically isolated from building-borne noise, noise from neighbors, and if possible, station noise (e.g., heavy equipment). A small, highly insulated window operable only in emergencies is desirable in every room. The window should be blacked out easily, and the amount of daylight moderated either by the glass or by a shade. All windows should have a view (i.e., not just one that faces the next building over). Lighting systems should enable fine adjustment for the occupant, and should be able to be automatically dimmed or brightened to simulate a more regular sun cycle.
4. Dorms should be monitored automatically, and occupancy sensors (not schedules) turn off lights and allow rooms to cool while people are out working. Interior walls should also be insulated. Dorm systems recover heat when

possible, for example from the boiler or the in-house laundry room, when present. Laundry rooms in dorms are should not draw a large volume of fresh air into the building. Vestibules are also large and laid out to prevent the escape of warm air.

5. Buildings should be robust, well-insulated, and constructed to the highest standards and recommendations for cold regions. Materials and systems must be tested for the local climate conditions and are not experimental, obscure, or difficult to maintain.

9.1.2 Other Observations

A Large-scale Multi-building Station Makes Well-Insulated Inter-structure Connections Desirable But Also Poses a Potential Safety/Fire Hazard

Scott Base has them. Halley Station has them in a fashion. But most other Antarctic stations larger than one building do not have building connections. Structures are generally separated, and people must go outside to enter another building. This is a logical choice when considering the following: for a large-scale station building one large structure takes longer and costs more than dragging in smaller prefabricated structures, and once those structures are in place they must be protected from fire and the spread of fire. Additionally, different building types may not necessarily benefit from being connected, or being part of the same structure (e.g., galley and medical, waste storage and science lab, vehicle repair, and dormitory).

The middle ground is to connect only some functions to each other, never to connect high risk operations (e.g., the power plant), and to blanket the connections with redundant fire safety measures. The caveat is not to design a structure that shuts people off completely from the outside (see “Halley Station” and “Casey Station” in Appendix F). Outside access between buildings is still necessary and allows people the chance to “get outside” from time to time. The connections can themselves be visual breaks between buildings, giving people the feel of being outside (e.g., the view and even the slight decrease in temperature). These connections may not need be limited by labels such as “hallways” or “corridors,” but as larger spaces where one could linger. They may, however, need to be above ground level so as not to cut off parts of the station from access by emergency vehicles.

This design approach would need extensive analysis. It would first have to pass fire code and any recommendations brought forth by people with experience building or fighting fires in Antarctica. An energy modeler would need to consider ventilation rates, probably creating separate zones for these “in between areas.” If none of the previous objections exist, this design would rank highly on the design matrix.

Single Rooms Are Worth the Extra Cost, But Their Worth is Diminished If They Come At the Expense of Losing Popular Socialization and Exercise Areas.

Expanding on a point made in Section 7.7.2, the expansion of single rooms should not encroach on spaces for socialization, regardless of season. Private rooms help solve many problems, most prominently providing extra privacy to those working at the station. Just as important are spaces for group interaction. Relying on the Galley for this is not a solution. Spaces with character, with a sense of history, and with a change of scenery offer a welcome relief from the sometimes relentless daily routine.

For examples, the Galley is an everyday space (three times per day), and while is it is open, egalitarian, and brightly lit, it does not provide the more intimate, less institutional atmosphere of the Coffee House or the other bars at the station, which are physically and visually separate from all living and working areas. In the old Navy days there were designated areas for different ranks. Now anyone can go anywhere, and some of these spaces can becomes very crowded as the station population grows. Limiting these types of places further without replacing them would remove an important source of stress relief at the station. Replacing these spaces without acknowledging why they are so beloved would also be a mistake.[235]

In addition, every opportunity to install places for physical exercise should be taken. These spaces should be easy to access –if there is any function that should be close to or attached to the dorms, it is places for physical fitness. Nosier spaces (e.g., group workout spaces and basketball courts) should be physically separated or acoustically isolated from quieter parts of the building. Other exercise spaces could be more closely integrated with residential functions. Exercise should be encouraged, and easy access to multiple facilities may remove two barriers for those not wanting to go outside to get to an overcrowded gym.

For these reasons, it is important to include these spaces in future plans that feature more single rooms. They cannot be pushed out by the increased number of rooms, and they should not be too closely associated with everyday spaces. They need

[235] The proposal to convert the wood-lined NSF Chalet into the new Coffee House is a positive step, although the building is inconvertibly located on the other side of the station

to feel separate, different, *away* from work and the dorm room, even if they are still located on the same small speck of land as the rest of the station. As stated previously, they should not all disappear during the winter.[236]

Quantifying the effects (i.e., energy usage, monetary) of increased single rooms and the careful upgrading of social areas is beyond the scope of this dissertation. The GreenPlay survey results (see Appendix P) should be mined for information on the types of recreational spaces people prefer, and a second survey may be useful to narrow the results. What is clear is that although these spaces may add to the total energy demand of the station, they should be considered an important part of occupant health and well-being, and therefore given higher priority.

9.2 Future Work

The scope of this dissertation did not include detailed discussions on several areas that could be independent studies on their own, such as the embodied energy in the buildings in Antarctica, the cost of completely redesigning the station, and a detailed daylighting study. Each of these topics would be a fascinating, complex study and should be pursued in the future.

The lack of public information on the history of master plans for McMurdo and how they were created left some questions unanswered, as did the lack of public information about the energy use by individual buildings to maintain a well-lite,

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[236] Spaces kept close to or inside the residential areas would be easier to keep heated and open during the winter.

comfortable environment. While this study attempted to pull together as much information as possible to create a single narrative of these documented decisions, it is still incomplete. Future efforts, such as OZ Architecture has stated, should be publically documented and added to the public history of the station.

Time and logistical constraints prevented more extensive occupant surveys, follow-up surveys, group discussions, and long-term collection of temperature, CO_2, and RH data. With more financial support, an extensive collection of these types of data could add to a more complete picture of the station and its current condition. An online survey could be especially useful if the appropriate measures could be taken to ensure user confidentiality/anonymity.

Group discussions about completed design proposals could be used to provide valuable insight before final decisions are made. Certainly a POE should be undertaken whatever final design is implemented. With more time and more portable temperature/relative humidity data loggers, detailed hourly profiles of each building could help guide future designs. Wireless loggers would allow for more efficient automatic data collection. Such measurements could require leaving the portable data loggers in place longer (in conjunction with the recording of coincident hourly weather, occupancy, and event data) as well as placing them vertically[237] within a space to note thermal stratification.

Specific areas that were mentioned in this study but not fully pursued include:

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[237] That is, a high and low vertical location in the same spot

1. Further study of building form and a snow drifting analysis of McMurdo Station's current location: Evidence exists of this being done for past buildings, but not on the scale of a multi-building station.
2. Further study of the station from the point of view of a resident, not a visitor. Occupant surveys are very useful, but so is a more nuanced perspective coming from designers who have experienced the station for a season or more. Being embedded at the station (not as a VIP) brings a better understanding of the changing dynamics of a typical year, and the typical highs and lows experienced by contract employees and scientists.
3. Further similar studies on other buildings types in McMurdo. This study looked closely at dormitories, but there are also many other building types with specific needs, including recreation (e.g., bars or gyms), offices, warehouses and storage, vehicle maintenance, food preparation (including hydroponic greenhouses), and common (i.e., public) areas.
4. Further study of daylighting designs for rooms and hallways at very high latitudes (i.e., 77^{o}S): as mentioned in Appendix N, the weather file had trouble when used with DOE-2.1E when placed below the Antarctic Circle. High latitudes often pose this kind of problem, and those in the southern hemisphere are sometimes even worse (because of the reversed seasons). A focus on daylighting design would shed light on better ways to control daylighting that enters a building all day and at a very low angle, but doing so would require an improvement to modeling software.

5. A cost-benefit analysis of window-less rooms versus rooms with windows of various sizes and materials (e.g., aerogel): including a more focused look at rooms with no windows, with artificial LED "windows," with the newest quadruple-paned windows, and with the up-and-coming aerogel windows would add more clarity to the decision process.
6. An analysis of the contributions of solar thermal systems to the energy used by station buildings (not just field camps) during the summer months: it is important to understand the contribution of such a resource that is absent much of the year, but is plentiful when the station population is at its highest.
7. Recommendations for water conservation, for example a grey water reuse system for toilets; it is important to quantify the amount of energy saved by reusing some water before it enters the waste water treatment facility, and if this in any way makes greenhouses more feasible.
8. An analysis of the use of hydroponic greenhouses through the station, which includes budget, energy, and moral issues; the greenhouse is very popular with some people, but it is not clear how many would volunteer to manage it, or wish to combine one with a lounge area.
9. An analysis of the embodied energy in the buildings at McMurdo Station (i.e., transporting all people, provisions, fuel, materials, tools, etc., annually to and from the continent); this is a very complicated calculation but one that would help inform decision-makers about replacing or renovating a building.

10. The continuous measurement and public posting of redundant, Class A weather data for McMurdo Station (see Appendix N); as stated many times in this thesis, the absence of such a file is a serious impediment to further studies.
11. The development of a fully automated design matrix in which scores across the matrix change as other inputs change; it is the wish of the author that the design matrix one day be able to be partially autonomous, or that it make use of expert system decision analysis.
12. The development of an energy model that includes water use (i.e., one that includes water use data on toilets, sinks, water fountains, and ice machine use). Actual data would be far more useful than manufacturer estimates, in this case.
13. The development of an energy model that uses real building energy use data (made public) collected by Raytheon Polar Services (RPSC) or Lockheed Martin contract workers; while some data was made available, it was very late in the execution of this dissertation.
14. The development of a detailed energy model of the proposed dorms in the OZ proposal, specifically an hourly model that considers the building envelope, internal convection air flow, and the laundry energy use.

These areas were outside the scope of this study or limited by time and resources. It is the hope of the author that they may one day be fully pursued.

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APPENDIX A

HUTS OF THE HEROIC ERA

Summary

Like most building problems in Antarctica, huts used by early explorers generally suffered from one or more building flaws: draftiness and poor ventilation, thermal stratification, group accommodations and privacy. They were easy to transport and erect but difficult to maintain at a comfortable temperature. In the harsh Antarctic climate the shelter provided by a building is only half the battle: keeping that structure heated requires a constant fuel supply. The image of men burning slivers of their shelter (the *Discovery* hut) to survive is a powerful reminder that without a heated shelter, humans are not adapted for such a climate and can perish quickly.

The most successful hut did the most to achieve a balance. The *Framheim* was allowed to become buried in snow but maintained good ventilation. Its small square footage was alleviated by the snow tunnels, which provided private work areas for the men during the long winter. The inclusion of a sauna was also a welcome addition and big morale booster. The hut was well suited to the climate in that it did not try to be something it was not.

Huts of the Heroic Era (1897-1922)

Both Pearson (1992) and Harrowfield (1995) reviewed Antarctica's historic huts, looking not only at their historical importance and preservation but also construction methods, inspirations, lifespan, and their individual merits and drawbacks according to accounts from the men who lived in them (Table 1). With this information in hand it is possible to gain a better perspective on why these various huts differ in appearance and degrees of success. Each provides valuable lessons that helped pave the way for future explorers to survive the climate and the long, dark winters.

Pearson categorized the huts into three styles: Scandinavian, British, and Australian: **1)** *Scandinavian-style* Antarctic huts had heavy plank walls with cellulose-based insulation, gabled roofs with lofts, no verandah, oil-burning lamps, and a spatial organization that did not separate enlisted men from officers (“egalitarian”); **2)** *British-style* huts had timber frames clapped with weatherboarding and insulation, gabled roofs without lofts, protected entrances without a verandah, acetylene lighting, and a spatial organization that separated the party leaders from the enlisted men, if not all the officers from the men; and **3)** *Australian-style* huts had timber frames insulated with felt or cork, a pyramidal roof over a large square area, a verandah on three sides, framing posts sunk directly into the ground, and a spatial organization that separated the party leaders from the enlisted men.

Scandinavian Style

Both Borgrevink and Amundsen’s huts were prefabricated in Norway, with components numbered and disassembled for easy reassembly once in Antarctica. Both included saunas, another Scandinavian import. Each used layers of thick planks attached to frames, layered with extra boards attached to battens, and insulated with either *papier mâché* or another cellulose-based material (a recent technological innovation in

Scandinavia). Borgrevink's huts were of interlocking sections of Norwegian spruce, a typical Scandinavian style. The outer faces were rounded and the planks "were half-notched at the corners in a traditional Norwegian plank construction" (Pearson, 1992, p. 262). Both huts featured a loft and were heated by stoves. The wall construction of these Scandinavian and Arctic-inspired styles worked well, but only to a point, since Borgrevink's shelter was not able to balance insulation and ventilation for a comfortable and stable interior air temperature (Pearson, 1992). This proved to be a crucial lesson in construction and ventilation techniques.

The camp at Cape Adare was the first permanent building in Antarctica (Figure 12). Its occupants, the *Southern Cross* expedition led by the Norwegian Carsten Borgrevink, spent the winter there from 1899-1900, the first men to do so.[238] The tongue-and-groove boards used for constructing the huts were cut from either side of the heart of a tree, resulting in substantial thicknesses (2.4 – 2.8 inches). They were held together by steel rods inserted into pre-drilled holes (Pearson, 1992, 262). This would have saved construction time at the camp site. Entrances were small and low, no more than a sliding trap door (Harrowfiled, 1995). This type of door must be well placed or dug out frequently if placed such that it experiences extreme snow drift. Additionally, the men hung furs on the walls of the living huts for extra insulation and to reduce cold drafts of air (Pooley, 1999).

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[238] Although these men were the first to winter over on the continent, a Belgian Antarctic Expedition sailing on the *Belgica* had unintentionally wintered over the previous year aboard the ship. Among the multi-national crew was Roald Amundsen who was marked by the experience, noting the importance of proper planning, ventilation, accommodations, nutrition, and good morale in Antarctic expeditions.

The terrain may have been rugged and the air cold and clean, but inside the huts it was "cramped, stuffy, and dirty" (Harrowfield, 1995, p. 13). Everyone slept in the living hut: 10 men occupying less than 400 ft^2. Each man had a bunk, and some were fitted with drapes for some visual privacy. Besides the bunks, a single large table and coal-burning stove completed the living quarters. The air quality was frequently poor, especially as the winter wore on. The small room may have been easier to heat, but its confined quarters took a toll on the men, who were happy to leave Antarctica after their year-long stay.

The party used Siberian sled dogs[239] for transport and a Primus stove, a recent Swedish invention, for cooking.[240] Snow drifting up against the side of the building provided some protection from the wind and extra insulation, and it was here that one of the expedition members built a sauna, no doubt a welcome form of relaxation and warmth for the party. The snow drifts also provided a sheltered place to kennel the dogs (Harrowfield, 1995, p. 14). Snow, one of Antarctica's few natural resources, can be a very good thermal and acoustic insulator, and in some cases it is possible to take advantage of its protection.

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[239] Sled dogs continued to be used in the Antarctic –notably on Amundsen's successful trek to the South Pole in 1911- until the mid-1990s all dogs were removed from the entire continent. Under the provisions of the 1991 Protocol on Environmental Protection to the Antarctic Treaty no foreign species are allowed on the continent (U.S. Department of State, "Protocol" Art. 3, 1991). Keeping the dogs meant not only that the local seal population was possibly exposed to canine distemper, but also that 60 seals were harvested each year for dog food. Now all transportation is by gas-or-diesel-powered vehicle, a method that carries its own somewhat less offensive forms of environmental contamination.

[240] Invented in 1892 by Frans Wilhelm Lindqvist, the Primus is a smoke-free, kerosene-based, portable cooker. It became a popular item for adventures and explorers: Mallory, Amundsen, and Hillary and Norgay all carried one on their famous expeditions. (www.primus.eu, "All round the world.")

Unlike all the other huts mentioned here, Amundsen's hut, called the *Framheim,*[241] was located on an ice shelf, not solid ground (Figure 13). As a short-term residence (one year), its location proved to be an advantage because it was quickly buried in snow, an excellent insulator from cold and noise (wind). A series of snow tunnels extended the area of the shelter (from 325 ft^2), allowing the nine men some extra room and privacy. This was "important to the psychological well-being of the party, a factor which Amundsen was very conscious of after his experience on the *Belgica*" (Pearson, 1992, p. 265). Amundsen's telling of the polar expedition indicates the design of the hut (and the presence of a sauna) contributed to the psychological and physical wellbeing of the party.

The area was divided into two spaces, one for bunks and a dining table, the other for cooking; above there was a storage loft. The table in the main room could be raised to the ceiling for cleaning or to provide extra room. The thick walls were heavy timber planks with cellulose pulp insulation; the roof was covered in tar paper, while the floor had a layer of linoleum (Pearson, 1992, p. 264). There may have been one or two windows, but once the structure was buried, they no longer would have provided visual connection to the outside.

To Amundsen's credit, the *Framheim* was one of the only examples of early historic huts to feature a well-planned, functional ventilation system (air intake and separate exhaust). This system, combined with the wood plank sandwich walls, the extra snow insulation, and ample heat from a kitchen stove helped make the interior

[241] Named after the ship which bore them to their destination, the Fram.

reportedly one of the most comfortable of historic huts: warm, dry, and supplied with fresh air all winter. It is also described as the most thermally efficient hut (Pearson, 1992).

Amundsen's hut and successful journey to the pole featured important construction, logistic and quality of life designs issues that make Antarctic living easier: 1) construction and transportation methods suited to the climate; 2) comfortable accommodations that provided a clean air, a stable interior temperature and a modicum of privacy; 3) access to hot meals; and 4) living and work areas that promoted camaraderie and group cohesion. In contrast, the *Southern Cross* expedition exposed a few problems when living in such harsh conditions. For example, with frequent bad weather (including high winds), the men spent long periods inside the small hut and reported that they suffered from boredom during the long, dark winter. There were problems with inadequate ventilation, as there was no system in place; in one incident it was only by luck that they did not asphyxiate.[242] This can be a problem in well insulated buildings; additionally, when a building becomes buried by snow, all openings can ice over, creating an airtight enclosure, which is dangerous to the inhabitants. Therefore, snow-free vents and trap doors in ceilings for escape become important survival precaution.

Another problem reported at Cape Adare was the constant threat of fire; one incident almost destroyed the living hut and made clear the need for compartmentalized

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[242] A change in wind direction caused the stove vent to cease working, filling the hut with poisonous carbon monoxide.

construction and emergency supplies. Morale was generally low, in part because of a death during the 1899-1900 winter[243] and personality problems stemming from Borchgrevink's poor leadership skills (Harrowfield, n.d.). Still, the expedition further proved that people could survive the Antarctic winter, something necessary for proper long-term planning and logistical preparation for Antarctic journeys.[244]

British Style

British-style huts were constructed of timber frames clapped with weatherboarding and insulation such as felt or Gibson Quilt,[245] gabled roofs without lofts, protected entrances but no verandah, acetylene lighting, and a spatial organization that separated the party leader from the men, if not all the officers from the men. Two examples of this style include the buildings built by Shackleton in 1910 and Scott in 1911. While these structures have withstood the test of time, they were not especially efficient or comfortable places for spending the winter (Pearson, 1992). Unlike Norway and Sweden, the British had little previous experience with Arctic conditions; however, they did have experience manufacturing prefabricated houses to export to their colonies, and this might have influenced the design of these Antarctic huts (Pearson, 1992, p. 273).

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[243] Hanson, a young biologist, died of an "…occlusion of the intestine," possibly scurvy or beriberi (nutritional deficiencies are common on long voyages) and in 1899 became the first person to be buried in Antarctica (Harrowfield, 1995, p. 14 and 17).

[244] This is in part because of the amount of time it took just to reach the continent from anywhere else, and also a function of sea ice conditions and weather. The sea ice had to break up before the ship could approach the land. By then only a few weeks of "summer" remained. By staying through the winter, the men could set depots, plan, and prepare for their journey ahead, once the sea ice reformed and the dark of winter retreated.

[245] This is finely shredded seaweed between two layers of hessian (jute) (Pooley, 1999).

Shackleton's hut at Cape Royds [246] (Figure 14) and Scott's hut at Cape Evans[247] (Figure 15) are each excellent examples of the British style of Antarctic huts. Each hut took advantage of snow drifts against the buildings for extra insulation, as well as extra air space provided by stacked provisions or the presence of pony stables. Inside the hut at Cape Royds, conditions were cramped, but with the benefit of being easier to heat. Shackleton had his own area as captain while everyone else slept in two-man cubicles with improvised curtains for privacy; some spaces ended up covered by artwork and outfitted with drawing desks. There was also a small lab area for specimens and a darkroom for photography (Harrowfield, 1995, p. 38). This setting is well preserved today, and one can visit the hut to get a sense of what life might have been like for the men on the expedition (Figure 18). Outside the front door was the world's southernmost Adélie penguin rookery at the edge of McMurdo Sound, and behind the hut there was a clear view of the Mt. Erebus, the active volcano on the island.

Scott's hut at Cape Evans was similar to Shackleton's. On his second Antarctic expedition, Scott designed his Cape Evans hut to be the primary shelter for the winter-over party, and more care was taken so that it would be suitable as a fully functional

[246] Before leaving home Shackleton promised Scott he would not enter the McMurdo Sound area, Scott having laid a proprietary claim over the entire region. However, ice conditions prevented Shackleton from landing in the alternate location he had chosen and he ended up back on Ross Island, just a few miles from the Discovery hut.

[247] About two years after Shackleton's 1908 Nimrod expedition, Scott sailed back to Antarctica, intending to make use of his first hut for his second trip to the Antarctic. Upon arrival Scott, aboard his ship the Terra Nova, found that the ice formation prevented any further progress south towards his old base at Hut Point. He chose instead Cape Evans, previously labeled as the Skuary for its population of skua birds, and there he built another hut to live in during the winter.

winter camp.[248] Its location was chosen by Scott and the expedition's carpenter, who noted of the ground "'[t]he surface was like cinders, quite loose, but a few inches of below it was frozen solid. This formed a good foundation'" (Harrowfield, 1995, p. 43). The building was about 48 x 24 ft., with a central ridge 14 ft. high, and a makeshift stable for the ponies on the north side. The hut accommodated 25 men from January until the following summer when a field party attempted to reach the South Pole.

The interior space was divided into two main areas by boxes of supplies, one side for the 16 officers and the other for the nine enlisted men: the way a ship would have been designed. The men slept on cots or bunked beds, sometimes with curtains hung around them for additional privacy. As was common on British expeditions –especially ones led by Scott– the captain had his own corner of the hut, physically and visually separated from the men. This was important in maintaining authority, an idea well established with the British Navy, which had many years of experience dealing with crews in sustained periods of dangerous and confined conditions (i.e., in ocean-going vessels).[249] This tradition of order, discipline, and strong leadership[250] which can make or break any expedition, appeared again 44 years later during the early years of McMurdo Station, when it was initially a U.S. Naval station.

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[248] In 1901 on his first Antarctic expedition, Scott built a shelter at Hut Point which he ended up using as a backup shelter rather than a full-time residence.
[249] Indeed, even in makeshift emergency shelters this tradition was revered. When Scott's Northern Party was unexpectedly forced to winter on Inexpressible Island in an ice cave with less than 6 feet of clearance, "…an imaginary line separated officers from men" (Harrowfield, 1995, p. 29). It was here, in a space 12 x 9 ft. imbued with seal blubber smoke they spent the winter, never bathing, and enduring "bouts of depression brought on by hunger, poor hygiene, cold and the cave's gloom" (Harrowfield, 1995, p. 31).
[250] Or, as Smith (2005) put it, "… class structures and hidebound rigidities …" (p. 46).

Australian Style

Australian-style huts were constructed of timber frames insulated with felt or cork, a pyramidal roof over a large square area, a verandah on three sides, framing posts sunk directly into the ground, and a spatial organization which separated the party leader from the men. Two examples of this style include the buildings built by Scott in 1901 Figure 15) and Mawson in 1911 (Figure 17). Pearson (1992) noted that while Australia had no experience with cold climate construction, they were good at producing lightweight, prefabricated buildings that were strong enough to withstand cyclones, that used air spaces as an insulator against heat, and featured air-tight construction to help keep out spindrift and dust. These two huts are essentially transplanted Australian outback houses, with a verandah on three sides, a large overhang to keep the sun off the walls, and lots of windows and skylights. Interestingly, with a few modifications, this type of building could be suited for the Antarctica climate. Mawson's hut exhibited these modifications, resulting in much greater success (thermally) than the Scott's hut.

Scott's hut, now preserved at the tip of what he named Hut Point Peninsula, remains to this day a symbol of early discovery and lessons learned about building in Antarctica.[251] Completed in less than six weeks, the hut's primary purpose was as a backup shelter in case the ship, where Scott and the crew lived, was suddenly blown out to sea or made inaccessible –an important early example of the compartmentalization of

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[251] This is due in part to its proximity to the well-visited McMurdo Station.

supplies.[252] This structure was the forerunner to Mawson's hut, with a square shape and pyramidal roof. Scott did not cover the sides of the verandah but he did pack it with crates of supplies (Pearson, 1992), a less effective strategy for thermal insulation. He did not modify the number of windows; there were seven double-glazed windows and six skylights, which during the short summer months could have allowed light into the room (possibly saving on fuel) but would also have been a major source of heat loss. For heating, two stoves were provided but only one was installed: another mistake as it was inadequate to keep the space warmed, and the men were more comfortable in the ship's bunks despite the formation of frost on the walls all around them (Harrowfield, 1995, p. 34).

The foundations were relatively deep. In the account of his first Antarctic voyage, *The Voyage of the Discovery*, Scott wrote of the hut that

> …its erection was no light task, as all the main and verandah supports were designed to be sunk three or four feet in the ground … but an inch or two below the surface the soil was frozen hard, and many an hour was spent with pick, shovel, and crowbar before the solid supports were erected and our able carpenter could get to work on the [wood] frame. (Scott, 1902, p. 216-217)

[252] This was one "adventure" endured by a few of Shackleton's men on a later expedition; the ship became unmoored during a storm, marooning some men on the land and confining others to a months-long drift back to New Zealand.

The icy soil of Ross Island remains an obstacle to foundations and drilling to this day, with the choice method of excavation a few sticks of well-placed dynamite (e.g., 1.5-4 lb. sticks) in rows of pre-drilled holes.[253]

Luckily on this expedition it was never necessary to rely solely on the hut for shelter; mostly it was used for drying seal pelts, skinning birds, repairing equipment, and staging occasional theater productions[254] (Harrowfield, 1995, p. 34). These productions were one of several ways the officers and men entertained themselves, and Scott believed they were important for overall morale and health of the crew.

The *Discovery* hut (Figure 16) is generally considered the least successful of the Historical huts, since it was never used as a shelter until Shackleton's famous *Endurance* expedition,[255] whose members passed in it several long, uncomfortable months. That they lived, but not well, shows just how thermally inadequate the building was and how, in its unmodified form, the Australian "verandah house" was highly unsuitable for such a drastically different climate. The building provided shelter, but it was not a pleasant stay. With little to occupy the time, focus turned to talk of food, a custom noted by the leader of the group (Harrowfield, 1995, p. 35). This habit can be observed even in today's modern stations, when for some, the only change in daily routine is the menu from which certain items are conspicuously absent. In addition to cramped quarters in the hut, the interior air quality deteriorated when the supply of candles ran out and the

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[253] For decades, Seabees used dynamite, power drills, and giant blowtorches to reshape the landscape (USN, 1968, p. 36). See also Minneci, 2000.
[254] Its alternate name was "'The Royal Terror Theater.'"
[255] The 1914-1917 Imperial Trans-Antarctic Expedition

men turned to burning seal blubber for light and heat. Unfortunately, burning seal blubber is not only odious but leaves a greasy film on everything: walls, clothing, skin, everything. Over time the interior of the hut turned a sooty black (Harrowfield, 1995, p. 35). When the hut was once again used by the same expedition roughly a year later, conditions were no better, and with the supply of seal blubber running low, the men had to hack pieces off the very building sheltering them from the cold to burn for heat.[256]

Mawson's hut, built towards the end of the Heroic Era, was of a similar style to Scott's *Discovery* hut, but with some important modifications. Located at Cape Denison, it endured incredibly high winds[257] and problems with snow infiltration. The fact that it still stands its current condition[258] is testament to its construction. The pyramidal roof over the square living space was very structurally stable, something Mawson had stressed. It might have made the building harder to keep heated, but it provided better indoor air quality with more air space (acting as insulation) both inside the walls and above the inhabitants.

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[256] In 1956, after decades of solitary neglect, the Discovery hut was declared "… a shrine and monument to the human endeavor …" by the U.S. Naval Commander in charge of Operation Deep Freeze, Rear Admiral Dufek (Harrowfield, 1995, p. 36). Taking anything from it or even approaching the building without permission or was prohibited. The U.S. had just established a temporary base (in a few years it would turn into McMurdo Station) very close to the hut and had already pitched tents, bulldozed, and retrieved historic souvenirs from the site. Today, it is even more protected; the large fuel tanks that were originally located nearby have been removed and the area nearby is also no longer scraped for snow. The use of heavy vehicles near the building may have led to some uneven settling of the building. However, on the whole, after some minor restoration work, the hut is today "relatively sound," and a popular place for people at McMurdo Station to visit (Harrowfield, 1995, p. 36). Despite the view from the tip of Hut Point (to the sea ice and beyond, the Transantarctic Mountains), the building remains a dark, bleak space to visit before returning to the relative comfort of a heated dormitory room or recreational center.

[257] During Mawson's stay at Cape Denison, he and the men recorded an average wind speed of 60 miles per hour in April, with gusts to over 200 mph. These "Herculean gusts" known as katabatic winds are described in his account, *Home of the Blizzard*.

[258] Still standing, cleared of snow drifts, and able to receive small groups of tourists every year.

Another modification was the verandah, which was typical of the style but this time enclosed with boards. This created a large space of still air next to the walls of the hut, a minor thermal advantage, but one that also made the hut less drafty and less permeable to snow infiltration. When the building was nearly buried by snow it became even easier to keep the interior heated (Pearson, 1992). The tight construction performed moderately well in keeping out fine snow and grit. Additionally, Mawson reduced the number of windows in the design. Although one of the smallest huts (in terms of living area per person) during the Heroic Era, it was considered generally comfortable and well built, which is more than can be said of the Discovery hut.

APPENDIX B

MCMURDO STATION GROWTH AND DEVELOPMENT SINCE 1956

NAF McMurdo Sound (1956-1961)

The U.S. was late to commence Antarctic exploration but was able to utilize the wealth of experience gathered by earlier explorers from other countries. Since the mid-1950s the U.S. has invested an enormous amount of time, energy, and money in establishing a continuous Antarctic presence that was in part a strategic military response to the Soviet Union during the Cold War in the years immediately following WWII (Belanger, 2006; Collis & Quentin, 2004, p. 4). The much sought-after prize was a presence at the geographic South Pole, which was finally achieved in 1956. The logistics for this operation were only possible with an impressive show of manpower, air and naval support, and the construction and maintenance of a critical logistical hub located along the coast: Little America V on the Ross Ice Shelf.

Admiral Richard Byrd, a naval officer and a veteran of Arctic exploration, had led early expeditions to Antarctica, establishing temporary “Little America” bases from the late 1920s to the outbreak of WWII; these helped pave the way for eventual long-term occupation by the U.S. Post-war Antarctic expeditions to explore and establish more permanent bases were logistical achievements executed by the USN. Admiral Byrd helped organize the first of these operations, Operation Highjump (1946-1947), which “…was then (and remains) by far the largest Antarctic expedition, with more than

4,700 naval and marine personnel, 44 observers, 13 ships, and a number of aircraft…" (OPP, 1997, p. 17). One of the goals[259] was to determine the feasibility of establishing a permanent ice base, "Little America IV," for scientific research during the International Geophysical Year (IGY) (Hoffman, 1974, p.1). After a second expedition[260] collected more aerial photographs of the coastline –an effort that aided in the final decision of where to locate a permanent station– Byrd led the first Operation Deep Freeze in 1955, which in December established Little America V and six other stations,[261] including the first buildings of the Naval Air Facility, McMurdo Sound[262] (NAF McMurdo) (Figure 35).

The NAF at McMurdo Sound and other bases erected as a part of the IGY were essentially temporary military field camps (Collis and Quentin, 2004, p.5). Documents from 1955 and 1956 indicate that in the first years of Operation Deep Freeze, NAF McMurdo Sound was neither a prominent research station nor a high-priority logistical hub[263] (NRC, 1957). It was important as an emergency landing point between other American bases, but Little America V was better positioned in relation to the pole and, being on the edge of the Ross Ice Shelf, it was easier to access by ship. It and other

[259] Collis, citing the U.S Navy's Development Project (1946-47), notes that other goals of Operation Highjump included "'training personnel and testing material, consolidating and extending U.S. sovereignty over Antarctica areas, investigating possible base sites and extending scientific knowledge in general,' but also 'prepar[ing] the U.S. military to fight the Soviet Union in polar conditions.' Specified instructions included 'develop[ing] techniques for establishing and maintaining air bases on the ice, with particular attention to … later applicability … [in] Greenland'" (Collis & Stevens, 2004, p. 2). Camp Century is the most relevant example of Navy Bases in Greenland (see Appendix C)

[260] Operation Windmill, 1947-1948.

[261] Byrd, South Pole, Ellsworth, Wilkes, Halley, and NAF McMurdo Sound (Figure 33).

[262] Archibald McMurdo was a lieutenant on Ross's expedition aboard the Terror.

[263] A shift in logistical operations placed more importance on NAF McMurdo Sound than Little America, but because the former was sited so closely to New Zealand's Scott Base, little or no science was planned for it (a policy that obviously has since changed) (Belanger, 2006, p. 35).

stations were supplied with more scientific equipment and accommodated more scientists.[264]

The 1956 layout for Naval Air Facility, McMurdo Sound, was a typical military grid roughly aligned along two parallel "main streets," with a parade ground on one end and a makeshift chapel on the other (Figure A- 1, Figure A- 2).[265] There were roughly a dozen buildings accommodating approximately 130 men in all. It was not until conditions on the ice shelf proved "unsuitable"[266] that NAF McMurdo Sound –built on the rocky shores of Ross Island, not an ice shelf– began to look more feasible for long term occupation.[267] The focus shifted away from Little America. No longer just an airfield, NAF McMurdo Sound was renamed McMurdo Station in 1961 (Lagerbom, n.d.; NRC, 1957).[268]

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[264] By 1961 Little America V was " … on stand-by because it is unsafe" because of the weight of the snow that had drifted on top of it (Tyree, in Dempewolff, 1961, p. 106).

[265] To some this layout is unintentionally symbolic, with two memorials to fallen explorers on either end of a line that runs along the "main street" and the chapel. "The chapel's siting links god, landscape, and human intervention, sanctifying American colonialism" (Collis & Stevens, 2004, p. 3).

[266] During the IGY preparations, the Navy "…refused to use the advancing ice shelf at Little America as a staging area for the South Pole, since compacted snow runways could not support heavy wheeled aircraft" (Belanger, 2006, p. 35).

[267] The Hut Point Peninsula, an 11-mile volcanic extrusion of Ross Island, was deemed the best location from which to service and supply the South Pole, even if it had to be done by air instead of overland caravan routes. The site of Little America V, an iceport known as Kainan Bay, was eventually determined to be too unstable to support long-term resupplying. In contrast, the relatively ice-free tip of the peninsula had Hut Point (where Scott's Discovery Hut still stands), a natural harbor (Winter Quarters Bay), and proximity to both a permanent ice shelf and seasonal sea ice thick enough to support large cargo planes (Hoffman, 1974, p. 1). Looking back, it seems a natural location for a long-term logistical hub, but McMurdo Station was not conceived this way. The site at Little America was probably chosen in deference to Admiral Byrd, who had chosen it based on Amundsen's experience, but also for geopolitical purposes (Belanger, 2006, p. 35)

[268] In the NRC document, NAF McMurdo Sound is described thusly: "The Naval Air Facility … serves primarily as the base of operation for the air-lift to the Amundsen-Scott South Pole Station and the long-range air supply of Byrd Station. It is used extensively for aircraft maintenance and support and as a communications and meteorological center" (NRC, 1957, p.3).

The earliest buildings built by the USN on Ross Island were metal Quonset huts and prefabricated panelized huts (Figure A- 3, Figure A- 4). Designed for military defense forces working in many different climates, these buildings were easy to erect and modify to specific site conditions or programmatic needs. Quonset huts in particular were well suited to the demanding weather conditions in the Antarctic, provided they could be fitted with extra insulation, and with the end of WWII and the Korean War (1950-1953), there was a surplus of these structures. Soon to follow was another type of hut, a boxy structure known as a T-5, Arctic prefabricated panelized wood hut . It arrived in palletized modules and could be assembled quickly and customized. These types of structures made up the majority of the station's first buildings. For more information about the early buildings of McMurdo Station, see Appendix C.

Although some today hold an affinity for the distinctive shape of the Quonset hut, these early buildings were made neither to last nor leave a lasting impression. Their exteriors are unremarkable to those unfamiliar with their history. Their mission was to provide a heated shelter to the men participating in Operation Deep Freeze,[269] and be easy to transport, erect, and disassemble. Today we characterize these structures as drafty, crowded, and offering little or no privacy, but at the time they served well and got the job done.

Each building was separated in order to reduce the threat of a spreading fire, but still close enough to allow men to move conveniently among them in cold weather and

[269] At the time it was unknown how long this operation would last: a year, a few seasons. It was not known that the station would still be there over sixty years later.

be seen easily in low-visibility conditions. The layout was a variation of the more typical subnivean naval station, which tended to be physically connected and branching off a single, long axis corridor (Figure A- 5, Figure A- 6, Figure A- 6), see also Section 2.2.1). (For a brief discussion of subnivean living, see Appendix D). The main roads formed two parallel “main streets,” with a parade ground at one end, the main barracks, a communications building, and a mess hall in the middle.

The access corridor in McMurdo was not a protected structure, but more like an open “street.” Unlike stations out on the plateau or ice shelf which became buried within a matter of months, McMurdo was on solid ground, in reality a tiny spec on the shores of a massive volcanic island. Even in the early days of the station, the NCEL manuals on Arctic T-5 assembly and layout directed users to orient the longitudinal axis parallel to storm winds and perpendicular to East and Northeast prevailing winds in order to prevent (or reduce) snow accumulation against entrances (Sherwood, 1964a; Sherwood 1964b; Naval Civil Engineering Laboratory [NCEL], 1957) (Figure A- 8). At the naval air facility, it appears that this guideline was generally followed, and either by chance or by manpower, the natural grade of the coastline was nearly perpendicular to the prevailing wind direction.[270]

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[270] Today, snow accumulation is a problem in McMurdo, but not as critically as in other locations. Bulldozers scrape the roads clear, but the buildings are elevated only a few feet off the ground[270] and are generally not designed to be aerodynamic. Even without the large snow accumulation, it is important for fire safety reasons to keep the roads clear and large snow drifts to a minimum between the dozens of buildings (see Appendix J).

Barracks, socialization areas, and even latrines in NAF McMurdo Sound were segregated by rank; in the galley officers ate separately from Chiefs[271] and enlisted men.[272] There were also three separate bars for socializing.[273] Collis and Quentin describe the facility as essentially a "…pragmatic…" naval establishment with "…tidy…" rows of Quonset huts and prefabricated buildings, yet with traces of colonialism in its inclusion of familiar social institutions and its layout (Collis & Quentin, 2004, p. 3).[274]

Despite the extensive mission and the high costs of perceived "non-essential" buildings, the USN still understood (and researched) the need for immediate access to reasonable comfortable quarters and more than just basic survival conditions for the men and officers (Sherwood, 1964a, p. 1). Rear Admiral Dufek noted this when reflecting on his years heading Operation Deep Freeze. Writing of things learned during his first year, he wrote that while preparing for the second operation, he decided that, "[f]irst to go up would be the barracks and mess hall. Last year's experience taught us that the sooner the men begin to live comfortably, the faster the rest of the work would go" (Wilson, 1956, p. 109). This is good advice in any setting, but it becomes even more urgent under extreme circumstances, such as extremely cold temperatures.

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[271] As in Chief Petty Officers and other chiefs who were not full officers.
[272] McMurdo would not see its first female [scientist] until 1970.
[273]The Galley was divided in the "E-side" and "O-side" for enlisted men and officers. Scientists were able to move freely between all of these places, including an unofficial fourth bar set up by the pilots and crew who flew the flights in and out of McMurdo Station. These class distinctions no longer exist officially, but people still tend to create their own groups and status symbols.
[274] Layout, i.e., the East-West axis that runs (roughly) from the memorial at hut point, Scott's hut, the flagpole, Main Street, the Chapel, and Observation Hill with its memorial cross.

McMurdo Station: 1961-1971

By 1961 most nations began to scale back their activities on the continent; in contrast, this was the beginning of a period of growth for the recently renamed NAF McMurdo Sound (Collis & Quentin, 2004, p. 4). The USN issued a plan for the station titled *Preliminary Study for Reconstruction and Improvement of U.S. Naval Air Facility, McMurdo, Antarctica*[275] (USN, 1961). According to the document, the station would grow to 58 buildings, accommodating up to 1,500 people in the summer and 500 in winter; it would be large but compact, with facilities close to those with related functions, and would include a central, all-purpose building in the center (Klein et al., 2008; DMJM, 2003 p. 3-4).[276] The addition of a nuclear power plant in 1962 helped provide power and potable water for the growing population (see Section 5.2.4). Unfortunately, Klein et al. (2008) notes, with the exception of a station core building and a few warehouses, most recommendations in the 1962 plan did not come to pass.

The first large building constructed –the steel-framed, 68,000 ft^2 station core facility with the illustrious title "Building 155"– dominated the center of the station, replacing several smaller structures and providing access to food, housing, and recreation in one building (Figure A- 10, Figure A- 9, Figure A- 11, Figure A- 12); it

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[275] This is mentioned in Klein et al. 2008 –in which he cites "ASA, 1999." However, the original document could not be found. Hoffman (1974) describes an "extensive redevelopment program" at the station once it was determined McMurdo Station would remain permanently after the successful IGY. This perhaps describes the 1961 Preliminary Study, but that fact cannot be proved at this time. If so, as Hoffman continues, one part of this initiative included replacing the temporary Quonset huts, Jamesway huts, and some of the T5 huts with more substantial structures that had heating and ventilation systems designed to improve comfort (p. 5-1).

[276] It called for more buildings for various scientific fields, including buildings for geology, atmospherics, and biology.

maintained the line of the two main streets but also changed the dynamics of the layout, with its large mass creating a barrier in the middle of the station (Figure A- 13, Figure A- 14, Figure A- 15).

By 1969 with or without the guidance of a LRDP, McMurdo Station had grown in scope and scale. At this time there was still a distinct military feel to the station despite a growing scientific program. The USN was still in charge of operations. Officers and enlisted men, along with scientists, ate in segregated areas in the "galley" (Figure A- 17), purchased candy bars in the "ship's store," and slept up on the second "deck" of 155. Terms like this still decorate the lexicon of the station, and in a way it feels like McMurdo is still transitioning from its historic naval roots. Here, change often comes slowly.

McMurdo Station: 1971-Present

While most accounts list the year 1972 as the time when control of the station was handed over to the NSF, it was actually a series of events spanning several decades, not a single point in time.[277] There is no clear-cut date for the handover; the transition away from the military leading the way and supporting the scientists was not officially completed until 1998, and today there are still Air National Guard pilots who fly LC-130s and C-17s on and off of the continent[278] (Figure A- 16). The reason for the shift

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[277] Just as most human events in the Antarctic, it took several years to finalize.
[278] These personnel and cargo flights are the main means of egress to McMurdo Station and South Pole Station (see Appendix Q). Palmer Station is generally accessed via ocean-going vessels, a trip of several days crossing the Southern Ocean with its wild, unimpeded waves.

away from Department of Defense (DOD) involvement appears to have been monetary. Each new private contractor has since taken on more responsibilities, including logistics, planning, hiring, and the development of long-range development plans (LDRP). For these reasons, there is little evidence of a dramatic change in direction in the way architectural, engineering, or planning projects were handled at McMurdo Station in 1972. (For more information about the transition from the USN to the NSF, see Appendix E.)

For several more years, despite an increased presence of private contractors, much support was still provided by the USN. It was the NCEL –not the first private contractor, Holmes & Narver[279] (H&N) – that in 1974 released an engineering manual for McMurdo Station (see Section 2.2.2).[280] The manual was intended to serve as a record of information gathered from years of research and experience which the USN had acquired. It described "…the terrain and environmental features in the vicinity of McMurdo Station … and present[ed] engineering methods and operational procedures for working within these natural constraints" (Hoffman, 1974, p.1). The manual included information on subjects ranging from working and building on the ice shelf to the properties of snow and permafrost, to the design and maintenance of station buildings.[281,282] There was even a brief history of the founding of the Naval Air Facility

[279] H&N was a subsidiary of Ashland Oil Company, based in Kentucky. H&N's headquarters were in Orange, California.
[280] See also Easton, 1969.
[281] At the time this still meant T-huts and Quonset huts. Most of the information had to do with foundations, heating set points, drainage, and the proper method to mix concrete. The results of the NCEL report on Portland cement in Antarctica are included in this Engineering Manual.

and its new designation as a permanent Antarctic station. This was not, however, a master plan. As the firm that designed the main science lab for the station wrote,

> [a]lthough technically successful in its purpose to establish a building standard for the station, the manual was not intended to address a comprehensive plan for the station's development. The functional needs of the building inhabitants, infrastructure, and esthetics were given a low priority, as can be seen in the expanding chaotic collection of metal building forms connected by elevated utility lines and pipes that finally resulted from the implementation of the manual in the absence of a station master plan (Ferraro Choi, 2010, Ch. 7).

It was a record of hard-won knowledge about building and working in McMurdo Station, and served as documentation of the often complex chain of events that led to the station's current state.[283]

Pushing the station towards a more permanent presence, it also recommended a transition to a metal version of the T-5: a "…steel clad three-inch insulated panel without any metal fasteners extending through it … [with a] coated steel vapor barrier at its interior side [to prevent] moisture penetration (Hoffmann, 1974, p. 5-1). It also allowed greater variation in the interior designs than the previous T-5 model. These structures were known as Robertson Buildings, and by 1968 they were considered the

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[282] "It should be noted that Antarctica, unlike the Arctic, does not generally have deep soils or permafrost. Thus, 'frost heave' which commonly affects historic Arctic buildings (such as traditional Siberian buildings) is not evident" (Hughes, 2000, p. 277).
[283] As time passes, more details are omitted, sometimes leading to chronological jumps or gaps in the story about the station's founding.

"… principal Antarctic structure, [having] been used to satisfy a wide variety of needs" (USN, 1968, p. 36) (see also Appendix C). The change to metal buildings was another step towards making the station more permanent.

The 1974 NCEL report changed the face of McMurdo Station, but as it was an engineering proposal and not a long-term comprehensive plan for a scientific community, the station survived but did not age well (Figure A- 18). As one of the architects who designed the Crary Science lab noted,

> … the [NCEL 1974] manual was not intended to address a comprehensive plan for the station's development. The functional needs of the building inhabitants, infrastructure, and esthetics were given a low priority …. The station's complexion became an affront to the serene beauty of the Antarctic and an embarrassment to the United States when the news media began to report on the status of the continent's environment. (Ferraro, 2010, Ch. 7).

So despite its growth, McMurdo Station was still being treated like a collection of buildings. There was a need to look at the station as a whole and create a comprehensive, long-term plan that also took into account the design and evaluation of the buildings not only from an engineering standpoint but from a more comprehensive architectural one: energy efficiency alongside human comfort, design, and productivity.

It was not until 1979, near the end of their 12-year contract, that H&N released a master plan, the *Long Range Development Plan*, *Antarctica*,[284] which focused on replacing existing small, temporary structures in McMurdo with larger, more efficient ones and consolidating buildings in already developed areas (DMJM, 2003). Under this plan, changes to the station could be implemented over the course of ten or more years.[285]

New buildings would include for the first time both attention to utility connections *and* personal privacy. With the backing of the NSF, science facilities, badly in need of renovation, were improved as well (Ferraro 2010, Ch. 8). Additionally, the main power and water plants were moved from a location on Observation Hill to locations closer to the ocean, although it is not clear why.[286]

According to Klein, "…station development since 1979 has generally followed this long-range plan" (Klein, 2008, p. 16). Yet, the reality remains that while a few facilities were consolidated according to the LRDP, the organic layout persisted and reinforced through the improved definition of existing circulation routes (DMJM, 2003, p. 3-4). However, the move away from a military-style station towards one focused on science was clear, and it began to be reflected in the types of buildings (more permanent)

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[284] This Holmes & Narver plan is described in greater detail in Section 2.3.3.

[285] Although the actual document is not available outside the Office of Polar Programs in Washington, D.C., others who have studied it describe the plan as including land use, utilities upgrades, a review of construction and engineering support equipment, and plans for specific buildings including improved dormitory facilities.

[286] Today there is some question as whether or not to take advantage of the site's natural topography to improve the efficiency of pumping water throughout the station, which would mean moving some water storage tanks (used for the storage of firefighting water) farther from the ocean and up the slope of the site, over 100' above sea level. The gravity-feed would improve reliability of water delivery for fire suppression systems (Augustine et al., 2011, p. 214). Current systems rely on pumps.

built and how funds were distributed (biased towards science efforts instead of maintenance). Slowly, the rigid lines of the old naval station blurred. The fading visibility of the military plan

> …also points to the demilitarization of the US Antarctic presence: McMurdo was initially constructed as a Naval Air Facility, but in a continent in which science rather than military might guarantees territorial influence, the station's military foundations, as well as its contentious use of military personnel in Antarctica, are increasingly downplayed. (Collis & Stevens, 2007, p. 246)

Over the next 10-20 years McMurdo developed as needs arose and budgets allowed. The layout gradually moved away from a grid and towards a more organic layout based on the topography of the site, although overall the patch of ground that is today's station has been graded extensively ("Planning for Tomorrow," 1993, p.4). Buildings sites were chosen where it was convenient, or wherever a patch of relatively flat ground could be created (DMJM, 2003, p. 3-4). The natural barriers – a steep slope towards the coast and the icy craters on all other sides– are the only things that contain the expansion.

Even today, larger stations in Antarctica are not budgeted all at once, but as needed. Unfortunately, the budgets rarely include funds for maintenance. Rather, buildings and stations must make do until a lack of maintenance impedes scientific endeavors. Only then are improvements funded. New buildings are generally built one at a time and years apart.[287] In one rare instance, the new South Pole station was completely replaced with one massive budget approval.[288] This is not the norm and at McMurdo it has not happened since the original IGY and subsequent decision to make the station permanent.

After H&N the next contract was awarded to ITT Antarctic Services, based in New Jersey, from 1980-1990. During this time, McMurdo underwent a number of new construction projects, including a new power plant (which housed diesel generators), a replacement to the burned down Vehicle Maintenance Facility (VMF, see Section 4.3.2), and four three-story dormitories (Buildings 206-209). No documents from this contractor could be found, so it is unclear which buildings (if any) were designed by ITT and which were projects slated for construction before ITT assumed the contract.

Between 1990 and 2000, Antarctic Support Associates (ASA), a joint venture between H&N and EG&G, held the Antarctic contract.[289] It was during this time that the USN formally pulled out of the Antarctic. In 1993, after 42 years serving the USAP, it announced its decision to withdraw. On February 20, 1998, a ceremony in Christchurch, New Zealand, commemorated the official end (although the USN still provided some flight support until the end of the 1998-1999 season) (NSF, 1998).

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[287] Dormitories are one exception. The 203 series are visually similar structures and were all built as part of one plan, as were 206-209 and 210-211.

[288] With plans initiated in 1992, construction on the new station began in in 1999 and finished in 2003. This new building replaced the old dome, which was dismantled, returned to McMurdo, and shipped back to the U.S. The last remains of the old station finally went back in 2010, with the final touches to the building in completed in 2008.

[289] Formerly Edgerton, Germeshausen, and Grier, Inc., they were a "provider of management and technical support services to U.S. government agencies" and a U.S. defense contractor since WWI (http://www.urscorp.com/).

By this time the role of the contractors had increased. Along with the NSF, ASA oversaw the completion of several projects, some of which had been outlined in the 1979 LRDP.[290] In 1995 ASA released an update to the H&R *Long Range Development Plan*. Known simply as the *1995 Update to the LRDP*, this report focused on consolidation, functionality, footprint reduction, and on replacing inefficient older structures.[291] It is considered more of a facilities replacement plan than a "city development plan" (OPP, 2003, p. 2). Considering the way Antarctic infrastructure projects are funded, it could be considered a pragmatic approach.

Raytheon Polar Services won the new bid in 2000. In 2003 it issued its own update to the LRDP, a report compiled by a company called DMJM.[292] This document covers land use, facilities development, utilities development, site development, vehicle and pedestrian circulation, and design controls. Aside from being the only easily accessible LRDP document, it appears to take into consideration comfort and "human factors" more than any previous proposal, and it includes what might be the first serious discussion of the need for improved energy efficiency. While paying the most attention to building upgrades and energy saving measures, the authors of the document attempted to create guidelines for new buildings, including more single-room dormitories. The

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[290] These included new dormitory facilities, a new heavy vehicles maintenance facility, and most prominently, the new science laboratory – the scientific heart of the station- the Crary Science and Engineering Center.

[291] For information regarding a 1993 design charrette sponsored by the NSF and AIAS, see Appendix I, p. 241.

[292] Daniel, Mann, Johnson & Mendenhall: DMJM Design was a transportation-related engineering firm, acquired in 1984 by Ashland Oil & Refining Company in Kentucky, the same company that created the subsidiary, Holmes & Narver, which held the first NSF contract. In 1990 Ashland was reconfigured and, as a result, created a spinoff, AECOM, an architectural design and engineering firm which now includes DMJM. AECOM worked with British architects on the new Halley VI station (see Appendix F).

authors explicitly state that "… energy wastefulness impacts comfort levels and operating costs" (DMJM, 2003, p. 3-24). Phrases like "productivity and spirit of community," and "quality of life" are used in an assessment of current conditions at the station. The DMJM authors list several other observations made during their initial site visit that are unusual for this type of document.

> (1) McMurdo's "remote outpost" feel combines "aspects of a mining town, military base, and college campus";
>
> (2) Although it is a remote, old USN base, it is still a community of science and support people, and there are ways to improve the feel and wayfinding systems on the station;
>
> (3) Logistics are the "life blood" of the station and it is imperative to provide for the people that make this possible;
>
> (4) The station has developed in an inefficient and haphazard manner;
>
> (5) Many of the buildings are some of the original ones from the 1950s and 1960s; and
>
> (6) In part because of the aging buildings but also because they require excessive travel between them, the station is not energy efficient (DMJM, 2003, p.1-2).

These observations are more architectural than in any previous report.

The same year, OPP released a housing report (OPP, 2003) also emphasizing human comfort as essential to the future success of the station. The report was a response to "… a request contained in the House Committee on Appropriations' Report 1-7-740 accompanying the FY 2003 Appropriations Bill for Veterans Affairs and

Housing and Urban Development, and Independent Agencies" regarding the upgrade of housing facilities at McMurdo Station, Antarctica (OPP, 2003). Identified in the report as one of the highest housing priorities is a 40% increase in single-bed rooms, highlighting the importance of privacy for everyone working at the station. The presumed increase in site footprint and the cost of providing more private rooms has so far been a barrier for this goal. Recently (2012) a new push for the actual realization of these dorm facilities was proposed, although it appears these plans involve a reconfiguration of existing rooms, not a series of new buildings (see Section 2.2.4).

Additionally Raytheon oversaw a 2008 energy study conducted by RSA Engineering out of Anchorage, Alaska (RSA, 2008) (issued just before the first stages of the Scott Base wind turbines began). It proposed to reduce overall energy consumption and improve employee living and working conditions (RSA, 2008). Many of their recommendations address the building envelope, including improved windows. The report stated that while all federally-funded buildings must comply with standards[293] which reference ASHRAE Std. 90.1-2004 and IECC-2004/2006,[294] existing buildings in McMurdo will not be able to meet these requirements; rather, the RSA recommendations employ the standards only as a "reference when providing wholesale retrofits in lighting, thermal or plumbing systems of buildings" (RSA 2008, p. 7). Since new buildings are

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[293] Energy Conservation Standards for New Federal Commercial and Multi-Family High-Rise Residential Buildings and New Federal Low-Rose Residential Buildings, effective January 22, 2008.
[294] ASHRAE Standard 90.1-2004 was used (at the time) for commercial occupancy buildings and the International Energy Conservation Code 2004 (soon to be 2006) for residential occupancy buildings.

not prescribed, there is no mention of actually meeting these standards for an entire building.

The RSA recommendations included: 1) adding new, insulated metal panels to the walls and roofs of pre-1973 buildings[295] to reduce heat loss at much as 70%; 2) installing new vinyl windows to reduce heat loss, improve daylighting, and provide additional escape routes; 3) installing Solatube lighting systems[296] for reduced dependence on artificial light in certain buildings; 4) replacing old wooden doors with insulated steel doors with relites[297] to improve the building envelope and to provide a little extra daylighting.

This was not a long range plan, but a list of short and long term projects aimed at reducing fuel and water consumption. It was possibly commissioned because of an increasingly volatile energy market. A few projects in the report were completed, such as the new generator building and the improved heat trace system. The proposed integration of the Scott Base wind turbines, completed in 2010, is now a reality.

Today the buildings in McMurdo Station have not changed radically in appearance; that is, despite several types of building types there is no arresting visual focal point, and no building that does not fall into the "mining town" aesthetic. Since projects are generally funded one at a time, the few modern buildings (built within the

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[295] This significance of this date is not clear, but may refer to older structures built prior to NSF's takeover of the station which were built to be permanent structures.
[296] A Solatube a "…high-performance daylighting systems that use advanced optics to significantly improve the way daylight is harnessed" (http://www.solatube.com/).
[297] A relite is a door with a small window inlaid in the door. It can let in additional light and, as a safety measure, provides a view to people on either side of the door.

last 20 years) are outweighed by dozens of others built in the last forty years, or even longer. However, upon closer inspection important differences appear.

Aside from a more permanent structure and appearance –one that shows fewer scars from years of harsh freeze and thaw cycles– newer buildings tend to be marked by larger windows, multiple stories, extensive sprinkler systems, steel frames, integrated HVAC systems, and less character. In a few cases concrete slabs replace heavy timber floors.

The type of framing (metal or wood) is more of an indication of size and structural requirements than age. Siding material (metal or wood) does not indicate age, since the oldest Quonset huts are metal sided while their contemporaries (i.e., the T-5 hut), are wood. Likewise, other buildings like the carpentry shop, the dormitory called "Mammoth Mountain Inn," and the newest Chapel of the Snows are wood sided. One must examine a section of the wall to distinguish older buildings from newer ones. Although the Robertson Building, as described in the NCEL Engineering manual, was promoted in the 1974 manual, examples at McMurdo Station date back as far as 1961 (e.g., the Medical Dispensary) (see also Appendix C).

The newest arrival at the station is the 40,000ft^2 Science Support Center (SSC) (Figure A- 19). An Arctic entry below a distinctive porch covering[298] leads into a double height lobby with many windows providing daylight to the main staircase. A front office walled off from the lobby behind a large window also benefits from some of

[298] Some might argue this design, which offers some protection from snow accumulation at the front door, could be considered an architectural embellishment. However, it does not shed snow itself, resulting in buildup that eventually blocks some windows on the third floor.

this daylight. The L-shape of the SSC affords more access to windows throughout the building. The floors are concrete slabs resting in a steel frame. Form-wise, it may seem like an unremarkable building, but if compared with the limitations of a Quonset hut or T-5 hut from the 1950s, it shows how more much construction and engineering techniques have evolved, and how design issues once thought to be details or luxuries are now receiving more attention.

APPENDIX C

EARLY BUILDING TECHNOLOGY OF THE U.S. NAVY IN ANTARCTICA

Early Building Technology of the U.S. Navy (USN)

One of the original seven U.S. facilities built between 1955 and 1957 as a part of the IGY and Operation Deep Freeze, McMurdo was not initially considered a major research station, serving rather as a naval airfield with a limited scientific program; it was built to support the larger or more important stations (e.g., Byrd station and South Pole station).[299] For this reason, its buildings have changed significantly over the years, beginning with small, portable buildings and culminating to date with a large, multi-million dollar science facility, a water treatment plant, and over a dozen personnel housing facilities.

Quonset Huts

This icon of "portable architecture"[300] was born out of the need for easy, quick housing for soldiers during WWII. Named for its original place of construction (Quonset Point, Maryland), the Quonset hut was designed and built by George A. Fuller

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[299] "The Naval Air Facility, located at Hut Point on Ross Island in McMurdo Sound, serves primarily as the base of operation for the airlift to the Amundsen-Scott South Pole Station and the long-range air supply of Byrd Station. It is used extensively for aircraft maintenance and support and as a communications and meteorological center. It is from this Facility that all the supplies and material [are] air delivered for the construction and establishment of the Amundsen-Scott South Pole Station" (NRC, 1957, p.3).

[300] Another example includes the Native American tipi. The association of permanence with architecture often excludes structures like this and the Quonset hut from being called "architecture," even though it has been argued that "[p]ortable architecture was the first fully manmade and inhabited form of architecture" (Decker & Chiei, 2005, p. xv).

and Company.[301] It not only provided soldiers with a dry, comfortable shelter, but one that could be easily constructed or taken down by 10 unskilled men in one day and be adapted to different climates (e.g., by adding a vestibule) (Figure A- 20). Basing their design on the British Nissen hut from WWI, the designers –architect Otto Brandenberger and engineer Peter Dejong– vastly improved on the design, making it lighter, easier to assemble, and much more comfortable. Over the years different people contributed to its improvement, making it even lighter, simpler, and more water-tight.

The original Quonset hut used paper insulation between metal panels and a thin layer of Masonite mounted to wood purlins. This, along with a wooden platform floor, was an improvement over the Nissen hut, which used only an air space for insulation and generally rested on an exposed ground.[302] Because of the war effort, the design, construction, and improvements to the Quonset hut happened very quickly, with the first design shipped merely two months after the commission. The Quonset hut proved easy to modify with changes applied quickly on the factory floor.

However, one early complaint with the Quonset hut was the wasted space from the curved walls. Within a year of the initial design, Brandenberger modified the curved walls to increase efficiency. This time, the arch (now two sections instead of three) rested upon a four foot vertical wall, providing more usable space. He also made the overall system lighter still. Shortly thereafter the design was altered by the Stran-Steel Division of the Great Lakes Steel Corporation, when it took over major production from

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[301] Later they were joined by the Merritt-Chapman and Scott Corporation.

[302] Another disadvantage was that the Nissen hut was complicated to assemble, with many small parts, bolts, and connectors.

the factory in Quonset Point. They removed the four foot vertical walls, expanded the footprint, and created a new framing system that was even lighter and eliminated the need for bolts.[303] It also relied more on stock metal that did not need to be modified in a factory. This also helped alleviate the demand for steel, which was in short supply during the war.

A special type of Quonset hut known as the Jamesway[304] is a hybrid structure with features of both a fabric tent and a metal Quonset hut (Figure A- 21, Figure A- 22, Figure A- 23). The Jamesway has wooden ribs covered by an insulated fabric, which lowered demand for steel. The sections are 16 feet wide and come in four foot sections; generally the entire structure is 32 or 64 ft. long, limited in the cold desert condition of Antarctica by fire safety precautions and logistical mobility (Sherwood, 1965).[305] It is light (1,200 lbs.) and easy for the Army Air Corps to transport and use in Arctic conditions. With few metal components and little need for work that required the removal of mittens or gloves, it is easy to erect. The covering is also fire resistant and vermin proof. An added bonus comes with the fact that the packing crates can double as the floor of the Jamesway (Decker & Chiei, 2005, p. 149). There is only one Jamesway

[303] Stran-Steel's "revolutionary" design was "…essentially two lightweight steel channels …tack welded back to back to form an I-shaped member. The gap between channels served as their patented nailing groove, serpentine in shape, into which nails were driven and deformed until clinched by friction (Decker & Chiei, 2005, p. 17).
[304] Created by the James Manufacturing Company of Fort Atkins, Wisconsin.
[305] Logistical mobility is a term used to describe the ease with which something can be disassembled often and moved easily, something required in snow drifted field camps.

left in McMurdo;[306] however, Jamesways have been used for decades in field camps Figure A- 24).

The legacy of the Quonset hut in the U.S. may not be as apparent today, but after WWII many people and organizations found it a perfect building for temporary and even long-term uses, especially with the dearth of postwar housing for returning veterans. For millions of people, these efficient, inexpensive buildings provided shelter and a home, even if it was seen as only temporary, practical, or a patriotic choice (Cuff, in Decker & Chiei, 2005, p. 73). Some of these structures were modified to appear more home-like, with extra windows, overhangs, and warmer, more permanent finishing materials than sheet metal, such as brick and wood. Quonset huts are still in use today, although they are often easily passed over by an undiscerning eye. While no remaining Quonset huts or Jamesways serve as dormitories, the structures can still be turned into "homey" settings for after-work socializing.

T-5, Arctic Prefabricated Panelized Wood huts

This plain, boxy building type is easy to transport, erect, and modify for different purposes (Figure A- 25). In Antarctica the T-5 served as a quick, no-frills building that could be assembled by a handful of men with only a few common tools: three hammers, three screwdrivers, one wrench, a 100 ft. measuring tape, and a level. The structural system was 4x8 ft. plywood insulated panels and steel or timber roof trusses, which meant that the structure required no load-bearing interior walls, and was thus very

[306] A kind of annex to the Coffee House, the Jamesway extension is now the movie room .

flexible.[307] It also meant interior walls could quickly and cheaply be made of plywood, or even simply a drawn curtain (NRC, 1957, p. 36).

The standard T-5, designated as a standard design in 1955, was 20 ft. wide and 48 ft. long structure but could be tailored to specific needs (i.e., a different module size), but it was intended to be relatively lightweight and transportable on an LC-130 aircraft (see Appendix Q).[308] The 4x8 ft. wall panels weighed 100 lbs. and came in three types: plain, window, and door. These were interchangeable, allowing extra flexibility with layout and window location (Figure A- 26). There were also floor and roof panels. Its designation as an "Arctic" building stems from its purpose to provide "…comfortable living conditions in ambient temperatures as low at 65^{o}F below zero" (U.S. Department of the Army, 1957, p.3).[309] The entire building was sealed with a "surface mounted wedge clip[310]" (Figure A- 27), which "…provided maximum rigidity with minimum heat loss…", at least at the joint connections (NCR, 1957, p. 36).

The interior of the T-5 was generally long and rectangular, with small, square windows about 64" above floor level. There was no built-in daylighting control, possibly because many of these structures ended up in the subnivean tunnels of stations

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[307] These buildings generally had a snow load capacity of 50 lbs./ft^2 and a wind load of 100 mph (Sherwood, 1964a, p.3).
[308] A 28' wide modified version of this 20'wide building allowed more floor space without having to increase (awkwardly) the length of the building; another modified T-5 had a 12' clearance and a heavy duty floor, suitable for a maintenance shop (Sherwood, 1964a, p.3). Additionally, a 16' wide version was created specifically for Camp Century, Greenland, which was a subnivean camp (therefore the structure had to be modified to withstand heavy snow loads) (Hedrick & Mazzoccoli, 1962) (see Appendix D).
[309] It was also labeled for use in tropical conditions, with the addition of an air conditioning system.
[310] As shown in Sherwood, 1964b, p.8.

located on an ice shelf. Windows were fixed[311] and composed of two triple-glazed 1/8-inch plastic plates that sandwiched another layer of 1/16-inch plastic. Wall panels were "stressed cover," consisting of 1/4-inch thick exterior grade plywood glued to a frame and lined on the inside (the warm side) with aluminum foil on Kraft paper, extending up the side of the frame to form a cup, which was then filled with fiberglass insulation (U.S. Department of the Army, 1957, p. 6). Floor panels were similar but made of slightly thicker plywood (weighing 130 lbs. per panel). All interior surfaces and walls were covered in "…attractive fire-resistant paint" (NRC, 1957, p. 36).

Heat usually came from a 70,000 Btu/h military model, fully assembled space heater. There was a roof jack and a special roof panel for it to vent. Additionally, below each window there were small slots, regulated with rotary covers, intended to help with ventilation of the building. This building type was probably not intended to stay in service for over 50 years, but in McMurdo a few of them have. One of the first buildings on Ross Island (besides the *Discovery* Hut) was a T-5 Arctic panelized building (Dufek, 1957). Its fate is unknown, but building 78, a T-5 building from 1960, is still actively used.[312] The T-5 Arctic hut served well as an easy-to-transport, easy-to-erect building, well insulated and very adaptable. With partitions it could be converted into a dormitory, recreational area, hospital, office, movie room, galley, whatever was needed; that is the beauty of the convertible (i.e., flexible) building.

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[311] These windows could be removed and replaced with screens if desired (for temperate or tropical climates).

[312] Now an aerobics room (the "Gerbil Gym"), it was once the "Acey Deucy," the enlisted men's club which served as a bar and hangout.

Performance studies conducted on these buildings by the U.S. Naval Civil Engineering Laboratory (NCEL) (e.g., Sherwood, 1964a; Hoffmann, 1964) indicate the USN's concern for the Antarctic mission and relative lack of experience in extremely cold climates (compared with countries like Norway and Russia). The reports begin by stating that "[c]omfortable living conditions in polar regions are essential for high morale and consequent productiveness of a work force" (Sherwood, 1964a, p. 1). In the rest of the report the implication for these modular, well-insulated buildings was that they would also be economical and energy efficient, but the fact that occupant comfort is mentioned so prominently at the beginning may indicate an awareness of how it affects productivity and health, especially in such cold, confined conditions.

A further study (in 1962) led to modifications to the T-5 to make it more comfortable as a barracks. Changes included better noise control, more one-man bedrooms, higher ceilings, and larger room sizes for two-man rooms. There were also improvements to the construction and assembly of the structure (Sherwood, 1964b). The result was a modified and improved T-5 structure, a "…prefabricated, straight-sided, frameless wooden building with load-bearing walls and a 1:10 gable roof supported on trusses"[313] (Sherwood, 1964b). Its basic length was 56 ft. but as usual it could be adjusted in four foot increments. The floor was also slightly thicker because it used a

[313] According to the report, the modified T-5 had a heat loss of 0.158 Btu/ft^2-h-^{o}F at a wind velocity of 2-3 mph and an air infiltration rate of about 0.6 changes per hour; the thicker ceiling in the modified T-5 reduced heat loss 26% over the original design. Additionally, the heating system was changed from a floor-based system to one in the ceiling, as the floor-based system could not provide fresh air, humidification, or enough hot air to heat corner rooms with two windows (Sherwood, 1964b, p. 10).

thicker layer of plywood. The entire kit weighed 31,718 lbs. (as shipped) and could be transported by plane.

Successfully tested in Barrow, Alaska, the T-5 and modified T-5 proved their ability in the field and were used extensively in the early years in McMurdo. However, as the mission ("Operation Deep Freeze") became more focused on the long term, the use of new T-5 structures in McMurdo ceased as they were replaced with a steel-frame version, a structure and siding system known as Robertson Buildings (Figure A- 28, Figure A- 29).

Robertson buildings are just as unremarkable in appears as the T-5 designs but were also better insulated and, as was mentioned, more flexible when it came to the customization of the interior design, as was needed for the increasingly wide range of activities occurring at the station. Crucially, they were still easy to assemble and were built from prefabricated parts both for the skeleton and the insulating panel siding.

Manufactured by the H.H. Robertson Company of Pittsburg, PA, this type of building can still be seen today, either as relics of the past (e.g., Medical) or as updated versions of newer buildings (e.g., the three-story dormitories). In the 1974 NCEL Engineering Manual, the building system is described as thus:

> The panel used at McMurdo Station [was] the H-Type Q-Panel, [which was] insulated with 3 inches of fiberglass and contain[ed] no metal fasteners [that extended] through the panel. A coated-steel vapor-barrier on the interior side prevent[ed] moisture penetration. [The manufacturer] stat[ed] that at -50^{o} F outside and 70^{o} F inside, condensation should not form even with a relative

humidity of 80%. (Hoffman, 1974, p. 5-1)

It should be noted that the insulation used was galbestos (galvanized asbestos, see Appendix F, Nomenclature) (Figure 39).

So popular was the Robertson building that the NCEL manual notes that only two buildings being replaced or built at the time were not of this structures: an old aircraft hangar and the USARP administration building (the future NSF Chalet), with its wood structure chosen for its "…more pleasing architectural style" (Hoffman, 1974, p. 5-1). Today the remaining Robertson buildings are used as warehouses and are showing their age, with the exception of the three-story dormitories, which were built in the late 1980s with a more modern, asbestos-free siding system.

APPENDIX D

SUBNIVEAN LIVING

It is important to note that McMurdo Station is built on exposed (ice-free) land, which is valuable real estate in Antarctica. For Antarctic stations located on ice shelves or ice sheets[314] –such as Byrd Station, the Little America stations on the Ross Ice Shelf, and South Pole Station, as well as in the Arctic at Camp Century[315] on the Greenland ice sheet– it was possible and even desirable to entrench the huts in the snow, allowing the structures to be buried over time, thus alleviating the snow load on the roofs (reinforced with corrugated iron arch structure known as the Wonder-arch), the wind forces on walls, and providing excellent thermal and acoustic insulation (Figure A- 31, Figure A-30) (NSF, 1962, p. 58). It also provided protected walkways between buildings. For smaller, short term stations (lifespan of 2-5 years) it was a big investment made to protect the station from being crushed by accumulated snow.

It is not easy to determine how much energy it saved in the long term by reducing heating demand; the arches rested on the edges of trenches, which had to be excavated using a 15-ton rotary snowplow called a Peter Snowplow.[316] This of course had to be flown in and filled with diesel. Even if it was an energy-saving solution, it was

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[314] Ice shelves are glaciers that have flowed down a coastline and met the ocean; ice sheets are large glaciers over land, sometimes called continental glaciers. See Nomenclature.

[315] Run by the U.S. Army Polar Research and Development Center, it was a subnivean camp located 800 miles from the North Pole.

[316] See USN, 1968, p. 35 for more information.

not an environmentally sound one.[317] In addition, the structures had to be relieved of their snow load every year or risk being crushed (Figure A- 32, Figure A- 33).

However, the psychological effects of living "underground" can be detrimental to the scientific program,[318] and the need to relocate the station every few years can increase the cost and carbon footprint of the station. At McMurdo Station, built upon the dark volcanic rock and permafrost of Ross Island's active volcano, this option was not necessary, let alone possible. Instead structures had to remain above ground, exposed to wind and blowing snow, with no protected passage between buildings.

Above-ground stations must contend with the forces of the wind and blowing snow. Instead of resisting the crushing weight of snow and ice from above, these buildings must withstand the lateral forces of wind and (ideally) minimize the sound of wind and any other building reverberations (e.g., whistling coming through crack or down stack pipes). On the plus side, windows are now possible.

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[317] Over time buried buildings will be crushed by the snow and ice, and can also drift along with the moving ice sheet, necessitating a new station every few years. Debris from these buildings is generally not extracted from the ice.

[318] That is, in terms of lowered productivity levels, which have been noted in a number of subnivean or extremely closed-off Antarctic bases (e.g., Halley III and the old Casey Station).

APPENDIX E

NAVAL TRANSITION TO THE NSF

As early as 1960, according to the NSF, the Bureau of the Budget (now the Office of Management and Budget, OMB) released a directive known as "Circular A-51, 'Planning and conduct of the United States program for Antarctica,'" granting the NSF power to "…continue to exercise the principal coordinating and management role in the development and carrying out of an integrated U.S. scientific program for Antarctica" (NSF, 1996). Major logistical operations at the stations were still handled by the DOD.

During this period, scientists at McMurdo Station lived and worked in the company of enlisted men and officers. All support, ground transportation, medical services, search and rescue (SAR), and accommodations were provided by the USN. Barracks, the galley, and clubs were segregated by rank, although scientists were able to move freely between these places. Then in the late 1960s the USN and NSF began to explore the idea of shifting the support role to private contractors. In 1968 the first private contractor, Holmes & Narver[319] (H&N), was hired to help oversee the station. The first project they built in McMurdo was the erection of the NSF "Chalet," the official NSF building at the station[320] (Figure A- 34).

[319] H&N was a subsidiary of Ashland Oil Company, based out of Kentucky. Their headquarters were in Orange, California.

[320] So called because the building, constructed of wood (not steel or metal siding) with its step roof and later addition of a large wooden deck, looks like a ski chalet at home in the Alps. "The Chalet" is the building's semi-official name.

A 1970 memorandum reviewed by President Richard Nixon and signed by Secretary of State Henry Kissinger, directed the NSF to continue its active presence in the Antarctic as stated in the 1960 A-51 Circular, but also to begin (officially) a transition of the responsibilities of the Antarctica program from the DOD to the NSF. These responsibilities included the continued use of government agencies for logistical support where a mutual agreement could be reached, but also the use of commercial (private) support when cost effective: “on a mutual acceptable reimbursement or nonreimbursement basis” (NSF, 1996; Memorandum 71, 1970). These changes were ordered to be finalized by 1972. The memorandum put the NSF in charge of the program, and it was up to the NSF to decide whether to use government logistical support or look towards private contractors. As it turned out, working with the private sector was much more cost effective.

APPENDIX F

NON-U.S. BASES

Overview

Each Antarctic station has its own unique set of challenges and each has met them with different solutions (Figure A- 35). A modern approach towards designing an Antarctic station includes not only energy efficiency (advances in materials and structural systems) and a light footprint, but also occupant comfort and well-being. It is important to remember that other stations have different programs, different life expectancies, different local environments, and most of all, these stations operate at different scales. But in this mix exists useful lessons for successful building in Antarctica, even at McMurdo Station.

Halley VI (U.K.): *adaptable modules provide shelter and comfort*

The U.K.'s Halley VI station [321] –like the previous five versions of the station– is perched on the 500 foot thick Brunt Ice Shelf (75ºS, 26ºW) (Figure A- 37). Any structure built here is exposed to high winds and blowing snow while the ice shelf drifts towards the ocean a quarter mile every year, warping and crushing any building or foundation buried in it (Broughton, 2006, p.1). The unstable nature of this location requires engineering solutions for the annual three-foot rise in snow level and the unrelenting movement of the ice shelf towards the ocean.

[321] Named after English astronomer Edmund Halley (1656-1742), for whom the comet is named.

To deal with these challenges, designers built Halley V to rise above the ice and snow rather than be buried in it.[322] Still, problems with the foundation meant Halley V still faced a complicated, annual jacking procedure. Halley VI was designed to greatly reduce this task. At the end of its lifespan, the structure will be completely dismantled and removed, leaving nothing behind. Such features make Halley VI the first fully re-locatable station in Antarctica (Broughton, 2006, p.8).

The first Halley station was established in 1956 during the International Geophysical Year (IGY, see Nomenclature). This and the next Halley station (Halley II) resembled the wooden huts of Captain Scott (see Section 1.1.2), which had been resting undisturbed for over 50 years on the solid ground of Ross Island, whereas out on the Brunt Ice Shelf the first two Halley stations were soon buried and lost. To deal with snow drift, the third (1973-1984) and fourth (1983-1992) versions were prefabricated huts housed in large metal tubes designed to be buried by ice and snow. However, this was only a temporary solution, as the structures could not resist the drift of the shelf and eventually were buried and crushed by the weight of the snow anyway.[323] Additionally, subnivean[324] living took its toll on the health and morale of the station's inhabitants.[325]

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[322] Compacted snow may exceed a density of 30 lb./ft. (Eranti & Lee, 1986, p. 18).
[323] It is not possible to calculate the weight of a snow load based solely on the depth of the snow. According to NOAA, you must first determine how much water is in the snow pack (which depends on the type of snowfall- dry and fluffy or wet and dense; officially this can be done by taking a core sample of the snow). Taking that estimation, one can multiply it by the weight of one cubic foot of water (approx. 62 lb./ft^3) to get the weight (per square foot) of the snow (http://www.wrh.noaa.gov). This calculation does not take into account the compacting that occurs during years of accumulation.
[324] That is, objects or actions occurring in places buried by snow. See Appendix Q.
[325] Germany's Neumayer station (now in its third phase) on the Ekström Ice Shelf had a similar problem and history of solutions, with several stations abandoned because they were crushed. The current station rises above the snow on hydraulic feet resting in an excavated "ice basement," which frees them from the forces of the snow and ice.

For Halley V, designers decided to raise the structure above the snow, thus returning daylight and views to the station. The boxy, non-aerodynamic form caused snow to drift around the station (necessitating the use of bull dozers to level the area around the station), and the support structure was still embedded in the ice shelf, necessitating annual repairs. The legs and feet had to be excavated, the warped sections cut off and replaced, and the entire station jacked up by a team of 40 people. This design did not solve the problem of drifting towards the edge of the ice shelf (Broughton, 2006, p.1-2).

Halley VI, the latest version of the station, is raised above the ice and snow like its last two predecessors, but is also moveable, thus overcoming the drift of the ice shelf (Figure A- 36). Its aerodynamic form keeps the area around the station relatively free of snow drift. Instead of being rebuilt every decade, Halley VI station can now be dragged to a new location on its ski footings. These footings do not need to be embedded in the ice and so do not suffer the extreme forces of ice deformation. The architectural firm that envisioned the station designed it to be energy efficient as well as an aesthetically pleasing, pleasant place to work, retaining its functional requirements or adherence to safety and fire codes. Therefore, modulation of the station is not only a safety feature, it also increases portability and flexibility. These two features were stressed in the design of this station, which accommodates up to 52 people.[326] For a station built on such unstable "ground," it is easy to see why flexibility and relative impermanence can be positive characteristics. Indeed, the design report of the station describes it as "… a

[326] The peak summer population is 52, with a winter capacity of about 16 people.

visitor, not a resident" (Broughton, 2006, p.7). This approach contrasts with the long-term mission and building design of the USAP in McMurdo Station.

With regards to housing, the architectural design team decided it was important to provide both private and socialization areas. They designed rooms that "…promote emotional well-being without being so comfortable that residents hide away from the community" (Broughton, 2006, p.3). Each room houses provides natural light, storage, and opportunities for personalization, even when there are two people in one room. At 8.2 x 11.8 ft., the room is small but "…homey…" and is painted in a "…warm color palette…," which is meant to combat sleeping problems associated with Seasonal Affected Disorder (Broughton, 2006, p.3) (Figure A- 38).

Aside from personal rooms, there is also a second story lounge in the residential module, where residents can quietly enjoy the panoramic view. The firm also designed the main common area –a larger red pod– to be colorful, well-lit, comfortable, and inviting. There is a small hydroponic greenhouse beneath a large window in the main pod (Figure A- 39), providing visual greenery and some fresh food for occupants without violating the terms of the Protocol on Environmental Protection to the Antarctic Treaty[327].

Design of the connections between modules was also considered important because the exterior shell of each one is essentially the same. Therefore, providing a sense of contrast helps differentiate one from the other, provides some visual variety,

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[327] The protocol prohibits the introduction of foreign plant or animal species (including foreign soil) (U.S. Department of State, "Protocol"Art. 3).

and helps define each module as a "… destination in its own right…"(Broughton, 2006, p.3). Ceiling heights vary depending on the location and function of the space, and the interior color palette also changes. Some areas in the corridor afford views to the outside, "…punctuating the journey through the station and providing spaces for chance encounters with other residents" (Broughton, 2006, p.3). While essential for safety reasons, the corridor becomes not just a way to move between modules but a space with its own identity.

An energy assessment led to the decision not to include wind or solar power systems right away, but there is room for their future inclusion. The station's main contribution to energy efficiency is its structure. The building is extremely well insulated, factory built, and low maintenance, but above all, it has a small footprint. Easy to construct, relocate, and demolish, this station should last 20 years, twice as long as any previous version. This allows future stations to take advantage of improvements in energy systems and innovations in materials more quickly than a more permanent station. Requiring less energy to maintain and leaving nothing behind, it is considered "…the most environmentally friendly and sustainable facility [the British Antarctic Survey] has ever built" (Broughton, 2006, p.7).

Overall, Halley VI is a prime example of a modern Antarctic architecture and engineering. The architectural firm that won the design competition for this project spent time on site studying the problems and lessons learned from previous British and international stations. In the end they decided that the best approach was one that combined the best working conditions with comfortable and healthy accommodations.

The station itself became an icon for scientific research in a very remote location. This approach could be adapted on a larger scale and applied to McMurdo Station.

Old Casey Station (Australia): *a cautionary tale*

Casey Station, one of the three main Australian Antarctic stations (i.e., Mawson, Davis, and Casey) was rebuilt in 1989 as a small group of buildings resting more-or-less on grade. The station it replaced, known as "Old Casey," was an elevated structure built to replace Wilkes station[328], which had suffered from severe snow drifting (in part because of poor siting choice). "Old Casey" was sited close to the shore on the Bailey Peninsula in Vincennes Bay, on solid ground that was mostly exposed by the wind. Its design was born almost completely out of a need for the structure's ability to withstand snow drift and minimize the spread of fire.

A unique form for the building emerged after extensive wind tunnel and fire testing. A series of 13 modular buildings,[329] laid out linearly at a right angle to the prevailing winds was first elevated about nine feet off the ground on a lightweight tubular scaffolding that could easily accommodate variations in ground level. A single, windowless walkway connected all the modules, running along the length of the windward side, giving it a semi-circular edge (Figure A- 40). Each module was separated by a noncombustible fire deck, which doubled as a loading dock. "The external access corridor … constitute[d] an all-weather non-combustible link throughout

[328] Wilkes Station was one of the original IGY U.S. bases, but was handed over to the Australians in 1959.
[329] The modules consisted of "zinc-coated mild-steel sheeting on a frame of Douglas Fir with a core of expanded polystyrene (AAD, 1970, p. 219).

the station and a fire-fighting access way complete with fire main and hydrant points" (AAD, 1970, p. 218). The design was successful, but after 20 years of driving winds and ocean spray, the galvanized steel siding began to corrode, limiting the thermal capabilities of the building envelope, and the station was replaced.

Despite the engineering achievements of the previous design, the new Casey Station does not mimic its form, following the more the model of Mawson Station (discrete, colorful, boxy buildings). A complete list of reasons that led to this choice is not clear, but Brooks (2000) writes that in part it was because the aerodynamic, self-contained buildings had worked so well that "… it was never necessary for personnel to expose themselves to the elements. This luxury was later perceived as a possible cause of lower productivity" (Brooks, 2000, p. 38). Perhaps the way the elevated station was often referred to as the "Casey tunnel" provides some insight not just to its outward appearance but the feel of it on the inside.

To some extent, the new Halley station addresses this problem, since it too is laid out linearly. The corridor connection not only have windows and places to pause, but the bridge connecting one side of the station to the other was deliberately left open, not just for fire safety[330] but so that people would need to go outside at some point every day, at least during the summer season.

[330] That is, to prevent the spread of fire and to create two self-sustaining "sides" to the station; in the event a fire destroyed one half of the buildings, those on the other side of the bridge could sustain the winter crew through a winter until relief arrived.

Princess Elisabeth (Belgium): *small-scale building runs on renewable energy*

Belgium's Princess Elisabeth Base (71^{o}S, 23^{o}E) sits perched on the Utsteinen *Nunatak*[331] near the Sor Rondane Mountains in Dronning Maud Land (Figure A- 41, Figure A- 42). Its aerodynamic design[332] and position on the *nunatak* prevent snow drifting and provide an excellent platform for the station's wind turbines to take advantage of the naturally windy conditions.[333] The station is a single building (~7,500 ft^2) anchored to the ice-free rock, with a garage and storage building protected by a granite ridge (Rodrigo et al., 2007). This base operates only during the austral summer (November to February) and accommodates a maximum of 20 people[334] (Rodrigo et al., 2007). Its claim as the first zero-emissions station on the Antarctic continent stems from its passive climate control[335] and near 100% reliance on wind and solar power for energy.[336] Although the total square footage is small[337] compared with other stations, its energy efficiency depends on a compact design with an eye towards human comfort.

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[331] This is an Inuit word meaning "a hill or mountain completely surrounded by glacial ice." See Appendix Q.

[332] According to the report,"[t]he aerodynamic design of the building is therefore one of the most important conceptual design drivers. Wind tunnel testing with sand erosion technique allows an efficient evaluation of the snow and wind comfort for different building block concepts and ridge integration alternatives" (Rodrigo et al., 2007)

[333] The area is classified as being a "dominant katabatic" wind zone. Katabatic winds are "produced by the flow of cold dense air down a slope… in an area subject to radiational cooling" (see Appendix Q). When the storms overwhelm the turbines, they can be temporarily shut down.

[334] An annex extension (i.e., free-standing heated shelters) will increase capacity by 8, with a new maximum population of 18 people (Rodrigo et al., 2007).

[335] There is also an active HVAC system that uses a series of heat exchangers that helps distribute warmed air around the station.

[336] There are batteries to store excess wind power, as well as two backup generators. Such safety features are essential in this harsh climate.

[337] The station provides are 4,305 ft^2 of living space (15,070 ft^2 total space). At 16 people that is about 270 ft^2 per person of living space, 942 ft^2 total space per person.

This station was intentionally kept small to reduce its energy demand so that it could be operated by renewable energy alone. With space at a premium, bunk rooms are relatively small (Figure A- 43). There are two bunk beds per room, providing less privacy than many other stations, but extra space is provided in the "day room" and office area (Figure A- 44, Figure A- 45). Each bunk room has a window, small desk, and extra storage space, but largely it is a place to go only for rest or sleep as opposed to small group activities or complete privacy.[338] Conveniently, all building functions are located in one structure, so there is no need to go outside for daily tasks aside from field research.

> [The Belgian design team] avoided the dark-corridor effect that many bases are notorious for by making it possible to walk through the base in different ways and by creating viewpoints at the landscape. [They also] devoted a great deal of attention to safety. [They] made it possible for the researchers to move safely between the main building and the utility areas, such as the garages, even in severe storm weather, simply by connecting all the areas together. (Verweire, 2008, p. 55)

Of course, for visitors living in the shelter extensions (when there is not enough room inside the main station) or in remote field camps, this does not apply. Portable habitations outside the station generally are not included in square footage or energy estimates.

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[338] Not shown in these images is a way to block the sunlight during sleeping hours, which would be necessary all summer.

As a (mostly) passively-heated building, it was important that the Princess Elisabeth station be well-insulated and have a robust ventilation/heat recovery system. To help accomplish this the structure was factory built and completely assembled in Belgium, then dismantled and shipped to Antarctica for reassembly. The walls and floors are very thick, with an estimated U-value of .012 (R-81).[339] The thick, modular wall structure consists of seven layers designed to retain heat and all but eliminate moisture problems[340] (Figure A- 46). Naturally the design of the windows is just as important. According to a report from Dow Corning, which provided the silicone insulating glass sealant for the windows,

> [t]he window system is designed as a double skin of insulating glass units with a 400 mm [15.7-inch] space in between. The insulating glass units are composed of a triple insulating and laminated glass system that use Heat Mirror™ technology … (Dow Corning, 2010)[341]

Installing high-performance windows (e.g., R-20) is essential to maintaining a tight, passively-heated building.[342]

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[339] A typical passive house in the U.S. might have a U-value of .03 (R-38).

[340] The seven layers consist of: 1) wall covering, 2) Kraft paper with an aluminum vapor barrier, 3) 74mm laminated wooden panel, 4) 40mm graphite treated polystyrene blocks, 5) another laminated panel, 6) 2mm EPDM waterproofing membrane, 7) 4mm polyethylene foam mat, and 8) a stainless steel plate (Samyn and Partners, 2007). http://www.antarcticstation.org/station/passive_building

[341] “In addition to supporting the Princess Elisabeth Antarctic Station, Dow Corning, the world 's leading manufacturer of silicon-based materials, was selected to provide silicone sealant construction material for the project. This offers the company an opportunity to further test its products in the most extreme of environments” (Dow Corning, 2007).

[342] “By suspending from one to three clear films in the airspace of insulating glass, Heat Mirror technology creates multiple insulating spaces — without adding weight — that buffer against heat loss or heat gain.

A heat exchange system preheats incoming air (without mixing it) and also humidifies the interior of the station, reducing the level of static charge (a necessity for electronic equipment as well as human comfort). In addition to thick walls, the building is laid out such that temperature sensitive activities are at the core of the building, away from the outer envelope. For example, the water system and backup batteries are housed in the interior, leaving the edges of the building for living areas with windows. This concentric design also keeps materials and maintenance to a minimum, with vulnerable systems (e.g., water pipes) centralized, which reduces pipe length compared with a station laid out on a long axis (Verweire, 2008).

From its inception, this station was designed to be a low-emissions building that uses renewable energy as much as possible (International Polar Foundation, 2007). Nearly all power needs are provided by wind turbines and solar panels, which are integrated into the design of the station.[343] It was also designed to minimize the impact on the site during construction, and eventual removal. The finite lifespan of the station and its eventual removal is an important feature of the station in a place where, traditionally, old stations were left to be destroyed by the elements. The high energy efficiency and low power demand can be attributed largely to the station's small size and efficient layout (including its modular design).

The result is center-of-glass thermal performance, or R-value, of up to R-20 (U-value down to 0.05) — insulation that equates to a typical wall" (Eastman, 2014).

[343] The panels were placed on the optimal side of the building at the optimal angle to collect solar radiation. Again, this this does not include remote camps or the temporary, overflow housing.

Unlike the multiple modules of Halley VI, this station's functions are contained in one building on solid rock, and the station therefore does not have to contend with the movement of an ice shelf. It takes more advantage of renewable energy than Halley VI, but it is also a smaller station. With its sleek, modern appearance, the historical image of long metallic tubes, domes, or boxy huts from previous stations is left behind. It is in many ways the exact opposite of McMurdo Station and stands as a powerful example of what is architecturally possible in the Antarctic.

Mawson (Australia): *historic station upgrades its energy systems*

Australia's Mawson Station, located on the windy, rocky coast in Holme Bay in Mac. Robertson Land[344] (67°S 62°E) (Figure A- 47), is the continent's oldest, continuously running station (since 1954), and was the first station to install a large-scale, wind-diesel hybrid power system. Unlike McMurdo Station, the small collection of buildings along the coast seems to be oriented in the same direction facing northeast. As with McMurdo, Mawson is built on solid ground and has roads, a power plant, and a liquid waste treatment facility, but it its natural harbor is about 100 meters from the station, which means that people, supplies, and building materials must be ferried by shallow-draft boats or by helicopter. With a typical population of 24 people (16 in winter), it is still a fraction the size of McMurdo Station.

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[344] Named after Sir Macpherson Robertson, a patron of Mawson's 1929-1931 expedition. In the U.S. this area is known as Mac. Robertson Land; in Australia it is referred to as Mac.Robertson Land (no space after "Mac."); in Russia it is MacRobertson Land (no "." and no space) (SCAR, 2012).

In Mawson Station, the residents live in a large building known at the Red Shed. They enjoy single bedrooms[345] with shared bathrooms, as well as access to an indoor climbing facility, a small theatre, a photographic dark room, a library, and a number of communal sitting areas (AAD, 2012a). This means that during severe weather[346] there are few reasons to leave the building. Only during certain times of year is it necessary for some people share rooms or move into temporary housings, some of which do not have windows and are less spacious. Available elsewhere at the station are more gym and recreational facilities, a music room, a spa, and a sauna. All three Australian stations (Casey, Davis, and Mawson) enjoy the benefits of fresh food and greenery provided by a hydroponic greenhouse located near Building 155, where the kitchens and Galley are located.

Unlike New Zealand's Scott Base, all Australian stations are comprised of separated buildings. With their three stations located in windy locations, fire safety has long been one of the highest priorities. The Australian Antarctic Division (AAD) felt that connected stations and those that were allowed to be buried by snow were too unsafe. However, snow drift is also a big problem in these windy locations, creating another incentive to separate buildings. "Careful orientation of buildings with regard to wind direction and building placement with attention to snow drift accumulation has resulted in clear doorways for escape in case of fire" (Nelson, 1991, Section 7.1).

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[345] Known by the Australians as "dongas."
[346] E.g., a blizzie (blizzard).

Therefore Mawson is laid out more like McMurdo Station, (spread out and with no building connections) but with a little more order to its layout.

> Building separation has resulted in stations which are quite spread out. This has been criticised [sic] as making stations look messy and creating more damage to the natural environment. The reasons behind the site layout which as well as fire protection include habitability issues and control of snow drift justify any disadvantages caused by building separation. (Nelson, Section 7.1)

This is in direct contrast to the approach taken by New Zealand's Scott Base (Section 1.4.4).

Additionally, all buildings materials were chosen for their fire resistant qualities. The polystyrene foam core in the wall panels would normally be considered a flammable material, but since it was treated with a fire retardant, will melt if exposed to a flame but will not ignite (Nelson, 1991, Section 7.3). The panels are further reinforced with two layers of half-inch gypsum plasterboard[347] (a standard practice) to provide a one-hour fire rating and prevent damage to the panels. All buildings are equipped with smoke detectors, fire doors, and escape hatches. Centrally located tank houses provide water for sprinkler systems; service mains are not located beneath buildings, which allows easier maintenance and prevents them from being consumed in a structure fire (Nelson, section 7.3).

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[347] South Pole station features "Type X" gypsum board on its wall panels (see Nomenclature). It is not clear if this type was also used at Mawson Station.

In 2003 Mawson Station integrated wind power into its power grid, which can now provide 58-95%[348] of the station's power needs (AAD, 2012b)[349]. It was the first large-scale wind-diesel power station on the continent. Because wind power is intermittent and the station needs continuous power, the designer of the system, Powercorp,[350] decided that a hybrid system was the best solution, allowing reduced diesel consumption with a continuous supply of energy. The use of short-term energy storage systems (i.e., flywheels, batteries, fuel cells) allows the station to maintain continuous power while power sources switch from wind to diesel generation[351] (AAD, 2012c). While the station resembles a smaller version of McMurdo Station (a small collection of colorful boxes by the shore), their integrated energy system and commitment to reducing human impact in Antarctica is a model for what could be possible, at a larger scale, on Ross Island.

Scott Base (NZ): ***corridor connections create homey sense of enclosure***

New Zealand's Scott Base (77°S, 166° E), sited on Pram Point, Ross Island (Figure A- 48), is McMurdo Station's closest neighbor. The two stations have a close, long-standing relationship of logistical and scientific cooperation, with McMurdo Station providing air and sea logistics program and the New Zealand Antarctic Institute,

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[348] The 95% figure is estimated for optimal wind conditions; 58% is the station's best monthly average (AAD, 2012b).

[349] A more recent estimate puts that number at roughly 70% (Priestly, 2012).

[350] In December of 2011 Powercorp was purchased by the Swiss company ABB. According to their website, they focus on "…power and automation technologies that enable utility and industry customers to improve their performance while lowering environmental impact." They were formed in 1986 when Allmänna Svenska Elektriska Aktiebolaget (ASEA) and Brown, Boveri, and Cei (BBC) merged. (http://www.abb.com)

[351] The Australian Antarctic Division (AAD) has documented their power systems at Mawson Station and published it online (AAD, 2012c).

often referred to as Antarctica New Zealand (ANZ), in exchange for U.S. access to airport and staging facilities in Christchurch, New Zealand[352]. Scott Base, with a peak population of 80-120 people, is small and homey in contrast to McMurdo Station which is large and institutional. However, the dependence on McMurdo for high volume fuel storage, helicopter pad, and three air strips allows Scott Base to operate on a smaller scale.

In 1962 the base was designated a permanent station, thus necessitating an upgrade to the existing structures. There had already been a few improvements to the station, which by this time had increased to 11 buildings. In 1965 the orange huts were repainted green, now known as "Chelsea cucumber" green.

Further expansion of the station in the late 1960s was followed by a general cleanup of the station and surrounding area as greater awareness of sustainable environmental practices took hold. As recently as 2005 Scott Base saw its newest building, the 9,687 ft^2 Hillary Field Center,[353] which provides heated bulk storage, offices, vehicle storage, a training room, and a gymnasium. It is a modern facility with large windows and energy efficient HVAC systems. Built by 8 people in 3 months, the building is "…demountable with pre-cast concrete footings and floor panels, and pre-

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[352] i.e., for clothing distribution as well as the airport. There are several other areas of cooperation, including medical facilities, fuel storage, and most recently the shared use of three wind turbines between Scott Base and McMurdo Station (which were funded by ANZ but transported and erected using USAP heavy machinery). Without the use of an airport and staging area in New Zealand, the logistics of moving U.S. personnel and supplies by air in and out of Antarctica would be much more difficult and expensive. However, without the logistical capability of the USAP, it is doubtful that the New Zealand Antarctic program would exist.

[353] Named after the New Zealand national hero Sir Edmund Hillary (1919-2008). Sir Hillary and Nepalese Sherpa mountaineer Tenzing Norgay were the first (confirmed) people to summit Mt. Everest. Sir Hillary accomplished many other adventurous endeavors, including participating in an overland trek to the South Pole.

formed steel framing" (Australian Observer Team, 2005, p. 14). Again, the small scale of the buildings allows for quick completion with a small team of people. In contrast, the Crary Science Lab in McMurdo, a 46,000 ft^2 facility, took over five years to complete.

Scott Base has a small footprint (compared with McMurdo Station) with buildings resting on timber piers that would be easy to remove "… with little residual evidence" (Australian Observer Team, 2005, p. 14). Even the older buildings, most of which have since been removed, have left little behind. As an observer team[354] noted, "[t]he site of the original Scott Base has been rehabilitated so that it is not visible unless pointed out" (Australian Observer Team, 2005, p. 12). The timbers piers (Figure A- 49) allow the station to resist some of the snow drift and elevate the station above the sloping ground.

Until 2009 electrical power at Scott Base came from diesel generators, just like nearly all other Antarctic stations. Before the wind turbines were installed in 2009, Scott Base was powered by three 225 kVA Caterpillar diesel generators located in two buildings away from the station (for safety reasons). Only one generator would run at a time, the other providing a level of redundancy necessary for safety. Waste heat from the generators supplements four diesel boilers to heat water.

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[354] "Article VII of the Antarctic Treaty provides that each Consultative party has the right to designate observers to undertake inspection in Antarctica. …The provision for inspecting is a key element of the Treaty and is designed to promote the objectives of the Treaty and ensure observance of its provisions" (Australian Observer Team, 2005, p. 6).

For heating and power, the station consumed about 119,000 gallons of diesel oil annually. However, now that the three wind turbines are fully operational, this number has dropped significantly, with the generators at Scott Base often silent, and the extra power flowing to McMurdo Station.[355] The numbers are difficult to separate between the two stations,[356] but the power provided by three turbines is reported to be the equivalent of burning 119,000 gallons of diesel oil annually, the former fuel demand from Scott Base. Some have noted that these turbines have changed the way power consumption is managed at the two stations because there are no longer two discrete power systems but one Ross Island power grid (Priestley, 2012). Three wind turbines are not enough to power both Scott Base *and* McMurdo Station entirely, but this proof-of-concept project demonstrates that one day on Ross Island diesel generators may be needed only for backup and emergency power. (See Section 5 for more information.)

Today the base is a series of small, interconnected green buildings set against a white, snowy backdrop: the inverse of the white English cottage surrounded by green trees and hills (ANZ, 2005). It has been modernized and most of the buildings essentially replaced, but its image has not changed much since it was first envisioned in 1956 as a temporary "… series of six huts connected by covered walkways…" (ANZ, 2005). Unlike Mawson Station, the New Zealand Antarctic Research Programme (sic)

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[355] With its annual demand of over 15 million gallons of diesel oil, the amount of power diverted to McMurdo Station is an insignificant yet important step in the direction of renewable energy.
[356] When the winds are not favorable and the turbines are not generating electricity, power from McMurdo Station provides power to Scott Base until their generators are back up and running; there is also a 6,600 lb. flywheel (1800 -3600rpm) at the base that can sink [absorb] or source 500kW for 30 seconds (Bennett, n.d.).

(NZARP[357]) chose to connect their buildings for safety (during severe weather events) and comfort.[358, 359]

The buildings were built both in Australia and New Zealand, with fire resistant foam cores and interlocking panels similar to the Australian design. The buildings of are spaced at least 25 ft. apart, but –in a striking departure from Mawson Station– they are connected by corridors (Brady, 2011, p. 129). These corridors act as both a passageway and a way to isolate fires; however, one could also argue they provide more ways for fires to spread and create an unnecessary risk. As a precautionary measure, the construction and materials of the corridor are fire retardant, like the rest of the station. Fire extinguishers and fire doors supplement a network of heat and smoke detectors connected to an automatic sprinkler system. Added to this layer of protection is the structure and materials chosen for the buildings; like Mawson Station, the walls at Scott Base consist of polyurethane sandwiched between panels of sheet steel. In addition, there is always at least a 27,700 gal. (105,000 liter) supply of water for dousing fires.[360] In a worst-case scenario, back-up from McMurdo Station is available if needed, since McMurdo Station retains a 24/7 firefighting crew[361] (Cudby, 2010).

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[357] NZARP was taken over by ANZ (aka, New Zealand Antarctic Institute) in 1996. On a similar note, the USAP used to be called the United States Antarctic Research Program (USARP) but (oddly enough) the word "research" was dropped in 1971 during the handover to the NSF. This is reported to be because the NSF was now responsible for both science and science support operations (NSF 2010, p. 3).
[358] See Section 4.1.5 for a discussion about building connections and fire safety.
[359] In ANZ 2005, find tab locations "1957 to present day" and "Designing and building Scott Base."
[360] Split between two tanks, this water is made up in part of the station's potable water supply, and is never allowed to fall below 40% (Cudby, 2010, p.23).
[361] Access for McMurdo Station to Scott Base can be cut off during bad weather any time of year, but particularly in winter.

The decision to connect the buildings gives Scott Base a unique feel: a small-scale station that feels homey but not too confined (Figure A- 51). It is similar to the design used in Halley VI, but it is not laid out in one long line. The different huts (buildings) allow for extra space and segregation of activities (unlike a station in which all activities essentially take place in the same space). The corridor connections allow people to move through the base without cold weather gear or the need to go outside (Figure A-50). The corridors are not kept as warm as the main buildings, but are not cold, frosty passages. They allow work to continue uninterrupted regardless of weather. Although fire is always a risk, it has been managed with a sprinkler system, fire retardant materials and smoke detectors). In addition, McMurdo Station would always be available if fire destroyed some or all of the base. The Australian bases like Mawson do not have this option.

APPENDIX G

DORMITORY DESIGN ALTERNATIVES

There are other approaches to dormitory design that deserve consideration. In regards to Danish architect Erik Asmussen's designs for dormitory facilities at a complex in Sweden, Coates (1997) notes that Asmussen's designs take into account more than simply fitting in as many people as possible into rows of identical rooms.

> As a building type, dormitories typically have stacked floors each with a number of identical rooms running along both sides of a long central corridor. The large communal bathrooms, which are designed to handle peak-load crowds efficiently, contribute to a sense that there is very little real privacy and that living with others is a stressful rather than pleasurable circumstance. Even with a shared social space on each floor, it is often hard to develop a feeling of community in such buildings. Yet double-loaded corridor plans have so many advantages in terms of efficiency and cost that they continue to be built even when their human costs are recognized (Coates, 1997, p. 40-43).

Asmussen saw that while residential facilities had to provide privacy in order for people to live harmoniously in a community, it was also necessary to forge a sense of community in these buildings that made up part of the complex. For example, it is worth looking more closely at the architecture and details of the residential facilities he designed for the Vidar Clinic.

APPENDIX H

MECHANICAL AND HVAC CONSIDERATIONS FOR MCMURDO STATION

Expanded Discussion of Site Planning (Section 4.2.1)

Historic Legacy

McMurdo Station was not originally intended to be a long-term installation, and so its original layout from the late 1950s and early 1960s was typical of military camps: temporary and functional for military operations. During this period the buildings were spaced closely for ease of access (which is also a safety concern during periods of low visibility) but far enough to impede the spread of fire. The Quonset huts and T-5 huts (see Appendix C) were laid out in a grid parallel with the prevailing winds and perpendicular to storm winds (Figure A- 8).

By 1959 the Naval Air Facility was roughly organized along two parallel "main streets" (Figure 35). Over the years, the original military organization, with its many small buildings and segregated facilities, became less apparent as the footprint of the station evolved. Since the 1970s, authors of long-range plans have recommended station consolidation, but few of these were ever fully executed, resulting in the haphazard building orientations that define McMurdo Station today.

Topography

The relatively ice-free tip of Cape Armitage (Figure 24) where the station is located is a steep, rocky beach with a good view of the McMurdo Ice Shelf to the south and McMurdo Sound and the Transantarctic Mountains to the west. The steep coastline to the south and the ice-covered high ground to the north and east[362] provide McMurdo Station with natural boundaries. The slopes to the north also shelter the station from the full impact of storm winds ("Planning for Tomorrow," 1993, p. 4). Buildings exist very close to the coastline, but the main parts of the station are located starting from about 80 ft. above sea level, with most buildings located on the slope between 80-120 ft. above sea level (ratio 1:5).

A road curves down the coastline towards the ocean and along the base of Observation Hill, which rises quite steeply (slope: 6:5). Because of the long distances and exterior-only access, vehicles are often required to move people or cargo from one side of the station to the other, especially from the steep coastline to service buildings in the heart of the station. This has been cited as an area for potential carbon footprint reduction.

Roads and Fire Safety

Keeping the roads clear is not just for convenience but safety. The original USN station had buildings laid out perpendicular to prevailing winds, with the roads parallel to them; this recommendation can also be seen in the UFC Design guidelines for Arctic and Subarctic construction (DOD, 2004, p. 1-6). Unfortunately the way the station has changed over time has not kept this layout.

Keeping buildings apart allows roads and access not only for cargo but emergency vehicles, specifically fire trucks. A number of buildings have payload bays

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[362] I.e., Fortress Rocks and Observation Hill (Figure 24).

designed to receive large vehicles and cargo/equipment. Large vehicles (bulldozers, DC-5s, drill rigs) must be able to access the road to the coast as well as the VMF and other places in the station. Dozers keep the roads free from snow accumulation. Large fuel tankers must pull up alongside storage tanks that fuel individual buildings (See Section 4.3.1).

Fire safety and access to buildings is very important for this large logistical hub, but such access often conflicts not only with the miles of insulated pipelines running throughout the station, but also with pedestrians with large hooded jackets which impede hearing and peripheral vision.

Utilities

Distance between buildings is also an important factor with regards to power lines, water and waste-water pipes as well as the waste heat loop (Figure A- 52, Figure A- 53). While unsightly, it is easier to maintain above-ground power lines than to bury them. The same goes for water, wastewater, and glycol pipes. The network of above-ground, highly insulated pipes is a daily reminder of the difficulties of providing basic services to the station. Siting buildings in a way that allows the pipes to be laid out efficiently helps keep their lengths shorter. Siting the buildings close to the central power house –and source of waste heat— allows the glycol loop to circulate around the station more efficiently (see Section 3.3.4).

Proximity to the Ocean

Proximity to the ocean also influences the location of certain buildings, mainly the seawater desalination plant and the wastewater treatment facility. These two buildings are located close to the coastline, with intake and outfall (discharge) pipes projecting into the ocean. However, locating the pump houses at a higher elevation (e.g., on Observation Hill (Figure A- 54) could help reduce the amount of energy needed to pump water to the station. Some long-range plans have suggested this in the past, but currently there are no plans to move the desalination or wastewater treatment plants.

Sun Path and Solar Heat Gain

There is potentially significant direct solar gain during the short summer months (November-January). Unfortunately the 360^{o} solar path makes it difficult (but not impossible) to harness the warmth provided by the sun that shines on vertical surfaces because of the low altitude angle above the horizon. One solution would be a 360^{o} sun-tracking solar collectors or building facade. However, during the winter, there would be no use for this feature since the sun never even rises above the horizon from April-August. The problem extends to photovoltaic solar power panels as well.

Prevailing Winds

Winds from all directions bring cold air and blowing snow, which drifts and collects around the buildings and in the streets. Because of this, roads must be cleared of snow regularly for routine traffic and emergency vehicles in case of fire. Snow drift must also be kept away from doors and emergency exits, as in a matter of hours it can quickly prevent access or egress. The distance between buildings is viewed as a way to reduce the spread of fire, a rule stringently followed at Mawson Station but reworked at Scott Base, with its hallway connections between buildings (see Section 1.4 and 3.2.5). (Building spacing can make a significant difference, but so can building form (see

Section 4.1.2) and building materials, which are increasingly allowing architects and engineers to create fewer, larger buildings, rather than multiple smaller ones (see Section 2.2.4.) UFC guidelines recommend orienting buildings so that their longest side is parallel to storm winds, along lines that are perpendicular to prevailing winds; in McMurdo's case, storm winds come from the south east and the prevailing winds are from the north east. If one looks at the original naval layout it is possible to see this recommendation in action (Figure 35) (DOD, 2004, p. 1-6). The idea is that large amount of blowing snow will not accumulate during storms. Additionally, in order to keep doorways clear, it is recommended that doors be placed on the upwind side, not downwind, where blowing snow may accumulate as it clumsily blows around boxy buildings.

Wind also affects the location and usefulness of wind turbines (see Section 5.2.1). Aside from make and model, safety mechanisms during storms, and backup power during "down times," wind turbines also need proper citing to maximize their efficiency. Drift patters may also affect the location of other relevant equipment, such as flywheels, battery storage buildings, and power stations. This is something future engineering and design will need to consider as wind power becomes a more prominent source of energy in Antarctica.

Expanded Discussion on Multi-building vs. Composite Building Station Layout (Section 4.2.2)

Aside from the point of view of heat loss through building form, it is important to step back and view the form of the station as a whole, not just at the individual building level (see also Pressman, 1998). Some Antarctic stations are relatively small, composed of one main building along with some older or ancillary structures (e.g., storage) and utility buildings. Others, like McMurdo Station and Mawson Station (see Section 2.3.4), have developed over the decades and are spread out, with dozens of buildings of all sizes. This dichotomy holds positive and negative aspects for both sides, so it is important to understand the implications of having either a single large structure or multiple smaller structures, and design them so that the negative aspects are mitigated.

In their document called the "Unified Facilities Criteria" (UFC) for Arctic and Subarctic buildings,[363] the U.S. Department of Defense (DOD) considered the differences between multiple versus composite building concepts for military buildings. This is a good place to begin.

First, noting that multi-building stations are often the result of remote sites, the UFC document points out that these more organic layouts suffer from large physical footprints and high heat loss from multiple exterior walls and roofs, which necessitate large capacity heating systems.[364] However, these losses may be deemed acceptable if

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[363] Overall, the document praises plans that meet three basic criteria: reliable, easy to access both in routine and emergencies, and simple (DOD, 2004, p. 1-1).
[364] Furthermore, the document notes, centralized heating and power systems require extensive distribution, something instantly visible in McMurdo Station.

one considers adaptability and fire safety to be a high priority. Multi-building stations can be flexible when it comes to building on uneven terrain, and in terms of HVAC systems (if there are certain small structures that do not require mechanical ventilation); smaller buildings also do not require complex foundations. Additionally, the authors of the document add that "[i]n cold weather there are psychological advantages in being able to get away from living and working areas by walking in the covered passageways" (DOD, 2004, p.1-1) .

However, the authors of the UFC document also acknowledge that composite-building stations have their advantages. Besides advantages like a lower surface-to-volume ratio (lower heating demand), lower construction costs (fewer roofs and foundations), and easier maintenance, composite structures also benefit from centralized heating (fewer distribution lines) and amplified savings for multi-story buildings. On the downside of course there is a great risk from fire spreading (great protection is required) and less flexibility when it comes to standardized building systems. The authors of the document recommend moving noisy, odorous functions (e.g., power supply) to a separate structure for the sake of health and morale of the station occupants. Although the authors of this document recommend the composite-building approach, they also indicate that it is best for remote and *small* installations. McMurdo Station outgrew this label decades ago.

Expanded Discussion on McMurdo Fire Safety (Section 4.2.5)

The specter of a structure fire in Antarctica drives many decisions in the design and layout of the station, and this will continue to be the case (DMJM, 2003, p. 2-13). The magnitude of the loss to fire of an entire structure –be it at the height of the season or the dead of winter– is eclipsed only by the loss of multiple buildings should the fire spread. As many Antarctic explorers (both past and present) have learned, it is important not to concentrate all supplies in one area, less that critical sled or person or structure be lost (see Section 2.1). Even with a mild breeze the speed with which fire spreads in the cold, desert air is alarming, and with supplies of liquid water at a premium, more often than not fires simply burn until there is nothing left. Often the best outcome is that the fire be contained to a single building or single part of a building. This makes building separation –by physical space or by the appropriate fire walls– a very important design decision.

Smoking is no longer allowed inside any buildings at the station, although this decision probably had more to do with indoor air quality than fire safety. Smokers must now stand some distance from exterior doors, often away from the protection afforded by building.[365] Special receptacles for spent cigarette butts are provided outside the building.

[365] Observations made by the author in 2009 and 2010 indicated this rule is not always observed.

As with Mawson Station, McMurdo divides and separates its buildings.[366] This allows room for roads and pipes to pass between buildings, and it provides an extra degree of fire safety (emergency vehicle access). McMurdo has many more buildings than Mawson Station, covering a larger area,[367] so unfortunately the effect is sprawl, a negative for environmental impact.

On a smaller scale, McMurdo's neighboring station, Scott Base, has taken a different route, although their basic approaches could be described as similar: "… stringent fire prevention measures backed up by 'early detection and massive, rapid response' (Cudby, 2010, p. 22). (For information about Scott Base's and its fire protection measures, see Appendix F).

Should McMurdo Station shift towards connecting its buildings, taking a cue from Scott Base would be a good place to start. Although the Scott Base corridors are essentially heated links between buildings, the idea could be adapted and expanded for McMurdo Station so that they also provide extra indoor space for residents, making use of the space between buildings. In addition to benefits already described, a passageway would also act as a large vestibule, reducing the amount of outside air entering the dormitories.[368]

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[366] The 2003 Long Range Development Plan (LRDP) pointed out, "…McMurdo Station was originally expeditionary in nature and was not intended to be a long-term, scientific research facility. Therefore, earlier facilities construction did not follow a logical or well-conceived development plan" (DMJM, 2003, p. 3-7).

[367] A shuttle van is available upon request for those needing to cross the station who do not wish to carry their load or walk out in the cold. This solution increases emissions and fuel consumption. "Walkability" was included in the most recent proposed update for the station in 2013 (OZ Architecture, 2013).

[368] Currently, there are no such inter-building connections with the exception of the 203 dormitory series, which was created for budgeting purposes and serves as nothing more than a large vestibule and a place

A recent proposed update to the station by OZ Architecture (see Section 2.2.4) included walkways between certain buildings (e.g., the station core, the Crary Lab, and medical). Some of these are labeled "structured walkways" and others "overhead walkways," presumably if they span a winter snow bank or a road. Although further details are not currently available, these walkways are simply ways to allow passage from one building to another, not destinations themselves. While the effort to improve safety and walkability is commendable, these structures have not yet reached their full potential.

The large fuel tanks placed around the station are also an obvious fire hazard; they also pose a significant environmental risk. Double-walled, they are nonetheless susceptible to the decay of time and the severe weather conditions. Placed in the middle of large craters surrounded by berms,[369] the tanks can hold over one million gallons of JP-5 or AN-8 fuel (see Section 5.1). In the past, steel pipes replaced flexible hoses to transport the fuel in an effort to make the station safer as the operation moved away from temporary fixes to long-term solutions. As the station grew, some tanks were relocated, also for safety, since their rupture or the rupture of the fuel lines presented "… a serious threat to the station" (Barber, 1968, p. 141). Ideally these tanks would one day be reduced in number and their contents used as a back-up supply of energy, or in as part of

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for recycling and trash bins. The large, central building acting as the station core (Building 155) features a hallway that cuts through the building – passing by the galley– and is often used as a shortcut for people needing to get to the other side (Figure A- 55). The Crary Lab, with its three phases sloping down towards the beach, also has a connecting hallway (Figure A- 56), but the phases are all considered one building. Proving a protected walkway between certain buildings does not have to be a fire hazard, and the result could become something more than just a hallway.

[369] Under UFC guidelines, these types of tanks are required to be behind dikes or have a double wall construction (DOD, 2004, p. 404).

a wind-diesel hybrid system (see Section 5.2 and Appendix F). Should they be moved or the station shift significantly, the placement of these behemoths and any fuel lines extending from them should be considered not only as a potential environmental hazard, but also a potential fire hazard.

Expanded Discussion on McMurdo's Boiler Systems (Section 4.3.1)

In an article which includes information from a veteran Antarctic HVAC technician, Fey (2009) discusses how the station's multiple boilers work, pointing out several areas in which it is necessary to modify the typical North American equipment for the harsh Antarctic climate. First, since jet fuel has a lower Btu content (about 22% less per gallon), it is necessary to increase the pump pressure at the burner[370] of these otherwise identical pieces of equipment (Fey, 2009). This change in pressure makes up for the lower Btu content of the JP-5 but of course requires more fuel.

Second, high winds common much of the year in Antarctica make conventional barometric exhaust dampers problematic. Storms that bring waves of cold air and gusts up to 70 mph can cause problems with the natural flue draft, causing the flame on the boilers to go out, or be "pulled away" (Fey, 2009). In a properly installed system, the damper will self-adjust the flow of air into the chimney flue. "When the barometric damper senses the draft is at its optimum level the opening will hover in the same position with the weight not acting on the system at all" (Michigan Precision

[370] In order to be used in a furnace or boiler, oil is atomized under pressure, creating a spray that is then ignited by a flame or spark, depending on the type of boiler.

Fabricators, 2011). At this point the damper will remain slightly open, and the system will be at equilibrium. When the weight attached to the vent is not properly adjusted the flame is at risk, or the damper flap can be in a constant state of flux, creating a noisy nuisance. In some cases of extreme weather, doubling up on dampers is necessary. When the dampers fail to protect the boiler flame, quick, knowledgeable action and system redundancy are essential.[371]

Hence, third, modular boilers provide a way for technicians to perform maintenance or even replace sections of the system (sometimes three or four boilers) without having to shut down the whole system, chill the building, or disrupting daily activities. Additionally, most systems are linked to a computerized monitoring system which sends an alert to a technician if one or more boilers go offline. This is important especially in winter with fewer people at the station and overnight, when many buildings would be deserted or its occupants asleep (i.e., not as aware of a temperature drop). Once a building loses its heat and becomes cold it can take days for it to become comfortable again, and it can lead to moisture problems. In the worst case, pipes containing potable water or water for fire suppression can freeze. Quick action by knowledgeable people –working with a handful of well-known boiler makers– makes this process much easier.

[371] In unusually cold or windy conditions –sometimes experienced in field camps- even boilers or oil-burning stoves with barometric dampers may not be able to be maintained. Heated mechanical rooms make this less of a problem in McMurdo Station.

Expanded Discussion of Heat Recovery (Section 4.3.3)

Taking advantage of waste heat recovery in McMurdo goes back to at least 1981, when heat from the power generators was used to boil seawater to make potable water, a highly energy intensive process (see Section 4.2.4). Today, the McMurdo power plant provides waste heat for nine buildings using a glycol loop.[372] Although the increased presence of wind turbines will reduce the amount of waste heat generated in McMurdo, the current heat recovery system captures waste heat from engine coolant and exhaust systems (Rejcek, 2011b). Even with a (predicted) decline in waste heat afforded by the three new wind turbines (see Section 5 and Appendix F), the 2008 RSA energy study recommended expanding the waste heat loop to more buildings deemed close enough to existing lines to make it more energy efficient.[373]

A second example of heat recovery methods is Davis Station (Australia), which uses plate heat exchangers to heat water that is then circulated around the station.[374] The exchangers, located in the main powerhouse with the station's four diesel generators, "…collect latent heat from these generators, transferring this heat into the primary heating hot water … service pipework system, which runs in a continuous ring main around station to all buildings requiring heating" (AAD, 2011).

A third example (this one a bit farther away and focused on a water-oxygen loop rather than heat recovery) is NASA's International Space Station (ISS). This station

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[372] Buildings 1 (Crary Lab), 4(Science Support Center) ,155 (Station Core), 165 (Mac Ops), 189 (JSOC), 196 (Power Plant), 198 (Water Plant), 208 (Dormitory), and 209 (Dormitory) (RSA, 2008, p. 31).
[373] The waste heat loop is considered supplemental heating, with the majority of building heat still coming from individual building furnaces.
[374] Plate heat exchangers work by using metal plates (large surface area) to transfer heat between two liquids, quickly and efficiently (see Section 4.2.4).

does not have the problem preheating frigid air for the intake, but it does face the challenge of having to create and maintain a breathable atmosphere. The solution is fitting for Earth-based life forms, for it is from water that occupants of the ISS obtain their oxygen. Working as part of the Environmental and Thermal Operating Systems (ETHOS), a water recovery system (WRS) draws water from crewmember waste and respiration.[375] The water is processed, distilled, and checked for purity. Some of this water (H_2O) is diverted to the oxygen generation system (OGS), which electrolyzes it.[376] The result is oxygen, which is sent to the living areas,[377] and hydrogen, which is either vented or sent into another piece of equipment which combines it with carbon dioxide to produce water and methane (NASA, n.d). This solution relies heavily on technology and a source of power but is elegant in its ability to operate in a closed-loop system.

Expanded Discussion of Logistics (Section 4.4.1)

The distance from the CONUS to McMurdo Station makes transportation of materials, supplies, and manpower a true logistical feat. Once executed solely by the USN, today it is a joint venture between NSF, the U.S. Air National Guard, Antarctica New Zealand, and the current USAP contractor, which is usually a large organization with experience in complicated logistical planning and often military ties (e.g., Raytheon, Lockheed Martin). In addition to flights for scientists and civilian support

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[375] That is, urine and "…cabin humidity and condensate…" (NASA, n.d.).
[376] I.e., the OGS breaks apart the water using a small amount of potassium hydroxide and a 50 amp current (NASA, n.d.; NASA, 2008).
[377] Here it is also necessary to provide forced air circulation since there is no natural convection in microgravity. Having a well laid out airflow pattern keeps pockets of CO_2 from forming around ISS occupants and creating respiration problems (Cristoforetti, 2012).

personnel, food and supplies, building materials, and mail arrive by air. Some supplies come from CONUS, others from New Zealand (e.g., fresh food). Once a year, a supply ship brings fuel oil and other heavy equipment, construction materials and dry goods that can be scheduled a year in advance and can tolerate the long trip from Port Hueneme, California. When the ship arrives at McMurdo is preceded by an ice breaker –usually not an asset of the U.S. The supply ship returns to the U.S. laden with a year's (or more) worth of trash, human waste, failed mechanical equipment, and recyclables.[378]

The enormous costs and logistics of this transport needs to be acknowledged but is not within the scope of this study to identify and price each stage of production, delivery, and then carbon footprint for a lifecycle cost. However, it is recognized that such an accounting is needed, especially when considering the journey all building materials must make in terms of distance, weight, dimensions, ease of construction, longevity, and durability.[379] These challenges are amplified by the very cold temperatures, unpredictable weather delays, and a very short construction season.

Expanded Discussion on Sound and Vibration Control in Dormitories (Section 4.4.2)

In the McMurdo Station dormitories, there are two main potential sources of noise: mechanical equipment (including ducts and pipes) and the building occupants. Sources of information on the control of mechanical system noise and vibration control

[378] Any people, materials, or waste coming out of South Pole Station also passes through McMurdo.
[379] This is also relevant with regards to the need to minimize fuel demand and reliance on fossil fuels. This is addressed in Chapter 5.

include ASHRAE, HUD, the NBS, OSHA, and the Acoustical Society of America. ASHRAE includes this information in their *Handbook for HVAC Applications 2011*, in the chapter, "Noise and Vibration Control." These guidelines are also referenced in design guidelines for hospitals, since the reduction of these types of unwanted sound (i.e., noise) can contribute to the well-being of patients.

To contain the noise and vibrations of a mechanical room or a noisy lounge, the main objective is to dampen as much of the sound and vibration as possible and keep it from spreading throughout the structure: in other words, to isolate it.[380] What the lounge or mechanical room becomes is essentially a "box within a box," with sound and vibrations transferring to absorptive pads or springs below and above the room instead of the building frame. Equipment can rest on inertia blocks, which must be supported by a floating floor that will not sag (eliminating the effects of sound absorption). The hanging ceiling above and below the floating floor must also be specially designed, with an additional absorptive layer in the cavity above the suspended ceiling. Walls face less of a problem from this kind of noise transference, but must still be protected from noise like loud talking, music, and television. Even the detail of padding room doors to prevent them from slamming shut should not be ignored. Details of all these construction specification can be seen in HUD's *Guide to Airborne, Impact, and Structure-Borne Noise Control in Multifamily Dwellings* (1974).

[380] Even before this step, choosing equipment with low sound power output ratings, locating it away from dwelling areas, and installing it correctly can greatly reduce equipment noise (HUD, 1974, p.5-5--5-7).

The construction documents for South Pole Station are also a useful reference; it is not surprising that OZ Architecture looked at successful solutions tested at the station and incorporated them into their plan for McMurdo Station (Petersen, 2013). For example, the "emergency power generation/fan room," which is contained within the main building in Pod B and located under the "game room/emergency," shows the presence of 2 inches of Tectum Finalé, a panel systems "…for spaces that require a Noise Reduction Coefficient of .75 to 1.00" (Tectum, Inc. n.d.).[381]

Stairwells can be very noisy places, especially when they are linked with vestibules. Groups of people tromping up and down the stairs in their bunny boots or heavy hiking boots can create both noise and vibration, especially for rooms adjoining the stairwell. Additional doorways (i.e., unlinking them from vestibules), different siting of rooms, or extra acoustical dampening features are required to keep these transitional spaces quiet enough for a dormitory.

Individual rooms, which need to be protected from the noise of neighbors' music, conversation, and snoring/coughing, do not have to be quite so robustly protected, but should again refer to hospital or even hotel design for noise control. The goal is not to meet HIPPA guidelines for privacy, but rather facilitate good sleep and eliminate a noise from a list of possible source of stress. This extra protection may mean more costs for structure and materials, but the benefits of well-rested employees are difficult to overlook.

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[381] These values mean that the room absorbs nearly all of the sound.

In healthcare design, noise reduction is taken seriously, as there is extensive research that shows it worsens patient outcomes by increasing blood pressure and raising stress levels (Ulrich, et al., 2006, p. 40). McMurdo Station dormitories do no house ill or recovering patients, but being well-rested and productive is extremely important to those who work at the station; those who do catch a bug will fare better with good quality rest. The dormitories may not experience the noise levels of hospitals, but since they house both day and night shift workers and provide places that are not meant for sleeping (e.g., lounges, hallways, showers, laundry rooms) which may produce noise, making sure those functions to not interfere with each other is important.

In hospitals, providing single-bed rooms are not only helpful in preventing the spread of disease, it also protects patients from excess noise (as well as a reduction in privacy). Room materials like high-performance sound-absorbing ceiling tiles also help, although carpet is usually discouraged because it is more difficult to keep clean.[382] Lighting fixtures should not generate a noisy buzzing sound. In hospitals, doctor's beepers and paging systems can be made to alert silently; in McMurdo Station this is also applicable because many people are on call (e.g., mechanical technicians) and carry with them beepers, alerting them to call using one of the many phones located around the station or in their room.

Expanded Discussion of the Pros and Cons of Different Structural Systems and Materials (Section 4.3.3)

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[382] In McMurdo dorms it is preferred, not just for sound absorption but also comfort and safety (floors slippery floors from melt water).

At a temporary station such as Byrd (1961), it was possible and sometimes desirable to bury the buildings in the snow. This not only partially alleviated the snow load on the roofs,[383] but protected the walls from the force and noise of the wind (NSF, 1962, p. 58). A similar approach was used at Camp Century in Greenland (1959 - 1966), in which 21 massive tunnels were created below the snow, in part an effort to camouflage the station (Clark, 1965) (see Appendix C). Amundsen and his men found that once their hut became buried by snow, not only were they better insulated from cold and noise, but were able to tunnel in the snow, expanding the total square footage of their winter dwelling.[384] Today most stations built on ice shelves are designed to resist being buried (see Sections 2.3.1 and 2.3.3). In McMurdo, which is built on the dark, hard soil[385] of Ross Island's active volcano, Mt. Erebus, it is not possible to dig into the snow to gain its protection, and there is no need to resist the movement of an ice sheet. Instead, structures must remain above ground, anchored to frozen soil, and must be able to withstand the full force of wind and blowing snow.

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[383] "Trenches are cut with 'Peter' snow-milling machinery and are roofed over with arches of corrugated iron; insulated buildings are then constructed in the trenches and thus the pressure or snow on roofs is minimized" (NSF 1962, p. 58).

[384] The solution to these comforts was discovered by accident. As well as Amundsen had prepared, somehow he and his men had forgotten to pack any snow shovels. As one expedition member set out to make some, the snow drifted alongside the Framheim, until they day the shovels were ready. A suggestion to tunnel into the drift instead of clear it away was instantly accepted (as they were in dire need of a place for a carpenter's shop), and before long they had an entire "underground village" allowing each member to have a small private work area (Amundsen, 1913, p. 269-270).

[385] Specifically, black basaltic bedrock and rocky soil. "Below 8 to 24 inches … the ground is permanently frozen and generally consists of angular basaltic rock particles cemented with ice" (Keeton & Stehle, 1969, p. 1-2)

Early Structural Systems

The earliest structures built by the USN on Ross Island were prefabricated rectangular huts, metal Quonset-style huts, and Jamesways, a tent-like structure similar to Quonset huts (see Section 2.2.1). Built for military defense forces working in many different climates, Quonset huts were easy to construct and modify to specific site conditions or programmatic needs. They were in particular well suited to the demanding conditions of the Antarctic, provided they were fitted with extra insulation. They are also easy to package and transport on a large aircraft like a C-130. It is still possible to see Quonset huts on the station today, because of their age and limited lifespan, they are no longer as well insulated as newer structures and are generally not being renovated.

Wood Frames

Wood is a very good material for cold environments if builders take proper precautions. Wood is lightweight (compared with steel), easy to work with, durable, and even gains some strength when the temperature drops (Eranti & Lee, 1986, p. 377). As long as proper adhesives are used (water-resistant and able to endure the freeze-thaw cycles), the only other problem faced by wood is exposure to water or excessive moisture, which can lead to shrinkage, cracking and rot (Eranti & Lee, 1986, p. 379).

Until recently, wood-framed buildings had long been the standard in Antarctica. These tend to be smaller buildings, relatively light, easy to assemble, and with proper heating and insulation, quite comfortable. Since the operation in Antarctica was intended to last a few years at most, wood frames seemed adequate. The Arctic T-5 (see Appendix B) buildings were a perfect solution and were easy to customize for size and layout. Indeed, the Quonset hut and T-5 designs were born out of a time when steel was in short supply.[386]

However, wood frames tend to be more susceptible to the spread of fire, and over time these buildings tend to age poorly.[387] They are also not capable of the size and strength of steel-framed buildings, which are now the most common sight for large buildings and new stations, especially those which must resist snow drift, like Halley VI (see Section 2.3.1). Mostly wood studs are used for interior walls only.

The UFC criteria recommend that if the structure is a wood frame, it should be finished with 5/8" fire rated Type X gypsum board (see Appendix Q; provides a 1-hour fire rating).[388] Any exposed wood should be treated with retardants, meaning that compatible fasteners should be used as well (DOD, 2004, p. 2-3 – 2-4) (see also Section 2.3.4).

Metal Frames and Applications

While aluminum is a very good choice for building in cold climates, steel tends to dominate. Aluminum has no ductile-to-brittle transition[389] (like wood, it tends to increase in strength as the temperature drops); it has few problems with corrosion, is

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[386] Most steel was diverted for the war effort (WWII).
[387] The wind takes toll on the wood, and the dry air will further desiccate the material (Freitag, & McFadden, 1997, p. 335).
[388] The UFC guidelines for Arctic construction also point out that, when it comes to vapor barriers/ retarders, "[p]olyethylene sheet does not meet the flame spread and smoke development rating …. It may be used, however, if covered by properly designed gypsum wallboard or a fire resistant material. The polyethylene material is considerably less expensive and easier to install than the other vapor retarders, resulting in fewer and better sealed joints and providing a more effective end product" (DOD, 2004, p. 2-12).
[389] "The ductile to brittle transition is characterized by a sudden and dramatic drop in the energy absorbed by a metal subjected to impact loading. …. As [the] temperature decreases, a metal's ability to absorb energy of impact decreases. Thus its ductility decreases. At some temperature the ductility may suddenly decrease to almost zero" (Meier, 2004).

easy to weld, and has a low weigh-strength ration (Eranti & Lee, 1986, p. 380). Steel is nearly as good and tends to be less expensive, thereby becoming the choice for most arctic construction. Aluminum is preferred for smaller applications, such as window frames, bolts, and corrugated sheets (Eranti & Lee, 1986, p. 380). It is also possible to treat steel for increased ductility at low temperatures[390] (DOD, 2004, p3-1).

Non-governmental military buildings in Arctic and Antarctic climates follow a code known as the Unified Facilities Criteria (UFC), which advises that steel structures in these cold climates should be outfitted with: 1) adequate fillets (avoids stress risers), 2) use of bolted joints when possible (as opposed to welded joints, 3) if joints are welded, limit impurities and ensure proper preheating and post cooling, and 4) steel structures made of low-carbon steel and nickel-alloy react well to low temperatures (DOD, 2013a, p. 45-46). While McMurdo is no longer governed by the military, information from the UFC could still apply.

Metal buildings tend to be stronger and more permanent. In a metal building the risk of fire is somewhat lessened, especially with the use of fire walls.[391] Moisture is less of a problem, although interior walls still tend to be wood-framed and therefore vulnerable. Heavy, metal-framed buildings also tend to be more difficult to disassemble,

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[390] One method is by adding nickel to the steel composition, but it may also increase costs (DOD, 2004, p. 3-2).

[391] Fire walls should be strong enough to remain upright even when adjacent walls have collapsed because of a fire, for the length of time identified in their rating (e.g., 1-hr, 2-hr, etc.). Fire walls are generally created by applying fire-rated sheet rock (5/8") to a stud wall. Every 5/8" layer of sheet rock adds 30 minutes to the wall's fire rating, so a stud wall with a layer of sheet rock on either side creates a 1-hour fire rated wall, provided that any penetrations (pipes, windows, doors) is sealed per NFPA standards, e.g., NFPA 80: Standard for Fire Doors and Other Opening Protectives; NFPA 105: Standard for the Installation of Smoke Door Assemblies and Other Opening Protectives

a tradeoff of their permanence. In McMurdo there is need for a balance between large, permanent structures and smaller, lighter, and more temporary buildings.

Concrete

The use of concrete construction Antarctica has a limited history, but its very presence was one signal that McMurdo Station would indeed become a permanent establishment. By 1968 this change was in full swing, with the newly-completed, relatively huge Building 155 replacing several Q-huts and Jamesways. Consolidation was the word of the day, and it was seen not only as a way reduce maintenance costs but also to conserve energy, i.e., "… economy of heating and compact utility systems" (USN, 1968, p. 36).

According to the UFC design guidelines (DOD, 2004), the use of concrete in the arctic and subarctic regions is favorable, as long as certain precautions are taken (DOD, 2004, p. 2-1 and 3-2). In this document it is described as durable and with high fire-resistant qualities, but it must be protected from moisture penetration (i.e., air entrained).[392] Quality control in the field is also more difficult, and the document cautions that the architect must carefully weigh the costs of shipping cement and aggregate versus shipping precast pieces.[393]

Unlike stations built out on an ice shelf, stations built on land had a relatively limited area in which to operate. Additionally, it was well known by then that it was

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[392] See Appendix Q

[393] Recently, concrete foundations for the Ross Island wind farm were imported rather than poured in place (which is typical). The decision was made in order to protect the environment from scraping for aggregate –which may be found to be inferior. The resulting "spider" foundation design was prefabricated and shipped to the site (Miller, 2010, p. 16). See Section 5.2 for more information about the wind turbines.

absolutely necessary to protect the integrity of the permafrost: wooden footings became a popular way to elevate these newer, more permanent buildings, and "…short concrete pillars offer[ed] promise" (USN, 1968, p. 36).

The American Concrete Institute (ACI) specifies conditions and techniques for working in cold weather, but not in temperatures below 20°F, which is quite often the situation at McMurdo (American Concrete Institute, 2002). In the late 1960s the NCEL conducted a study on the practicality of mixing and pouring concrete in Antarctica, specifically at McMurdo Station (Figure A- 57). The idea was to increase the permanence of the station as it became clearer that it was going to be a long-term installation. It would also reduce the amount of construction materials needed to be shipped or flown to the station (Keeton & Stehle, 1969). Additionally, pouring concrete on site would require less time than the current practice at the time: creating foundations of earth fill. This process amounted to a very slow strip-mining process of the surrounding hillsides,[394] a process which could take 12 months while the construction season was only four months (Barber, 1969).

The results of the study showed that there were sufficient quantities of appropriate aggregate nearby and that acceptable results could be achieved with an appropriate mixture of rock and aggregate mixed under specific conditions (Keeton & Stehle, 1969; Keeton 1970). To obtain rock for the tests run by the NCEL, they blasted 500,000 cubic yards of permafrost from a place known at the Fortress Rocks Quarry just

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[394] It was a sight to see: large bulldozers creeping up 50° slopes and then sliding down, blades lowered, to scrape about 2-3 inches of soil per day (Wilkinson, in Barber, 1969, p. 242).

northeast of the station (Figure 24). It was here, tests determined, that the best rock aggregate could be found (Keeton & Stehle, 1969). Many structures in McMurdo do not rest on cast or precast concrete slabs,[395] but rather are steel structures raised on precast concrete footings (Figure A- 58, Figure A- 59, Figure A- 60). Difficulties caused by the cold air, blowing snow, and limited source of local aggregate require most concrete footings to be cast offsite (off-continent) and impedes the practice of pouring large slabs, which require a certain temperature range over a long period of time in order to set properly. How often aggregate is mined for concrete in McMurdo today is unclear, but most concrete pieces are precast off-site, and large scale pouring is not feasible (Law et al., 2006, p. 6). Slab-on-grade would znever be desirable in this location because

> [s]oils [here] are predominantly volcanic gravel containing very little moisture (other than ice crystals). Voids in the lower lava and basalt formations and immediately below the rock surface are commonly filled with ice from refrozen snow melt. The ice-rich permafrost thus has more ice than pore space and earthslides or mudslides could result if the thawing occurs. Antarctic design parameters require that buildings be elevated to prevent heat transfer. The crawl space below needs to be accessible, this cross bracing or other framing [should be] minimized. (Law et al., 2006, p.1444).

[395] The few that are include the Science Support Center, the Vehicle Maintenance Facility (VMF), and utility buildings such as the power house and the seawater intake facility. The oil-and-grease-soaked wooden floor of the old VMF was cited as one of the reasons the fire at the building spread so quickly (see section 3.2.3).

This cold-climate solution is also extolled by Lstiburek (2009) as an elegant solution to protecting the integrity of the permafrost.

Prefabricated Building Parts

The "historic huts" from the turn of the century were all prefabricated buildings, labeled and shipped in pieces. Today's prefabricated buildings offer not only speed of construction but also a higher precision of the building components and connections. It can also be an economical choice; however, it is important to remember that these savings can be offset by higher shipping costs, especially when being transported to Ross Island on palates loaded in a C-130 or on the annual supply ship (DOD, 2004, p. 1-8).[396]

Prefabrication of buildings is one solution to a short building season although it also has its problems. For instance, if everything is built to high precision in an off-continent factory, it is more likely to be well sealed. Both Princess Elisabeth station (Belgium) and Halley VI (UK) were built this way. However unless there are spare or duplicate panels, if one of these large, prefabricated parts is damaged during transport or construction, there may not be an easy way to replace it on site, especially if it is a unique piece. These problems can be addressed with careful handling, detailed planning, and spare parts. This might include relying on keeping a surplus of a limited number of pre-fabricated types.

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[396] This might weigh the decision to use prefabricated concrete parts, an option praised in the UFC Arctic design criteria (DOD, 2004, p. 2-2), but perhaps not well suited for a site as remote as McMurdo Station.

High precision construction can ensure tight seals between joints the help lower air infiltration, one of the principal factors behind the building's overall energy efficiency. Walls, windows, and roof structures must also withstand very low exterior temperatures, large pressure differences (depending on the orientation to the wind), and spindrift of both snow and fine volcanic soil. Prefabrication also reduces on-site construction waste (and subsequent shipping loads). Structural insulated panels (SIPs) and vacuum insulated panels (VIPs) are examples of a type of prefab construction method already in use in Antarctica (i.e., SIPs) and possibilities for the future (i.e., VIPs).

Structural Insulated Panels (SIPs)

SIPs were first conceived of in the 1930s by the Forest Products Laboratory (FPL) in Wisconsin.[397] The panels featured some type of insulation, but it was not until the 1950s when the first foam core SIP was invented by Alden B. Dow, the son of the founder of DOW Chemical Company, Herbert H. Dow.[398] The popularity of the SIP increased, but the industry did not really take off until the 1990s with the advent of computer aided drawings (CAD) and computer aided manufacturing (CAM). SIPs are generally sandwich panels composed of a variety of materials that form a rigid skin on two sides, which is then bonded to a core (usually a foam product such as polystyrene or polyurethane).

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[397] The main idea behind the panels was that they would require less wood as a material and for framing.
[398] Alden Dow was also a student of Frank Lloyd Wright.

The advantage of the panels is that they can be factory built, easily shipped, and assembled very quickly, a useful feature for McMurdo Station. The panels come in an array of standard sizes and vary in thickness from about 4.5 inches to just over 12 inches, depending on climate and structural needs. The amount of framing required is small when using SIPs, reducing the total amount of wood needed for the building, as well as the weight of the wall. This idea, taken to an extreme, can be seen in the Belgian base Princess Elisabeth, with its hyper accurate fabrication and seven-layer walls (Figure A- 46). However, the use of SIPs requires that wiring and plumbing that is normally inside the framed wall be carefully planned well in advance of construction so that perforations are not necessary and wiring and plumbing installations are not dangerously exposed.

Vacuum Insulation Panels (VIPs)

Also on the forefront of wall insulation technology are vacuum insulated panels, which can achieve an R-35 (IP) per inch[399] (Mukhopadhyaya et al., 2008, p. 110). These panels cannot be used to replace a wall's structural framing in the way SIPs can, but rather are one thin layer in a conventional wall. By harnessing the increased thermal insulating potential of a porous material that has been subjected to a vacuum, researchers have been able to create panels with high insulation values (up to 10 times higher than contemporary wall systems of comparable thickness) without sacrificing space through bulky construction. They are generally made of noncombustible materials.

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[399] A German company called va-Q-tec advertises a a VIP panel (va-Q-pro) with a stated U-value of 0.18 W/(m²K) (0.03 Btu/in^2 ^{o}F) at 20 mm thickness, or R-31 per 0.78 inch.

These new vacuum panels, whose development is being led by researchers at the NRC in Canada, are especially useful in very cold climates. At the moment they are still very expensive, but research to bring their cost down (mostly though alternative core materials) is underway. There are concerns with the VIPs' vulnerability during the shipping process and during construction, when even a tiny penetration could compromise the integrity of the panel's vacuum layer, which seriously reduces the panel's R-value.

Additionally there are still problems with the aging of vacuum panels, as air or vapor could slowly leak into the core, which eliminates the vacuum and lowers the thermal resistance (Mukhopadhyaya et al., 2008, p. 111). This would be a challenge for the long journey to McMurdo and the long term - maintenance of the structure. However, if these problems are solved, a thin wall providing R-60 or better could change the way the station looks and feels.[400]

Aerogel

A translucent VIP has not yet been made practical because current technology does not allow the seal to remain gas-tight (Schneider, 2011, p. 883). However, the emerging field of silica aerogels is filling the void –literally– of the weak point in walls –their windows. Aerogels are lightweight materials[401] with a very low density and thermal conductivity that allow for the transmission of visible light. They are created by

[400] In their 2003McMurdo Station LRDP, DMJM recommended that future construction achieve R-values at least as good as the newly completed SSC. These were listed as R-40 for all types of buildings (roof, wall, and floor), with window U-values also consistently at U-0.25 (DMJM, 2003, p. 4-12)
[401] Generally aerogels are only about 15 times heavier than air (http://www.aerogel.org), making them still much lighter than other insulation materials.

slowly removing liquid from a gel (e.g., silica or aluminum oxide).[402] What remains is mostly gas (air) –a poor thermal conductor– and the solid, e.g., silica, which is also a poor thermal conductor. Aerogels are not technically a prefabricated building part, but they would probably have to be transported to the station already installed in a frame to prevent any damage.

While it still has a higher conductivity than a VIP, and aerogel can improve window R-values greatly. A window designed for a cold climate like the Canadian high Arctic would typically have a U-value of between 0.3 and 0.14 (R-3.3 – R-7), depending on a number of factors.[403] Although this is a much improved U-value for a window, in a wall that might be R-60 it is still a major source of heat loss. Windows incorporating aerogel can have a U-value 2.5-4 times less than conventional gas-filled triple-pane windows, and aerogel windows do not necessarily add extra weight. They offer high performance and would not require movable insulation. Their light-diffusing characteristics add another benefit, bringing light deep into rooms and reducing glare. Aerogel windows also have the ability to dampen sound, a testament to this material's ability to improve energy savings and interior comfort (Schneider, 2011, 883).

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[402] Specifically, they are the "dry, low-density, porous, solid framework of a gel (the part of a gel that gives the gel its solid-like cohesiveness) isolated in-tact from the gel's liquid component (the part that makes up most of the volume of the gel) (http://www.aerogel.org).

[403] These factors include the type of pane, number of panes, the type of inert gas fill between the panes (e.g., krypton or argon), the solar heat gain coefficient (SHGC), and the tightness of the window

Halley VI (UK) features a light-diffusing silica aerogel known as OKAGEL in the windows of their red, double-height main pod (Figure A- 39).[404] OKAGEL is 97% air and weighs 0.63 lbs./gallon (Okalux, n.d.).[405] The east-facing 2,543 ft^2 ($72m^2$) window contains OKAGEL, which has a reported U-value 0.05.[406] A typical, gas-filled window with a butyl seal would not withstand the extremely low temperatures and would allow gas to leak and moisture to penetrate the window cavity (Schneider, 2011, p.886). For these reasons, the British design team decided aerogel was the best option.

Moveable Insulation

Supplemental or movable insulation provides extra protection but is often a problem itself. Exterior shutters can be lost or damaged during an Antarctic blizzard, not only failing to perform their job but becoming a safety hazard as large flying projectiles. Interior shutters may cause condensation problems, something already an issue in some buildings. Although curtains can reduce drafts, they can sometimes create condensation problems.[407] For example, a double-pane window remains frost free down to -20^{o}F, but when it is covered by a curtain, that point goes up to about 0^{o}F, with condensation forming around 15^{o}F. These numbers are higher the more panes of glass are present (DOD, 2004, p 2-8 – 2-9).

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[404] Other windows of regular size are triple glazed with a low-E coating on the two inner layers to absorb heat. They are filled with either Xenon or Argon gas, with U-values of 0.08 [0.45 W/(m^2C)] and0.12 respectively (BAS, n.d. p.42).

[405] 75grams/liter = 0.625905328 lbs./gallon

[406] U < 0.3 W/(m^2K)

[407] This occurs when the dew point is reached on the inner window pane surface of the window, but the curtain can also trap spindrift which can melt once it is inside, causing more problems for windows with infiltration.

Makeshift interior insulation (in the form of large foam window plugs is already in use in a number of buildings because of drafty windows and uncontrollable spindrift (Figure A- 61). These foam pieces, attached to plywood and outfitted with handle for easier lifting, are heavy and cumbersome, and they effectively remove any usefulness or pleasure brought by the window. Obviously the best solution is not to need the extra insulation, which is possible with aerogel or other high R-value windows. In a recent study, the Cold Climate Housing Research Center (CCHRC) in Alaska determined robust, well-installed windows do not get much benefit from additional insulation. Movable insulation brings with it extra costs, other problems (e.g., added maintenance, condensation, additional cost), and does more good bolstering the effectiveness of older or poorly constructed windows than new, well-constructed windows (Craven & Garber-Slaght, 2011).

Additional Material Considerations

Additional considerations for energy efficient materials to be used in Antarctic stations include the following:

1) All materials exposed to the elements should pass endurance for extreme cold, temperature swings, and other harsh conditions. For example, the glass sealant used in the windows at Princess Elisabeth was chosen for its strengths in resisting these extreme conditions as a silicone, which also exhibit " …high tensile and tear strength, long-term flexibility, resistance to harsh, weather, temperature extremes and ultraviolet light and excellent adhesion [to] building materials" (Dow Corning, 2010).

2) Antistatic interior finishes should be considered, especially on floors and door handles. In the dry Antarctic environment, the repeated experience of small electric shocks to the hands can become a tiresome recurrence. Additionally these finishes can reduce the risk to sensitive electronic equipment in laboratory or communications equipment. Safety measures are already in place at McMurdo's "gasoline station," where a grounding device is provided to protect people and vehicles during the refueling process.

3) Ergonomic shapes will not only provide a more pleasant experience but can sometimes be a matter of safety; for example, door and door handle design. Many buildings have doors that are essentially refrigerated building doors, heavy and with large push-activated deadbolts or long-handled releases. Other buildings and many interior rooms rely on door knobs, which can be difficult to grip with gloves and nearly impossible to manipulate with mittens. These should be avoided. Railings near steps are a similar problem –not their absence but the distance to them and the feel of the grip. In the same vein, interior circulation patterns should be considered as matter of designing for a human scale. The width of major hallways should be addressed in section to ensure easy passage of 2-3 people of American proportions wearing "Big Red," the large winter parka ubiquitous during the Winter and Win-fly seasons.

4) Sensory reactions, such as sounds, sights (colors) and smells should also be considered as part of the health and well-being of the station inhabitants. With so much time spent indoors, especially during the Winter and Winfly seasons, the interior design should not be left as a final thought. The designers of Halley VI incorporated these ideas

early on in their design, keeping sleeping areas away from nosier pods (e.g., social areas and plant areas) and using designs and materials that limited noise transmission (see Section 4.3.2). Colors were used to designate different areas, and those colors were chosen to fit the program, being either more energetic in social areas or soothing in private, quiet areas. While there are very few natural smells in the Antarctic and the human body tends to sweat less in the arid environment, there are still smells from food preparation, engine exhaust, and (eventually) body odor.

APPENDIX I

THE IGLOO

One example of building form for cold climates is the igloo, which has been used by high Arctic populations in various forms (Cook, 1996, p. 280). Its form and materials are a prime example of indigenous architecture responding to climate (Bull, 2000). Gonzalez-Espada, Bryan, and Kang (2001) provide equations that show how the insulating properties of snow and ice can keep the inside of an igloo above freezing, even when the temperature outside the igloo is below freezing, without destroying the structure. Igloo-building techniques are still taught in survival courses for teams working outside of McMurdo Station; in the event of an emergency or stranding away from town, a proper shelter can mean the difference between life and death. In the Arctic, the igloo is regarded as "…solid, sound-proof, and wind resistant, and large enough for comfort…" by the indigenous peoples who use them (Cook, 1996, p. 280). Also advantageous is that the building material (snow) is plentiful during winter months, costs nothing, and can be rebuilt each day in a new location as needed.

Indeed, the simple, clean form of the igloo belies its careful construction, design, and relatively small volume inside requires thoughtful organization for the inhabitants: animal pelts or sleeping bags along the edges of the wall with low clearance provide an extra thermal barrier –tallest people sleep in the middle, and the cook sleeps near the stove. There is also order to the structure: the entrance should lead to an elevated shelf upon which people sit and enjoy a higher temperature, the aerodynamic walls should be symmetrical to avoid a “pointed” igloo with and undesirable thermal stratification, and a vent hole in the ceiling must be created and maintained to provide adequate ventilation (Cook, 1996, p. 281-282).

Snow itself has significant insulating properties. “New snow is composed of a high percentage of air trapped among the accumulated snow crystals. Since the air can barely move, heat transfer is greatly reduced. Fresh, uncompacted snow typically is 90 to 95 [%] trapped air” (National Snow and Ice Data Center [NSIDC], n.d.). Igloo walls have been estimated to be approximately R-3.5 (Thomas & Garnham, 2007, p. 204).

APPENDIX J

MCMURDO STATION AND THE FIRE CODE

Fire detection/prevention

The first line of defense once a fire has started is the smoke detection and fire suppression system (Figure A- 62, Figure A- 63). These systems are covered in Chapter 9 of both the International Fire Code (IFC) and International Building Code (IBC), and in the National Fire Protection Association (NFPA) 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*.

Installing heat or heat/smoke combination detectors in rooms, hallways, attics, bathrooms, and boiler rooms covers all major areas. These detectors should be connected with a central control panel activates an alarm and alerts the fire department. Dormitories are not usually equipped with pre-action sprinkler systems,[408] but in McMurdo, because there may not be alternative housing, a system that limits false alarms is beneficial, and is currently what all but the oldest dorms rely on. The current system is connected to a water reservoir (located in another building) and a pump system. Fire-flow and flow durations for water-delivery systems are determined by construction type and square footage, and can be found in the IFC, Appendix B (Table B105.1).

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[408] Pre-action sprinklers require two triggers before releasing water (or a fire-retardant agent). For instance, there must be a drop in pressure and a certain temperature (e.g., 155^{o}F) reached before the system activates. These systems are more common for buildings that hold sensitive equipment.

Currently only the newest McMurdo Station dormitories feature these systems, while older dorms which are slowly being phased out have simpler systems (e.g., single-action sprinkler or dry-pipe systems).[409]

Structure

The structure of the buildings should meet IBC regulations (ICC 2012, Chapters 6 and 7) regarding fire safety.[410] A fire-rated structure should provide at least a one-hour window. Fire walls are one way to accomplish this, and a steel structure (as opposed to wood) also helps. Dormitories are high priority areas and fairly permanent, so investing in their longevity should pay off. Most likely future dormitories will be built with steel-frames and sheet-rock fire walls, and will possibly be connected to each other or to another large structure, as in the OZ Master Plan.

In the case that buildings are kept separate, it may be necessary to reference Table 602 in the IBC 2012, which regulates the fire-resistance rating requirements for exterior walls based on fire separation distance.[411] If this distance is greater than 30 ft., no extra precautions are needed. Once buildings are connected or moved closer, the fire rating increases. The design decision to create fewer, larger buildings also brings with it the need to include more fire walls, more fire exits, and additional means of egress.

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[409] The berthing area in 155 has a different protocol, with a dry pipe system that release water when heat is detected. The kitchen area has its own system.

[410] Chapter 6 covers the control of the classification of buildings as to type of construction (e.g., combustible and noncombustible structures and materials, ductwork, and electric wiring methods). Provisions in Chapter 7 govern the materials, systems, and assemblies used for structural fire resistance and fire-resistance-rated construction separation of adjacent spaces to safeguard against the spread of fire and smoke within a building and the spread of fire to or from buildings.

[411] The IBC sets the “fire separation distance” as the distance measured from the building face to the closest interior lot line, to the centerline of a street, alley, or public way, or to an assumed imaginary line between two buildings on the same lot.

Therefore, although it is not necessarily a bad decision, extra care should be taken should designs use larger, fewer buildings.

Materials

Material choice also contributes to the fire safety of a building. Additionally, certain materials emit less smoke and toxic fumes when combusting. Steel framed structures are the most resistant to fire damage when built to code and encased in fire-resistant covers or coated with sprayed materials. Roofs, a major weak point in fires, can also be made safer by not being of a combustible material like wood.

Currently the large dorms in McMurdo are metal frame with metal roofs. The smaller dorms are more vulnerable, being of wood and cedar shingles.

Fire Safety in Dormitories

Unattended cooking equipment or equipment malfunctions account for 84% of dormitory fires (Campbell, 2013).[412] Because of this potential danger McMurdo Station dormitories do not include cooking facilities, beyond microwaves in lounges and small refrigerators. People are encouraged to eat in the galley, but residents like to keep snacks and personal food items (sent in the mail or bought in the store) in their rooms.[413] Therefore, the biggest potential source of dormitory fires has already been eliminated in McMurdo and needs to be continued. Smoking is also no longer allowed in the dormitories (or any station building), making bedding and trash fires less likely (with the

[412] Between 2007 and 2011, U.S. fire departments responded to an estimated annual average of 3,810 structure fires in dormitories, fraternities, sororities, and barracks. Cooking equipment was involved in 84% of these reported structure fires (Campbell, 2003, p. v).

[413] Hording is sometimes a problem, but there is no link to fires.

proper use of cigarette disposal boxes located at relatively convenient locations outside buildings).

However, fires from electrical equipment, heating equipment, light bulbs, clothes dryers, and human fallibility are still possible.[414] Although these fires tend to be small (Campbell, 2003, p. 5), in the dry air of Antarctica, any fire poses a risk. Fires spreading from other buildings or sources (e.g., a burning vehicle) are also possible, and therefore the dormitory needs to be protected from the spread of fire from adjacent buildings or even vehicles. The first line of defense once a fire has started is the smoke detection and fire suppression system. At McMurdo Station all three-story dormitories are protected by a pre-action sprinkler system[415] connected to a fire pump and reservoir at a pump house (Building 151). These systems are meant to stave-off the spread of fire until the fire department arrives.

In McMurdo Station all U.S. fire codes are used extensively and enforced to the extent possible, although there are a few instances when the reality of the harsh climate demands a creative solution (Fey, 2011; for more information about fire code in McMurdo, see Appendix J). Laboratory and utility buildings may have additional systems, such as halon, which is also subject to code.[416] Housing units in McMurdo are

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[414] Individually, these potential sources of fire represent only 1% of fires in dormitories, fraternities, sororities, and barracks between 2007 and 2011.
[415] This type of sprinkler system requires two fire indicators, be it smoke, heat, or a pressure change. The extra requirement prevents the sprinklers from engaging in a false alarm and is usually used for buildings that house sensitive equipment. The two triggers for the dorms are heat and a pressure change in the sprinkler system.
[416] E.g., NFPA 12A: Halon 1301 Fire Extinguishing Systems.

subject to U.S. fire codes.[417] Windows are another layer of fire safety, especially in residential buildings. Authors of the UFC Arctic design guidelines note that the Air Force Design Manual (AFR) requires that any room used for sleeping must have operable windows as a matter of fire safety (DOD, 2004, p. 208). Clearly this standard is not used (or no longer used) at McMurdo, as several rooms in the station are located in interior hallways; South Pole Station does the same, and the latest plans for a new McMurdo Station hub follow suit.

All dormitories in McMurdo Station are classified as Occupancy Group R-1 (Transient Residential). Fire walls for Group R-1 should have a fire rating of three hours, but for Type II or V construction, a two-hour rating is permitted.[418] At McMurdo no firewalls exist in the dormitories, probably because they are not large enough, are unconnected and spaced at least 25 feet apart.

The four large, three-story dormitories (24,000 ft^2) are classified as “Type II, 1-Hour, non-combustible.”[419] They have a steel-frame structure with 2-1/2" thick foam-insulated metal siding and roofing, a product known as a Robertson Versawall panel.[420]

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[417] E.g., NFPA 72: National Fire Alarm and Signaling Code; NFPA 70: National Electrical Code; NFPA 101: Life Safety Code; NFPA 13R: Standard for the Installation of Sprinklers Systems in Low-Rise Residential Occupancies (Current Edition: 2013); NFPA, 10 Portable Fire Extinguishers; and NFPA 101: Life Safety Code.

[418] ICC 2012, Section/Table 706.4: Fire-resistance rating, p. 118.

[419] It is unclear, but this could be Type II-A, Protected-Non-combustible. This type features 1-hour fire rated exterior walls, structural framing, and floor/ceiling/roof protection.

[420] From the H.H. Robertson company. Buildings in McMurdo Station typically used to be covered with “H-Type Q-Panels,” an insulated metal panel made of three inches of fiberglass topped with a special felted metal siding known as galbestos (i.e., galvanized asbestos, see Appendix Q) (Hoffman, 1974, p. 5-1). It is not clear how many of those buildings remain, or if they were refurbished (removed of asbestos). The more modern Versawall panels (also patented by Robertson, which is now part of a company called Centria) used on the three-story dorms do not contain asbestos products and rely on polystyrene for insulation.

Built in 1988-89, these buildings have a steel-framed heavy timber first floor and a steel-framed second and third floor. Interior walls are also steel-framed, with metal-stud gypsum board interior partitions.

Built just ten years before the three-story dorms, five smaller, two-story dormitories (8,500 ft^2) from 1980 are classified as “Type V, N, combustible.”[421] They feature wood-framed exterior walls and roof with 5-1/2-inch fiberglass insulation, foam-backed aluminum siding, and cedar shake roofing; interiors are wood-framed gypsum board interior partitions. These smaller dorms may have been designed so that they were completed quickly; such a small structure may not warrant a steel frame. However, they are less protected than the steel construction, making them a less-than-optimal choice in terms of fire safety.[422]

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[421] Type V-N construction is under Type V-B, Unprotected Wood Frame. They are usually single family homes and garages, which often have exposed wood and this no fire resistance.

[422] It should be noted that smaller or more intimate settings often rank higher for occupant satisfaction.

APPENDIX K

ENVIRONMENT II DESIGN CHARRETTE

1993 Design Charrette, *McMurdo: Planning for Tomorrow*

In 1992 a student competition called "Environment 2" was sponsored by the NSF and the AIAS. It is not clear how much of this curious, vaguely-titled document contributed to any design changes in McMurdo, but it is nonetheless a very interesting landmark along the way, and one of the few instances where architectural design was emphasized at the station. The competition culminated in January 1993 with an 11-day trip for the 12 competition finalists to McMurdo Station. While there they presented their designs entries, they also made several on-site observations, which led to modifications in their designs. Articles in the *Antarctic Journal of the U.S.* (AJUS) and a 39-page final report, *Environment 2: A New Town for Science*¸ detail the process (NSF & AIAS, 1993). Those involved with this project did not present their designs as another master plan, but rather as a tool for future improvements to the station.

Overall, the finalists –all architecture students– observed that there were a number of positive attributes to the site and the station, foregoing their original plan to raze the ground and replace all existing structures. Rather, their approach –a familiar one by now- was one that evolved over time, gradually replacing certain structures and renovating others in place ("Planning for Tomorrow," 1993, p.5). Like the 2003 LRDP to come, they created a "science/science support" zone, a social center, and a recreational facility.[423] A proposed town center would help create a sense of identity, as would modifications to dormitory rooms, allowing their occupants more leeway to customize their habitation.

Additionally, the station would enjoy energy savings through improved air-handling units (AHUs), the capture of more waste heat from the power plant, the inclusion of a desalination plant, and a wide-scale retrofit of building insulation. Also suggested was the greater use of a hydroponics facility, which could double as a space for socialization and relaxation ("Planning for Tomorrow," 1993, p. 5-6).

Many of these changes –relatively low-hanging fruit– have since been carried out, including the desalination plant upgrade. Others remain the same: room designs have not changed, and the hydroponics facility remains woefully small and underused. But perhaps the best use of these proposed designs is to look at the student groups' graphic representations of their improved station (NSF & AIAS, 1993). Here can be found truly visionary, radical changes for the station: ideas that may have little chance of being built, but that are nonetheless essential in the conversation of how McMurdo can – and must– respond to this new century.

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[423] It should be noted that in 1993, these students would have seen the original galley in Building 155, which was still segregated and lacked any natural daylight. The galley renovation did not occur for another 10 years. In their plans, the students create a separate food service facility (still attached to Building 155), apparently wishing to bring more light into the dining area (from the drawing it seems there is a fair amount of glazing in the facility). This idea would also bring the galley closer to most of the dormitories, an added convenience. Dorms 210 and 211 are the unfortunate losers in this plan, absent in the building overview. Fire safety is not stressed in the overview of the project, but may have been mentioned in individual designs.

APPENDIX L

DESIGN GUIDELINES FOR INCREASED HEALTH IN HOSPITALS

A well-designed, restorative place, such as a garden or break spot, can be hugely beneficial not just for those in a hospital setting but anyone seeking a moment of reprieve from the stress of everyday life. These restful places can reduce levels of stress and, for some, even reduce perceptions of pain.

1) In McMurdo Station, this type of setting could be a place for people to relax at the end of the day and enjoy a view of the place they came to see (not the station). Private rooms are another example of this type of setting, with important factors such as room size, materials, and noise reduction all contributing to the occupant's well-being (see Section 4.3.2).

Restorative settings can be places for social support (another stress reducer) or places where one may sit alone in peace (Ulrich, Zimring, Quan, & Joseph, 2006). Visual exposure to familiar nature scenes produces significant recovery from stress within five minutes, as indicated by reduced blood pressure and muscle tension (Ulrich, et al., 1992). Whether it is a healing garden in a hospital or a park near a group of office buildings, an outdoor area provides people with the opportunity to be outside, come into contact with nature, and take a break from the everyday routine.

2) In McMurdo, this idea may have to be adapted, but it is possible, even if it happens to be a greenhouse.

In order for people to benefit from restorative places, they must be well designed with proven design guidelines. Marcus and Barnes (1999) list a number of design guidelines for restorative garden areas, a few of which are:

3) Spaces should be accessible, contain views (of the garden from interior spaces as well as when one is inside the garden), provide seating near a food source when possible, offer choices (provide a *sense of control*) such as type of seating and amount of privacy and sun exposure, contain a variety of plants and other features that stimulate the senses, sometimes feature well-chosen art, and be well-proportioned with a sense of enclosure and safety.

Even though the populations in a hospital and McMurdo Station are different (people in McMurdo are not in pain or recovering from a surgery), they are still confined to the interior environment most of the time which can cause stress. Typical views of nature (i.e., biodiversity) do not exist around McMurdo Station, but people gravitate towards windows, especially when it is too uncomfortable or dangerous to be outside.

4) There are other ways to simulate "green nature," be it digitally or with hydroponics.

Design guidelines for stress relief must be adapted for McMurdo Station, with its unique situation and unusual climate.

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APPENDIX M

SOURCES OF ENERGY FOR MCMURDO STATION

Non-Renewable Energy Options

Energy sources are considered nonrenewable when " …they draw on finite resources that will eventually dwindle, [become] too expensive or too environmentally damaging to retrieve. In contrast, renewable energy resources—such as wind and solar energy—are constantly replenished and will never run out (NREL, 2015). Fossils fuels like diesel and heating oil are considered nonrenewable energy.

Diesel and Fuel Oil

The mechanical systems used at McMurdo Station have traditionally relied on fossil fuels for both heating and power. Diesel generators (Figure A- 64) provide power while hydronic boilers that run on jet fuel (JP-5) and furnaces provide heating.[424] While there have been improvements to these systems (e.g., heat recovery and a heat trace[425]) and upgrades to the equipment (i.e., new generators and a new power house), McMurdo still requires a large quantity of fuel every year for approximately 550,000 ft^2 of heated

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[424] During the IGY when McMurdo Station was founded, all of the stations relied on diesel-electric generators, namely the Caterpillar D-315 diesel engine with a self-regulated generator. This model provided 60-cycle, 34-kW continuous output at 1200 rpm. The power was 3-phase (except at South Pole) and each building had 110-220 volt outlets. Every station had a separate generator in a separate location, for fire safety. (NRC, 1957, p. 38-39).

[425] Heat trace is an " … electrical system [that] carries heat along … [exposed] plumbing to keep the water from freezing in the pipes…" (Rejcek, 2011b). In McMurdo this nine-mile system has been patched together and repaired over the last 15 years, resulting in a maintenance nightmare, but a recent budget allotment has allowed crews to improve the system as a whole, instead of piecemeal. In 2008 RSA estimated that the heat trace consumed approximately 180,000 gal. of fuel annually, but that proposed retrofit could reduce consumption by 78% (RSA, 2008, p.27).

space: 521,000 gallons (65,138 MMBtu) for building heat and 1,161,000 gallons (145,153 MMBtu) for electrical generation (13,182,536 kWh generated in 2007).[426] This represents 25% and 48%, respectively, of the station's annual fuel allotment. The station also keeps at least a year's supply as a backup[427] (Figure 29, Figure 30). Part of the power plant output goes towards processing the 15 million gallons of potable water required by the station, which it desalinates (and later processes out the waste) on site.[428]

Prior to 1990 JP-4 ("Jet Propellant") fuel was commonly used in the U.S. Antarctic Program (USAP) for all its heating and power needs. It has a lower freezing point but it also has a moderate combustible risk. For safety reasons, in 1990 the U.S. Air Force switched to kerosene-based JP-8 fuel for as many applications as possible, but the USN moved towards a similar type, JP-5, which is less volatile but also more expensive. This practice carried over to the U.S. Antarctic Program. Both JP-5 and another type of fuel, AN-8, are stored in McMurdo. JP-5, which gels at -50°F, is adequate for McMurdo , while another type of fuel, AN-8, which has extra anti-freeze additives and gels at -70°F, is required for South Pole Station and most deep-field camps (Blaisdell, 2008). AN-8 is also more stable, reducing the risk of fire in a place where – like an aircraft carrier—it has the potential to be catastrophic.

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[426] Heating value of JP-5 is 125,000 BTU/gallon.
[427] Recently it has become necessary to install more fuel tanks so the station can store at least two years' of fuel. This became necessary because the U.S. does not have icebreakers and can no longer rely on other countries for icebreaker support, which is essential to the delivery of fuel and other supplies by sea.
[428] Finding data on the energy required for this process is not readily available. Even the 2005 NREL study noted that it did not have good baseline data from the water plant (Baring-Gould, Robichaud, & McLain, 2005, p. 3, 14).

Keeping a large supply of fuel at the station requires large containment units (Figure 29, Figure 30). Aside from McMurdo's own fuel supply, it also houses fuel for South Pole Station[429] as well as for New Zealand, Italy, Australia, and Great Britain. Roughly a dozen medium to large tanks dot the landscape, holding the lifeblood of the station: JP-5, AN-8, and mogas (i.e., unleaded petrol). The five largest tanks hold up to two million gallons, although one is usually left empty in case the need arises to make an emergency fuel transfer from a compromised tank. These single-walled tanks are surrounded by berms lined with a heavy rubberized fabric, were designed to prevent a flow into the ground or through the station and into the sea.[430] Fuel is delivered to McMurdo by the supply ship and pumped into a network of pipes that disperse it to the various tanks around the station. Fuel trucks are then used to deliver diesel and oil to individual buildings and to nearby field camps (Figure 25).

McMurdo Station's generators were also recently upgraded and provided with a new enclosure (Figure 32), increasing their efficiency from 11.4 kWh/gallon to 12.5 kWh/gallon, an improvement of 9.6% (RSA, 2008, p.18). Their presence is likely to remain in McMurdo, even if one day the station incorporates more wind power into its systems. Even at Mawson station, with its three large turbines providing the majority of the station's power needs, diesel generators are necessary as a safety backup. Wind-diesel hybrid systems allow the station to enjoy peace of mind when it comes to

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[429]Fuel used to be flown to the South Pole, required a liter for every one delivered, but today much of the fuel arrives via an overland traverse, which is based out of McMurdo. The 3,000 mile traverse can offset over 25 LC-130 flights.

[430] This scenario would be the result of multiple catastrophic failures of more than one fuel tank (Australian Observer Team, 2005, "Fuel storage and handling").

continuous power. At McMurdo Station –and anywhere in the Antarctic– the goal of course would be to be able to rely on diesel generators only during extraordinary circumstances.

One promising recent development is the use of wind power to produce hydrogen (H_2) on site, thus eliminating the need for a diesel backup. The Australians have been investigating the feasibility of this energy system, but as in all places, the storage of large quantities of H_2 is still problematic (Steel & Guichard, 1993). Hydrogen is difficult to store because it must be kept under pressure and tends to leak from most types of containers. Should a financially viable technique be developed to store large quantities, it could effectively signal the end for the need of any type of hydrocarbon-based fuel in Antarctica, even for vehicles.

Nuclear

Nuclear power is not usually considered a renewable energy source –and it certainly raises some important questions about environmental impact, especially in Antarctica. However, at one time it was considered the energy source of the future on this remote, frozen continent (Figure A- 65). In the 1950s nuclear power represented a safer[431], more reliable source of energy, and provided enough power to allow heated water lines and the possibility of a desalination center for potable water (Tyree, 1962, p. 273).[432] During a brief period the nuclear power plant also reduced the need for bulk fuel to be delivered by ship to McMurdo and by air or overland to other remote stations,

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[431] This is because electric heat has a reduced risk of fire when compared with oil-burning devices.
[432] The current water plant would not be built until 1993.

saving pilots and crew from hundreds of dangerous flights to the Antarctic (Dufek, 1962, p. 712). The plan called for nuclear waste to be shipped back to the U.S., with only a small shipment of radioactive material imported every three years. In theory, it seemed like the perfect fuel source for remote stations like McMurdo, with its high power needs; in reality, the results were mixed.

The McMurdo Station reactor, nicknamed "Nukey Poo,[433]" went critical[434] on March 3, 1962 and operated with limited success for about 10 years (Wilkes & Mann, 1978) (Figure A- 66, Figure A- 68). Throughout its lifespan it experienced numerous technical faults that required frequent maintenance (Figure A- 67). It required 23 men to run and during its numerous shut downs, a crew was still required to run the diesel powered generators. Finally, after a minor event which could have become major without routine inspections,[435] the Naval Nuclear Power Unit decided that any long-term nuclear solution would be too difficult, expensive, and time consuming (Wilkes & Mann, 1978, p. 35; U.S. Naval Nuclear Power Unit, 1973, p. 87). Hence, in the same month as the Yom Kippur War and the Arab Oil Embargo, the final decision was made not to repair or replace the nuclear power plant. For the next 37 years, McMurdo Station would be run completely on non-renewable fossil fuels.

After its years-long decommission the PM-3A was completely removed from the continent, as required by the terms of the Antarctic Treaty (U.S. Department of State,

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[433] Allegedly named so because of how much the nuclear plant leaked (unsubstantiated claim).
[434] "Critical" in this context is the industry term indicating that the plant is able to sustain a nuclear chain reaction (Dufek, 1962, p. 716).
[435] Some cracks were found in the piping, which could potentially lead to a leak of the primary coolant water to escape, could lead to a meltdown. Today all nuclear plants of this type are fitted with safety features that would prevent this. Nukey Poo had no such backup. (Wilkes & Mann, 1978, p. 35).

"Antarctic Treaty," 1959, Art. V). In addition, 388,461ft^3 (8,000 tons) (Wilkes & Mann, 1978) of contaminated rock and gravel from underneath the plant were shipped back to the U.S., where tests determined it contained low levels of radiation (Collis & Stevens, 2004; Wilkes & Mann, 1978; U.S. Naval Power Unit, 1973). Currently, the former site of the plant is now being used for other purposes and not considered dangerous.

The power plant, labeled as a PM-3A, was built by Martin Marietta in 1959 and shipped in large pieces from California.[436] Promoted by the U.S. Atomic Energy Commission (U.S.A.E.C.) in 1960 as a cheaper alternative to diesel-generated electricity, the power plant was not only an economic[437] but political move. Nuclear power –clean, efficient, "unending" energy– was a means to achieve a permanent presence in remote areas such as Antarctica (Tyree, 1962, p. 273).

Nuclear power plants were also planned for South Pole Station[438] and the new Byrd station[439] across the Ross Ice Shelf. A second reactor for McMurdo was planned, but it was never realized. While the nuclear experiment in McMurdo could not be called a success, around the same time, the PM-3A's older sister, the PM-2A, operated with

[436] "PM" stands for "portable, medium powered." Portability was important since everything had to fit onto a C-130 Hercules aircraft. This would allow transport not only to McMurdo but also to more remote places like South Pole Station. The number 3 designates it as the third in the PM series, the other ones going to Greenland and Wyoming. The "A" stands for field deployment (Wilkes & Mann, 1978).

[437] "At that time diesel-generated power was 0.975 cents per kilowatt-hour, and it was calculated that the nuclear-generated electricity at McMurdo would cost 0.564 cents per kilowatt-hour. This was way back in the days when diesel fuel cost the Navy 12 cents per U.S. gallon, but, by the time they had transported it to McMurdo it was worth 40 cents per gallon" (Wilkes & Mann, 1978, p. 32; Dufek, 1962, p. 717).

[438] At that time fuel delivered to South Pole Station was $6 per gallon (Wilkes & Mann p. 32). For a time, diesel fuel was flown into the station. Currently it is delivered by overland traverse, and costs over $10 per gallon (Baring-Gould, Robichaud, & McLain, 2005).

[439] South Pole Station and Byrd Station must both contend with moving ice sheets, but the series of Byrd stations were always less permanent than that at Pole.

great success for its short lifetime (about three years) at Camp Century in Greenland[440] (see Appendix D) (Dufek, 1962). The PM-2A reactor[441] was the first of its kind to work in the field,[442] and had the Greenland ice sheet not been moving so fast that the subnivean camp had to be abandoned after only a few years, it might have continued providing useful power for a longer period.[443] It is unclear why one unit worked well while the other experienced a series of faults.

Although the advantages of nuclear power seem to make it a good fit for a remote location like McMurdo Station, the burden of intensive maintenance and lingering risks of nuclear meltdown (with limited means for station evacuation) in the end outweighed the "endless" supply of clean energy, although the loss was great when the station longer had a source of nuclear-generated steam for desalinating seawater (Figure 31) (see also Section 5.2.4). In addition, there was the question of nuclear waste, as well as the cost of maintaining the plant versus the price of diesel and gasoline in the early 1970s; of course with today's escalating diesel and gas prices, the story is quite different. Today there are no traces of Nukey Poo or indeed any nuclear power stations in Antarctica.

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[440] Camp Century was part of Operation Iceworm, a Cold War initiative. Based off previous Byrd stations, which were also buried in the snow, Camp Century was camouflaged from the enemy but needed constant artificial lighting and, of course, heating. Nuclear power solved this. Its scale was impressive: 21 tunnels –including a Main Street, much like McMurdo- which were over 1,000 feet long (see Appendix D) (Dufek, 1962, p. 713).

[441] This reactor was built by Alco Products, Inc. (formerly American Locomotive Company), not Martin Marietta, which built the PM-3A. Admiral Dufek, after retiring from the Navy, had consulted for this company, advising on problems in polar areas (Dufek, 1962, p. 721).

[442] The PM-1 was a prototype, also built by the Martin Marietta Corporation. Until 1971 it provided heat and power to an Air Force radar base on a mountaintop at Sundance, Wyoming. (Wilkes & Mann, 1978).

[443] The reactor, with 43 lbs. of uranium, could produce enough power to heat and light 1,500 American homes in 1962. The uranium was replaced every two years (Dufek, 1962, p. 724).

Renewable Energy Options

Although there has been recent progress increasing the use of alternative forms of energy in Antarctica, there is still much room for improvement on Ross Island. There are potentially great cost savings from the integration of wind power into McMurdo's power grid and perhaps some smaller savings from small-scale solar power. Other energy sources such as geothermal may one day prove feasible, but today they are not financially or logistically viable. Exploring renewable energy options is important to the long-term success of McMurdo Station not only because of rising costs of crude oil, but because the need for reduced size of the site under the Antarctic Treaty. The scientific program also benefits from the preservation of the pristine nature of the location.[444] Reducing the risk of environmental contamination (from oil or fuel spills, nuclear contamination, or habitat disruption) is not only required by the Antarctic Treaty, but is also crucial to the long-term viability of the station as a place of scientific research.

Wind

Wind is a major natural force for many locations in Antarctica. Its presence can make the difference between a chilly day and a weather-related disaster. Increasing wind speed can lead to a dangerous wind chill, decreased visibility in blowing snow, structural compromises, airborne projectiles, fast-growing snowdrift, and in a worst case scenario, the fanning of fire in an already arid environment (Figure A- 69). An unrelenting force, its howl can be maddening. To underestimate it can be a fatal

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[444] In many places in and around McMurdo Station, any sense of the pristine has long since vanished .

mistake. However, it can also be harnessed as a source of power in a place with few natural resources.

In 2009 and 2010, three Enercon 330-kW wind turbines erected between Scott Base and McMurdo Station by the New Zealand Antarctic program (Antarctica NZ; see sections 1.4.4 and 4.2.1) demonstrated the potential for wind energy on Ross Island (Figure A- 70). With only a few seasons of operation completed, these wind turbines have provided a strong proof of concept of the potential of local wind power as well as the advantages of a shared power grid between the two stations. After their first (relatively mild) winter and (colder) WinFly season,[445] the turbine project was deemed a success and provided important lessons about installation and maintenance.[446] "Since January 2010 when the facility first became operational, approximately, 20 per cent of McMurdo's and 86 percent of Scott Base's electricity demand have been supplied by the wind turbines. This equates to a savings of approximately [118,877 gallons] of diesel fuel per year" (Colston, 2010, p.29). This figure may not even include the fuel saved by not having to transport more fuel to the station. In the long term it also means having to store less fuel on site, which reduces the presence of environmental hazards. Between the two stations, the wind turbines are estimated to save 122,000 gallons of diesel per year (about 1,388 tons of CO_2 emissions) (Miller, 2010, p.16).

[445] Winter fly-in or WinFly is a short season that marks the end of the winter season, usually starting in the middle or end of September and lasting through the beginning of the Main Body season in early October. During WinFly, new personnel begin to arrive along with a few early science groups and supplies. This results in a jump in energy demand. Unfortunately, since this time of year is a transition season when the sun begins to rise, the weather is often more tumultuous than the experienced during the dead of winter.

[446] For example, the importance of using the correct lubrication oil that will not remain viscous under very cold conditions.

Wind energy studies, including one by the National Renewable Energy Lab (Baring-Gould, Robichaud, & McLain, 2005) and another by New Zealand's University of Canterbury (Hume & Bodger, 2004) helped pave the way for the $7.4 million wind turbine project funded by New Zealand and supported by the U.S. The NREL study in 2005 (which noted a lack of current data on wind, temperature, and station demand) focused solely on McMurdo Station, not a partnership with Scott Base.[447] NREL looked at several issues with installing wind turbines, including cost, size, spacing, and location. The report describes the site, known as Twin Craters (Figure 24), as being limited in size, with room for no more than five 250 kW turbines.[448] According to estimates in the report, these turbines could result in nearly 25% fuel savings per year,[449] a reduction of over 320,000 gallons per year (roughly 20% of the station's fuel demand). These turbines were never built.

The Ross Island Wind Energy (RIWE) proof-of-concept was spearheaded and financed by the New Zealand government and the University of Canterbury, and overseen by AntNZ and Meridian Energy Ltd., with " …significant logistical and technical assistance and investment form the USAP" (Miller, 2010, p. 14).[450] It is unclear why the USAP decided not to spearhead this project but instead assisted[451] the

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[447] The report noted that fuel savings at the more remote South Pole Station would be more dramatic, although any fuel savings at McMurdo would be beneficial.
[448] Model: Furlander FL 250, manufactured in Germany.
[449] Based on the cost of diesel energy production of $0.1589/kWh.
[450] The NZ Antarctic program already piggy backs on the USAP logistical program, and this extended to the transport and storage of the turbines, as well as the use of existing heavy equipment at McMurdo Station. One of the goals of the wind power initiative was "[t]o increase New Zealand's contribution to the shared joint logistics pool with the United States" (Miller, 2010).
[451] E.g., help with transportation to Ross Island and with loans of large equipment.

New Zealand Program with its wind power initiative; however, the cooperation and shared grid benefits both stations. When wind conditions are not favorable, McMurdo backs up Scott Base while their generators restart; meanwhile any excess power feeds McMurdo's huge demand for electricity (Miller, 2010).

The shared grid has simplified and streamlined the delivery of electricity on Ross Island, but one problem resulting from the shared grid was the issue of dissimilar frequencies. Scott base runs on 50 hertz (Hz) while McMurdo maintains 60Hz. Since it was a critical part of the grid that power be able to flow between the turbines and two diesel generation plants of both stations, it was necessary to install a Powerstore[452] flywheel, which allowed for grid stabilization. The flywheel, it is "…designed to provide grid stabilizing (sic) of both voltage and frequency by either sinking or sourcing real and reactive power" (Powercorp, 2009). In the event of a sudden change in wind (either overwhelming the turbines or requiring a changeover to the diesel generators) the flywheel can absorb or supply 500 kW for 30 seconds to maintain the electrical system (Power Technology, n.d.). It was also necessary to install a static frequency converter for the actual conversion of 60Hz (McMurdo) to 50 Hz (Scott Base). These two pieces of equipment make sense not only when relying on a hybrid power system, but when power systems are separated by two miles, like those at Scott Base and McMurdo Station.

The details of the turbines themselves are also important. Because of the cold temperatures, potential for storm winds, and the need for them to require minimal

[452] Formerly Powercorp.

maintenance, the turbines chosen are pitch-controlled, so that the blade can change pitch to take advantage of optimal conditions or during less optimal or storm conditions. The turbines also have a direct drive gear box, which is more efficient, quieter, and results in less wear and tear (Miller, 2010, p. 18). The concrete foundation was also a challenge (see Section 4).

One estimate figured that additional turbines could theoretically meet 90% of the electrical demand for McMurdo Station (Colston, 2010, p. 29). While the power generated for Scott Base was substantial and the benefit to McMurdo welcome, simply adding more turbines without addressing the inefficient design and maintenance of the station's existing buildings should not be considered an adequate solution. Furthermore, there are a limited number of sites available for wind turbines,[453] with some of the best locations already set aside for science projects (e.g., Arrival Heights, Figure 24). The question of electromagnetic interference from the turbines confounding these ongoing projects has yet to be resolved.

Active Solar

The potential for active solar powered systems in McMurdo has been addressed mostly at the small scale for remote camps. The extreme conditions (including the six months of straight darkness) make it less practicable than wind power. In addition to the extreme cold, solar panels would have to be protected from blowing snow and debris, and they would have to track the low sun altitude. During the autumn the amount of

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[453] NREL considered the minimum spacing of wind turbines to be two rotor diameters. This varies depending on the wind rose for the site. (Baring-Gould, Robichaud, & McLain, 2005, p. 11).

solar radiation would decrease rapidly, and during the winter months –and well into the early spring- there would be little or no usable solar radiation.[454]

No continuous weather file for McMurdo in a format suitable for energy simulation programs such as E-Quest or Climate Consultant could be located for this study. Therefore, to over this situation, a suitable weather file was synthesized by extrapolating an incomplete data set (see Appendix M). This file will help determine how much useful solar energy can be obtained during the short summer season. Since this is the same time the station population reaches its peak, even a relatively small contribution from solar energy could help offset some of the station's massive thermal and electrical demands.

Geothermal

Drilling for the purposes of obtaining heat and power from geothermal reservoirs may run contrary to the Antarctic Treaty (Article 7) (Alvine, 2010). However, the possibility of a geothermal system (i.e., Ross Island is volcanic) was considered in the early 1970s, but exploratory drilling showed little promise of such a system being economically viable at the time. Measurements taken at two holes drilled to depths of 500 ft. and 1,200 ft. and then extrapolated indicated continuous permafrost extending from 1,440 ft. to 1,640 ft. (Pruss, Decker, & Smithson, 1974, p. 133; Decker & Bucher, 1977, p. 102). Finding a shallower source of geothermal heat close to the station[455] or in

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[454] Even during the periods of 24-hour daylight, the sun at this high latitude would be at a low altitude and does provide much radiation on a stationary panel. During these times, the panels would need to capture more solar radiation by tracking the sun.
[455] The two holes were drilled near Windy Crater, just south of Twin Craters. (Figure 24).

an ice-free region does not seem likely. Since the base of the volcano and the most of the island itself is covered in ice and snow, drilling poses a challenge, as does the transport of any heat (or heated liquid, such as glycol) since the pipes could not be buried. It is also unclear if this process would violate the terms of the Antarctic Treaty, which bans mining for mineral resources other than for scientific purposes. No further geothermal research has since been conducted with the intent of establishing a new source of power.

A place where geothermal heat is actively used is Iceland's capital, Reykjavík. It is a good example of what is possible with access to "high" and "low" geothermal power for electricity generation (high temperature, i.e., > 392^{o}F) and district heating (lower temperature, i.e., < 302^{o}F) (Ragnarsson, 2010, p. 1). By 2008, 62% of Iceland's heating and power came from geothermal power, with another 20% from hydropower, which makes the island nation one of the few countries in the world that is able to power its buildings, heat its homes and pools, and keep its greenhouses alive from local geothermal plants that consume a minimum amount of non-renewable fuel (Ragnarsson, 2010, p. 1). While geothermal heat and power has a modest effect on the environment (e.g., land use, water use, and emissions of sulfur dioxide, nitrous oxide, and carbon dioxide entrained in the circulating fluid), this impact is considered small relative to other forms of non-renewable energy, including oil.[456] Since the process uses water

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[456] "Combustion of bituminous coal emits about 900 kilograms of carbon dioxide per megawatt-hour, and … natural gas releases more than 300 kilograms per megawatt-hour… In contrast, geothermal driven power plants … [release] about 120 kilograms per megawatt-hour. Binary geothermal power plants emit zero carbon dioxide" (Duffield & Sass, 2003, p. 27). In a "binary" system, "geothermal water is used to boil a second fluid (e.g., isobutene) whose vapor then drives a turbine generator. The waste water is

(which can be partially reused), there is some debate as whether to label geothermal power as renewable or simply sustainable (Duffield & Sass, 2003, p. 26).

Water

Antarctica is a cold desert with almost no sources of fresh water beyond snow melt, an energy intensive and non-renewable solution. A reverse osmosis (RO) facility located near the sea-ice transition desalinates up to 80,000 gallons of sea water per day for drinking and other needs (e.g., food preparation, dish washing, laundry, personal hygiene, etc.) (Figure A- 72, Figure A- 71). However, this is sometimes inadequate during the mid-summer period when the population approaches 1,200 people, and water rationing is sometimes required. It is also an energy intensive process, previously only feasible with the use of nuclear power on Ross Island (Tyree, 1963, p.273).

McMurdo Station uses about 15 million gallons of potable water each year.[457] Currently this water is produced by an effective yet energy intensive reverse osmosis (RO) system using sea water (RSA, 2008) that desalinates millions of gallons of sea water each year. Seawater is pumped into the plant at about 270 gpm. It is then heated to about 37^{o}F (from 28^{o}F) using waste heat from the power plant. Before going into the RO system the water is held in an 18,000 gallon tank (Raytheon Polar Services Company [RPSC], 2007, p. 8). After treatment, the water is not only stripped of most

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injected back into the subsurface to help extend the useful life of the hydrothermal system" (Duffield & Sass, 2003, p. 11).

[457] Average per-capita water consumption: Summer 69.1 gallons/day/person, Winter 156.9 gallons/day/person, Annual average 125.9 gallons/day/person (RSA, 2008).

(but not all) of its salt and much of its mineral content. In this state the water is a natural solvent, and a detriment to health if consumed regularly. In a process called "polishing," the water is fortified with minerals and adjusted for pH[458] and chlorine (RPSC, 2007, p. 9).

About 9 million gallons are consumed by station residents (as opposed to being used for operations such as the ice runway) (RSA, 2008). With the option for collecting snow for melt water no longer practical or desirable,[459] the only way to reduce the energy and cost of fresh water production is to reduce daily consumption through behavioral changes and by installing water-saving fixtures, such as water-less urinals, dual-flush toilets, low-flow shower heads, and automatic faucets. Some of these changes have already been implemented per the recommendations of the 2003 LRDP (DMJM, 2003).

In addition to drinking water, it is necessary to maintain a reserve of water for safety purposes. With structural fires being a high risk in this low-humidity, desert climate, it is necessary to have a reserve of water as well as water for use in an extensive building sprinkler system. To provide this, 100,000 gallons (about half the station's capacity) is kept in reserve in two of the four 50,000 gallon tanks located in the same

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[458] The use of soda ash (sodium carbonate) injected into desalinated water controls the pH level. Basic water (high pH) is corrosive, leaves stains on pipes and other fixtures, and can have a bitter taste. Optimal pH for potable water is 6.5 – 8.5 (Raytheon Polar Services [RPSC], 2007, p. 8).

[459] Melting snow takes too long for a large station, and scraping the ground for snow alters the environment. Both methods are relatively energy intensive, including the current solution: sea water desalination. In the early 1960s, nuclear power was supposed to solve this problem, providing enough energy for the desalination plant. When the nuclear power experiment failed, so did the hopes for the plant. It was not until the 1990s that the plant was finally installed, the benefit to the environment outweighing the cost of running the plant.

building as the RO system and then piped through insulated and heated above-ground pipes.

For more information about potable water creation before the reverse osmosis system was in place, see Pope (1967), USN (1968) and Whitmer (1967). These articles tell the story of complex –but convenient– water treatment and distribution system, the constant battle to protect and repair water intake pipes, and the many ways the pipes were guarded and monitored against freezing. The presence of the nuclear power plant was probably the main reason the desalination facility (using an Aqua-Chem distillation unit[460]) was located on Observation Hill, next to "Nukey Poo," although as a backup, the Aqua-Chem could also use steam from its own oil-fired boiler (an expensive alternative). Once the nuclear plant was dismantled, the next desalination plant was relocated closer to the shoreline and the diesel generator house.

Waste and Wastewater

At the other end of the water cycle is waste water treatment. Currently all waste water at McMurdo Station is treated and returned to the ocean from a treatment plant located near the shore (Figure A- 73). This water treatment system, a remarkable feat housed in an unremarkable building, is energy intensive but preferable to the pre-2003 alternative: dumping raw sewage into McMurdo Sound. McMurdo's waste water treatment facility is housed in a climate controlled building and processes about 43,000

[460] This little marvel was a " … multistage flash evaporator that [could] each day produce 14,400 gallons of fresh water from salt water" (USN, 1968, p. 38). There was a 55,000-gallon storage tank for fresh water and another for unprocessed salt water; estimates indicate that 10 gallons of seawater were needed to produce one gallon of fresh water. The byproduct, concentrated brine, was returned to the ocean.

gallons of grey and black water per day during peak season, returning clean[461] water into McMurdo Sound (Figure A- 74). Currently there is no reuse of grey water.[462] The remaining sludge is pressed, dried, and boxed up as a soil-like "cake" to be returned to CONUS, specifically California's Port Hueneme,[463] when the annual icebreaker docks in McMurdo's harbor, Winter Quarter's Bay (usually in January). The treatment of waste water more than complies with the terms of the Antarctic Treaty which prohibits dumping into the ocean, a standard practice in McMurdo for years.[464]

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[461] That is, fewer than 100 coliforms per 100 ml.
[462] Installing a system to reuse grey water could be beneficial if there are enough applications. It could be used, for example, in flush toilets or laundry machines, but there would have to be enough demand to justify installing a grey water return system, separate from the current ocean-intake system.
[463] The location of a major naval base, and the beginning of a sea route that continues across the Pacific to New Zealand and on to Antarctica. Waste, garbage, and recyclables arriving in Port Hueneme are transported to other locations for further processing or disposal. In the case of nuclear waste resulting from the decommissioned nuclear power plant, the contaminated rocks passed through Port Hueneme and on to Georgia (Wilkes & Mann, 1978, p. 36).
[464] U.S. Department of State, "Protocol" Art. 3, 1991

APPENDIX N

NOTES ON CREATING A WEATHER FILE FOR MCMURDO STATION

In the U.S., the most likely analogous environment for that of McMurdo Station is Point Barrow, Alaska. Even so, the Heating Degree Days (HDD_{65}) at McMurdo Station (23,363 HDD_{65}) are 15% higher than Barrow (20,226 HDD_{65}) (RSA, 2008, p. 41). Additionally the seasons (i.e., daylighting conditions) are reversed. This makes the use of Barrow weather data for an analysis of McMurdo Station (as done in the RSA energy report) less precise.

Antarctic structures and HVAC systems must contend with extremely cold outside air temperatures (the average outdoor temperature is 0^{o}F) that are much colder than temperatures found in U.S. standards. McMurdo Station (and the ocean around it) does experience a brief seasonal thaw, but not to the same extent as summer on the Arctic tundra.[465]

Because weather data for McMurdo Station are collected but not formatted for energy simulation (e.g., EPW, TMY, BIN), a specifically formatted file had to be created. Raw data logs collected from the station proved difficult to format, with readings taken every three hours but sometimes less. While temperatures could be approximated using linear interpolation, other data such as solar radiation and wind

[465] There are no terrestrial plants or animals in McMurdo Sound.

speed could not. For the sake of expediency, a weather file was commissioned from White Box Technologies (J. Huang, personal communication, February 13, 2012).

This file was created from actual data collected from the National Climate Data Center (NCDC) weather stations. Missing data was filled in using linear interpolation, Fourier interpolation, or by repeating the last available entry.[466] By any standard, once a source of weather data was found, the "packing" process routine, with one exception. After several failed attempts at running an input file in DOE-2.1E with the McMurdo weather file, it was discovered that it was necessary to alter the latitude of the location so that it remained above 65°S, the Antarctic Circle (McMurdo Station is at 77°S). It was necessary to change the latitude in the input file (Appendix T) and in the weather file.

This is because DOE-2.1E becomes confused when the sun does not set according to the weather file; the dialog box returns a message that a "Math Error" occurred, although in the output file there are no errors listed. Changing the latitude does not alter the solar data, which remain unaffected and correct in the file. "The only difference from setting the latitude lower is that the sun will be slightly higher on the horizon than [it is] actually, but since the solar radiation on the weather file is correct, the effect on the [accuracy of the DOE-2.1E] runs should be quite small, i.e., the sun position will show that the sun always rises every day, but on those days where the sun is actually below the horizon the weather file will show no solar radiation at all" (J. Huang, personal communication, March 7, 2014).

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[466] These data are labeled with "L," "F," or "R," according to the method, and can be seen in the .FIN4 file of each weather year.

At one point during the process (before it was determined that the problem with the weather filed stemmed from the high latitude), another source of weather data was tried. An AMY weather file from Weather Analytics[467] was used but eventually discarded because it still presented multiple errors;[468] it should also be noted that the data did not match the file from White Box Technologies and therefore was felt to be not as accurate.[469] The data used for the AMY file were not from the NCDC or from a ground weather station (a Meteorological Station). Rather, the information comes from the Climate Forecast System Reanalysis (CFSR) data set. "The CFSR data set consists of area-based weather stations and are split up into 35x35 km grid squares across the globe. The Weather Analytics station (144310) ... consist of the 35x35km grid square that is over McMurdo Station. Therefore the data [set] is an area average of the weather conditions in that grid square" (K. Anderson, personal communication, February18, 2014).

For these reasons, the weather file developed by White Box Technologies was determined to be the best data set; the change in latitude does not represent a significant problem for the bounds of this project; however, perhaps in the future it will be possible to modify the weather processing computer program to run high latitudes in DOE-2.1E without having to adjust the latitude.

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[467] www.weatheranalytics.com
[468] At first the errors were because of processing problems for the site; a glance at the data showed wet-bulb readings that were out of range. Even after a new file was sent it did not work, probably because of the high latitude problem.
[469] On a quick glance the temperatures were sometimes 20 degrees different.

APPENDIX O

CREATING THE BASE CASE

The following is an expanded discussion of what was required to create an energy model using DOE-2.1E. It can be found summarized in Section 7. This section includes more details and additional equations that help show how certain values for the base case were calculated. It also includes information on how the improved cases were calculated. It should be noted that the main building for the OZ proposal was not modeled because it became apparent that even the simple-looking double-loaded corridor of the base case, using DOE-2.1E to model partial conditioning was pushing the limits of the software. The OZ building, with the three dorm wings with twin double-loaded hallways (i.e., four rows of interior rooms and two rows of rooms with windows) connected to the main building, would need to be carefully simulated, possibly in another program. It would also help if the model were created with the backing of existing building data.

Documentation

Locating building documents

Aside from the basic building plans obtained while working in McMurdo Station there was no easy source of building documents. Previous contractors had worked with various architecture and engineering (A&E) firms, and before that the USN had employed its own A&E department. Unfortunately, with most of the previous contract holders dissolved, there was no source of historical building documents online, let alone a company to contact.

I discovered relevant information existed at the National Archives Branch[470] in College Park, Maryland, so I made a three-day trip to see what was there and retrieve what I could. In the documents section I found large format construction documents dating from 1959 to the late 1980s, stacked in over-sized manila folders; the contents were often out of order. Even with so many documents, it did not seem that these folders held the complete plans for every building, or even a complete set of plans for one building. Visitors to the archives are allowed to scan only nine pages per day; with limited time, it is necessary to choose quickly.

In the photo archive visitors are allowed to photograph as many images as they wish; there were several boxes relating the McMurdo Station. However, they too were not in any order that made sense (type of photo, time, or location). Anything felt to be relevant was photographed (e.g., buildings, utilities, construction works, unusual scenes, scenes of daily life) over the course of two afternoons.

Locating building data

Buildings at McMurdo Station are monitored for their energy consumption, and of course records are kept for the purposes of refueling and budgeting, but those data are not made public. I was told this during my stay at the station. While station power and water consumption are flashed on the scrolling information TV channel (also available

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[470] The information was there because of the U.S. Navy connection to Antarctica. This building is not the main archives in Washington, D.C., but a separate facility in Maryland.

on the station's intranet), exact numbers are not posted, let alone the daily or monthly numbers for any one particular building. An exhaustive search of the internet (e.g., Google, Google Scholar) was fruitless. The only data available were totals representing the entire station, not just one building (i.e., a three-story dorm) (DMJM, 2003). In addition, building documents (from the National Archives) provided no numerical information.

The Weather File

A custom weather file had to be created for this dissertation since no reliable source of weather data existed for McMurdo Station in a useful format. See Appendix N for a full discussion.

Age of the Building

Built during the 1988/1989 season, the three story dormitories replaced the last of the older T-5 huts and Jamesway quarters (see also Appendices A and B).[471] Thus it might have been necessary to refer to older building standards (e.g., ASHRAE Standard 62.1-1981 or Std. 62.1-1989), assuming they were followed at the time. If this were the case, it would also be necessary to determine relevant differences between the older standards and those which would be referenced today (e.g., ASHRAE Std. 90.1-2013, Std. 62.1-2013, or even Std. 189.1-2011).

However, because it would create difficulties comparing improved buildings (based on new standards) with the base case (using older standards), all measurements

[471] About ten years after the 203 series two-story dorms.

for ventilation are based on minimums and equations laid out in Std. 62.1-2013. A short discussion comparing older versions of ASHRAE standards follows here.

Changes to ASHRAE 90.1 (Energy Conservation)

Since the McMurdo three-story dorms were built in 1988/89, they were not able to benefit from changes made to energy conservation code in 1989 ASHRAE Std. 90.1 was still Std. 90A, 90B, and 90C-1980, an update[472] from the original Std. 90-75. The standard still combined commercial and residential buildings. It is not clear how useful it would have been –or if it was even consulted– for the dormitories, given the unusual circumstances (i.e., its extreme location outside any typical U.S. climate zone). No mention has been found in existing documentation, which has been noted here as being often thin and incomplete. The McMurdo 2003 update (DMJM, 2003) and subsequent energy studies include mention of the ASHRAE standards, although it is not always clear which version the authors reference.

Changes to ASHRAE 62 (Ventilation for IAQ)

ASHRAE Standard 62 defines, among other things, the required ventilation rates for buildings (in order to meet code), but these values have changed over time as the focus on IAQ have changed. Before 1997, when Std. 62 was split into Std. 62.1 and Std. 62.2 (the latter covering low-rise residential), the single document had already been

[472] "The updating of Standard 90-75 was undertaken by splitting the standard into two parts: 90A contained the prescriptive path to compliance, and 90B contained the alternative performance path. A new 90C was added in 1977 to provide a basis for considering building energy use on a source energy basis (Hunn et al., 2010).

revised[473] in 1989 and 1981 from its original version in 1973, which was based on decades of research from ASHVE [474] (Janssen, 1999, p. 51).

The forward sections to each updated standard give a brief overview of the changes made to the newly released version and those past. Further documentation of the evolution of Std. 62 is well covered in a number of sources, (e.g., Stanke, 1999; Persily, 2002; Janssen, 1999; Gallo, 1998); readers can also find information on the push and pull of ASHRAE with Big Tobacco (e.g., Bialous & Glantz, 2002; Glantz & Schick, 2004).[475]

In its current version, Std. 62.1-2013 [476] has a number of important differences between it and the version that may have been used in the design of the three-story dorms (used as the base case here). The following relevant points should be noted (adapted from Stanke, 1999): *smoking; calculation of the space ventilation rate*.

Smoking

Std. 62-1973 makes no distinction between ventilation rates in smoking and non-smoking areas. The 1981 revision, although scheduled as a part of the regular review

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[473] With every revision there are also multiple addenda that inevitably follow.

[474] I.e., the American Society of Heating and Ventilating Engineers (ASHVE), which has now become part of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, (ASHRAE).

[475] Additionally there is a memo (no author) in the Philip Morris collection in the Legacy Tobacco Documents Library at UC San Francisco, complaining that the new Std. 62-1981 put the Tobacco industry at a great disadvantage with the newly implemented rates for smoking and non-smoking spaces. They seem to have been blindsided by an organization they knew almost nothing about. Aside from criticizing the science behind the studies the new standard references, as well as claiming that most of the numbers are not based on any established facts, the memo ends with a suggestion that company insiders should be "sought out" to attend and observe the upcoming meeting in Houston in 1982.

[476] After the 2004 revision, the standard was " … placed in Continuous Maintenance status as a High Profile standard by the ASHRAE Board, meaning that the committee was directed to consider proposed changes continuously and update the standard and then to republish it every three years" (Lawrence Berkeley National Laboratory, n.d.) . Therefore it was again revised in 2007 and 2013. In a 2010 revision, ventilation for health care facilities was removed and given its own standard, ASHRAE Std. 170.

cycle, was still highly influenced by the energy crises of the 1970s (Stanke, 1999, p. 40), which made tighter (i.e., more energy efficient) buildings more desirable, thereby necessitating an increase in indoor air quality, including the effects of environmental tobacco smoke (ETS) (Lundstrom, 1987). With this new priority, separate rates for smoking and non-smoking appeared for the first time, and although the standard generally " … eliminated the higher, more energy-intensive recommended ranges found in the 1973 version," (Glantz & Schick, 2004, p. 54) it set rates 2-5 times higher than in smoking areas.[477]

Even Standard 62-1989 was "… mainly concerned with dilution of indoor-generated contaminants" (Janssen, 1999, p. 51) but still allowed a "moderate" amount of smoking in spaces. When ventilation rates for smoking areas were removed in 2002 because it was finally felt that enough evidence suggested that " … acceptable air quality cannot be achieved where smoking is permitted," they persisted in appendices (Glantz & Schick, 2004, p.55).

Today Standard 62.1-2013 contains provisions for buildings which choose to house ETS and ETS-free zones. These provisions are intended to minimize cross contamination of air using exhaust systems, signage, recirculation, and pressurization, but they " … do not purport to achieve acceptable indoor air quality in ETS areas" (ASHRAE Std. 62.1-2013, Sec. 5.17).

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[477] This in turn drove building owners to phase out indoor smoking as a matter of lowering costs, an action that did not please the tobacco industry (Glantz & Schick, 2004, p.54).

McMurdo Station used to accommodate more smoking than it does now. The last of the smoking dorm lounges were phased out in the last decade, and there is only one smoking bar (with rumors that it too will go soon). It can be viewed as a healthy choice and a safe choice (i.e., fire safety), but it is definitely an energy efficient choice.

If one were to model the original McMurdo Dormitories 206-209, it would be necessary to consider older building codes (which may not even have been met at the time). CFM may have been greater then, although it is probably no longer the case. Still, remnants of its past can still be found; for example, the lounges equipped with fans, possibly for increased ventilation during time when they accommodated smokers.

Calculation of the Space Ventilation Rate

Although it made very little mention of indoor pollutants caused by second hand smoke, Standard 62-1973 proposed ventilation recommendations in the spirit of occupant health, safety, and well-being. It suggested *recommended* ventilation rates for Bedrooms (under the "Hotel, Motel, Resort" space type) as being a between 10-15 <u>cfm per occupant</u>, with a set minimum of no less than 7 cfm/occupant. With a few caveats all spaces in Standard 62-1973 are assigned ventilation rates in this way. The standard also set an absolute minimum of 5cfm/person for any non-smoking space.

In ASHRAE Standard -1981, hotel bedrooms that allowed smoking had a recommended ventilation rate of 30 cfm/person, but that decreased to 15 cfm/person for non-smoking rooms [478] (ASHRAE, 1981, p.7). This standard also introduced the " … Indoor Air Quality Procedure (IAQP), which allowed for the calculation of the amount of outdoor air necessary to maintain the levels of indoor air contaminates below recommended limits" (ASHRAE Standard 62.1-2013, p. 2). The forward to Standard 62-2004 (p. 2) posited that this action would allow more creative ways to find energy efficient ways to ventilation a space, allowing " … the use of any amount of outdoor air deemed necessary if the designer could show that the levels of indoor air contaminants were held below recommended limits." As before, these numbers were recommendations, not requirements.

Standard 62-1989 continued to focus on minimizing adverse health effects of indoor pollutants, incorporating technological advances in pollutant removal in its pages.

> In this version, partly in response to rising complaints related to "poor indoor air quality," the authors chose to use visitor satisfaction (15 cfm per person) as the base ventilation rate instead of occupant satisfaction (5 cfm per person). Then, they adjusted the rates (usually by adding airflow) based on professional judgment related to the non-people sources in each space. (Stanke, 1999, p. 41)

[478] This in turn drove building owners to phase out indoor smoking as a matter of lowering costs, an action that did not please the tobacco industry (Glantz & Schick, 2004, p.54).

For bedrooms in "Hotels, Motels, and Dormitories" this meant the ventilation rate changed to 15 cfm/room. As previously mentioned, "moderate" smoking was still permissible, and needed to be taken into account.[479]

After 2001 ventilation rates began to appear as side-by-side area-based rates (e.g., from "30 cfm/room") *and* occupant-based rates (e.g., "5 cfm/person"). The Ventilation Rate Procedure, first seen in Standard 62-1989 (Section 6.1), thusly changed so that it required the input of both of these minimums; the goal was to address pollutants from occupant sources and those more related to the area of the zone (e.g., outgassing). In this procedure, the minimum ventilation rate was 15 cfm (Janssen, 1999, p. 51). In Addendum N to the Standard 62-2001, the method to determine the breathing zone outdoor airflow was put into the equation

$$V_{bz} = R_p \times P_z + R_a \times A_z$$

which is still used today, where A_z = zone floor area; P_z = zone population; R_p = outdoor airflow rate required per person (from a table); and R_a = outdoor airflow rate required per unit area (from a table). The calculations for ventilation follow next.

The three-story dorms in McMurdo (e.g., Building 209, the Base case) were probably built to different standards not just because of their age (when ventilation standards were different) but because the interior conditions have changed as well (i.e., smoking was allowed). Although these dorms were built in 1988-89, they may have followed Standard 62-1981.

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[479] This did not disappear until 1999.

The following figures and equations were used to calculate the ventilation demands for the base case building and the improved scenario. All final figures are based in ASHRAE Standard 62.1-2013 in order to maintain an equal comparison, but the figures based in Standard 62-1989 are included so readers may have a reference closer to the design date of the building.[480] For more information about the dynamics of the station, see Figure A- 75, Figure A- 76, Figure A- 77, Figure A- 78, Figure A- 79, and Figure A- 80.

1. Square footage:
   - Floor 1 area: 6,000 ft^2
   - Floors 2 & 3area: 6,240 ft^2 (each)
   - Corridors (includes stairs): 1,824 ft^2 (per floor)
   - Laundry room: 240 ft^2
2. Number of rooms:
   - Floor 1: 17 two-person rooms
   - Floors 2 & 3: 24 two-person rooms (each)
3. Occupancy:
   - Summer (max): 130 people
   - Winter: 28 people
   - Winfly occupancy: 62 people
4. ASHRAE Standard 62-1989 sets $30\,\frac{\frac{ft^3}{min}}{room}$ for each dormitory bedroom, a figure based only on the number of rooms. Corridors receive $0.05\,\frac{\frac{ft^3}{min}}{ft^2}$.
5. ASHRAE Standard 62.1-2013 sets this at $5\,\frac{\frac{ft^3}{min}}{person}$ plus an additional amount based on the square footage of the same ($0.06\,\frac{\frac{ft^3}{min}}{ft2} \times ft^2$). These numbers are understood to be minimum values. Corridors receive $0.06\,\frac{\frac{ft^3}{min}}{ft^2}$.

[480] The 206-209 dorm series was constructed in 1988-1989, but must have been designed in the immediately preceding years.

<u>Building ventilation ASHRAE Standard 62.1-2013</u>

Max occupancy (i.e., Mainbody)

Floor 1

$$5\,\frac{\frac{ft^3}{min}}{person} * 34\,ppl + 0.06\,\frac{\frac{ft^3}{min}}{ft2} * 6{,}000\,ft^2 = 530\ \frac{ft^3}{min}$$

Floor 2 & 3

$$5\,\frac{\frac{ft^3}{min}}{person} * 48\,ppl + 0.06\,\frac{\frac{ft^3}{min}}{ft2} * 6240\,ft^2\ = 614\ \frac{ft^3}{min}$$

Corridors (includes stairs)

$$1{,}824\,ft^2 \times 0.06\,\frac{\frac{ft^3}{min}}{ft^2} = 109\ \ \frac{ft^3}{min}$$

Total

$$530\ \frac{ft^3}{min} + \left(614\ \frac{ft^3}{min} \times 2\right) + \left(109\ \frac{ft^3}{min} \times 3\,floors\right) = \mathbf{2,088}\ \boldsymbol{\frac{ft^3}{min}}$$

Min. occupancy (i.e., Winter)

Floor 1

$$5\,\frac{\frac{ft^3}{min}}{person} * 8\,ppl + 0.06\,\frac{\frac{ft^3}{min}}{ft2} * 6{,}000\,ft^2 = 400\ \frac{ft^3}{min}$$

Floor 2 & 3

$$5\,\frac{\frac{ft^3}{min}}{person} * 10\,ppl + 0.06\,\frac{\frac{ft^3}{min}}{ft2} * 6240\,ft^2\ = 424\ \frac{ft^3}{min}$$

Corridors (includes stairs)

$$1{,}824\,ft^2 \times 0.06\,\frac{\frac{ft^3}{min}}{ft^2} = 109\ \ \frac{ft^3}{min}$$

Total

$$400\ \frac{ft^3}{min} + \left(424\ \frac{ft^3}{min} \times 2\right) + \left(109\ \frac{ft^3}{min} \times 3\,floors\right) = \mathbf{1,578}\ \boldsymbol{\frac{ft^3}{min}}$$

Once the flow rate for the building was established, it was necessary to calculate the energy needed to heat that air (assuming at first that it was constant). The next section describes how this was achieved.[481] First noted are calculations that include humidity; these were not used because, upon examining room data logged with a HOBO, there was no indication of humidification of the outside air provided to the dorm. Additionally, there was no information in the weather file that was needed to complete this calculation. Other buildings (like the Crary Science lab) are humidified, but not the dorms. Personal notes regarding persistent electrical shocks while in the dorm back up this assertion. However, it should be noted how much greater those values are, and what that would be should the dormitory be actively humidified.

Mainbody

$$2{,}088\ \frac{\mathrm{ft}^3}{\mathrm{min}} \times 0.087\frac{\mathrm{lb}}{\mathrm{ft}} = 169\frac{\mathrm{lb}}{\mathrm{min}}$$

$$169\ \frac{\mathrm{lb}}{\mathrm{min}} \times 60\ \frac{\mathrm{min}}{\mathrm{hr}}\ = 10{,}110\ \frac{\mathrm{lb}}{\mathrm{hr}}$$

$$10{,}110\ \frac{\mathrm{lb}}{\mathrm{hr}} \times \left(27\ \frac{\mathrm{Btu}}{\mathrm{lb}} - 7.36\frac{\mathrm{Btu}}{\mathrm{lb}}\right) = 198{,}570\ \frac{\mathrm{Btu}}{\mathrm{hr}} = 0.1986\ \frac{\mathrm{MMBtu}}{\mathrm{hr}}$$

$$0.1986\ \frac{MMBtu}{hr} \times 24\ \frac{hr}{day}\ = 4.77\ \frac{MMBtu}{day}$$

Winter

$$1{,}578\ \frac{\mathrm{ft}^3}{\mathrm{min}} \times 0.087\frac{\mathrm{lb}}{\mathrm{ft}} = 127\frac{\mathrm{lb}}{\mathrm{min}}$$

$$169\ \frac{\mathrm{lb}}{\mathrm{min}} \times 60\ \frac{\mathrm{min}}{\mathrm{hr}}\ = 7{,}641\ \frac{\mathrm{lb}}{\mathrm{hr}}$$

$$7{,}641\ \frac{\mathrm{lb}}{\mathrm{hr}} \times \left(27\ \frac{\mathrm{Btu}}{\mathrm{lb}} - (-)7.11\frac{\mathrm{Btu}}{\mathrm{lb}}\right) = 260{,}637\ \frac{\mathrm{Btu}}{\mathrm{hr}} = 0.2606\ \frac{\mathrm{MMBtu}}{\mathrm{hr}}$$

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[481] Assumptions include: the average dry bulb and dew point for the design day in Mainbody are 22°F and 18.7°F, with an enthalpy (h) of 7.36 Btu/lb. For the Winter design day, they are -30°F, -39°F, and h=-7.11 Btu/lb. Indoor temperature is 70°F, 56°F, and h=27 Btu/lb.

$$0.2606\ \frac{\text{MMBtu}}{\text{hr}} \times 24\ \frac{\text{hr}}{\text{day}} = 6.26\ \frac{\text{MMBtu}}{\text{day}}$$

Mainbody

$$2{,}088\ \frac{\text{ft}^3}{\text{min}} \times 1.08 \frac{\text{Btu}}{\text{lb°F}} \times 48\text{°F} = 108{,}246 \frac{\text{Btu}}{\text{hr}}$$

$$108{,}246\ \frac{\text{Btu}}{\text{hr}} = 0.1082\ \frac{\text{MMBtu}}{\text{hr}}$$

$$0.1082\ \frac{\text{MMBtu}}{\text{hr}} \times 24\ \frac{\text{hr}}{\text{day}} = 2.6\ \frac{\text{MMBtu}}{\text{day}}$$

Winter

$$1{,}578\ \frac{\text{ft}^3}{\text{min}} \times 1.08 \frac{\text{Btu}}{\text{lb°F}} \times 100\text{°F} = 170{,}433 \frac{\text{lb}}{\text{min}}$$

$$170{,}422 \frac{\text{Btu}}{\text{hr}} = 0.1704\ \frac{\text{MMBtu}}{\text{hr}}$$

$$01704\ \frac{\text{MMBtu}}{\text{hr}} \times 24\ \frac{\text{hr}}{\text{day}} = 4.09\ \frac{\text{MMBtu}}{\text{day}}$$

Description of the Base Case .INP File

The components of the base case are based on Building 209 in McMurdo Station, a dormitory from the later part of the 1980s. Information from the McMurdo Station Intranet describes the building as "Type II, 1-Hour, non-combustible; steel-framed structure with 2-1/2" thick foam-insulated metal siding and roofing, steel-framed heavy timber first floor, steel-framed metal second and third floors. Steel-stud gypsum board interior partitions." Through documentation from the U.S. National Archives and other sources (e.g., Hoffman, 1974), and from personal observation, it is assumed that the metal siding for the building (and roof) are Robertson Versawall panels (see Appendix J).

The building is a long rectangle, 48 feet wide and 168 feet long (Figure A- 81). The first floor is slightly different in floor plan than floors 2 and 3, but each one is 8,064 ft^2 for a total of 24, 192 ft^2 (there is a typo in the information from the Intranet). Each floor has a lounge which faces south towards Winter Quarters Bay (Figure 24). The first floor also has the laundry room for the whole building and the mechanical room. The rest of the floor is taken up by double-occupancy rooms connected by a shared shower and toilet. Floors two and three are the same, with rooms and lounges. A single hallway runs through the middle of each floor and connects to a staircase on either side of the building. The roof is slightly pitched, with no overhang (contrary to construction documents). Beneath it is an attic space which houses two air-handling units.[482]

A 2,500 gallon tank holds heating fuel for the building and is located just outside the north wall, accessible to fuel trucks (i.e., "gas hoppers," Figure 25). The mechanical room, with exterior access only, is also located close to the tank. Prior to 1999 the building was heated by a York Shipley oil-fired glycol boiler. It now features three 330,000 Btu/hr. input, oil-fired, cast iron, Hydrotherm glycol boilers which are staged in order to scale up or down the amount of heat needed.

The boilers are connected to a heat exchanger which also accommodates the potable hot water with a primary and secondary reverse-return configuration. According to the information from the intranet, "The temperature set point for the primary loop is

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[482] The Trane "Climate Changer" units supply fresh air at 60°F only.

180^{o}F. The secondary loop provides heat to the baseboard radiators on six different zones and to the two air handling units on one zone. The temperature set point for the secondary zone varies with the outdoor temperature. The range is approximately 100^{o}F to 180^{o}F. Heat is supplied from the primary loop to the secondary loop by means of a diverting valve." Potable water is stored in a 440 gallon storage tank, which is often inadequate for the building during peak periods during the day, especially during certain times of the year.

Although the layout of the rooms plays no part in the energy model, each has two beds, a window, and a number of outlets for appliances such as small refrigerators, radios, clocks, lamps, and personal devices (e.g., phone, camera, tablet) (these affect the energy load of the building, which does appear in the model). Four people share a shower and toilet, with a sink in each room. Each room is supplied with fresh air from a VAV box located over the sink; baseboards below the windows provide extra heat (Figure 37). Exhaust fans in the shower and toilet room area remove stale air, but it is not clear if there is any level of recirculation.

In the INP file,[483] the building is divided into several zones. Each of the three main levels has one hallway and one living zone; the first floor also has a laundry room. Two staircases on either end of the building form one three stories tall zone. The attic is an unconditioned space. A building shape representing Building 208 is on the north side (Figure 38). The hallways are created by two long interior walls that terminate at the staircase zones.

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[483] See Appendix T.

Additional Calculations

Calculations for water demand for showers and washing machines, as well as domestic hot water (DHW) and clothes washing/drying machines' energy requirements (including ventilation needs) were kept external to the energy model in order to keep those loads and heat gains separate from other building energy loads. Once again, the calculations were divided into three seasons which cover not only different dates but a different number of days.

Below are the calculations for the Mainbody season (130 people, 92 days); for Winter and Winfly, substitute the number of people (28 and 62, respectively) and the number of days (137 and 136, respectively). There is a summary of all values for all three seasons included at the end (Table A-1).

<u>Mainbody Showers and Laundry</u>: population 130 max; 92 days/year

Showers: Assume that each person showers 3 times/week for 4 minutes/shower and there is a general desire to conserve water.

$$130 \text{ people } \times 3 \frac{\frac{\text{showers}}{\text{wk}}}{\text{person}} = 390 \frac{\text{showers}}{\text{wk}}$$

$$390 \frac{\text{showers}}{\text{wk}} \times 2.5 \frac{\text{gal}}{\text{min}} \times 4 \frac{\text{min}}{\text{shower}} = 3{,}900 \frac{\text{gal}}{\text{wk}}$$

$$3{,}900 \frac{\text{gal}}{\text{wk}} \div 7 \frac{\text{days}}{\text{wk}} = 557 \frac{\text{gal}}{\text{day}}, \text{or for 92 days, } 51{,}257 \ \frac{\text{gal}}{\text{yr}}$$

$$557 \frac{\text{gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}} \times (110 - 55)°\text{F} = 255{,}561 \frac{\text{Btu}}{\text{day}} \text{or } 0.2556 \frac{\text{MMBtu}}{\text{day}}$$

$$0.2556 \frac{\text{MMBtu}}{\text{day}} \times 92 \frac{\text{days}}{\text{yr}} = 24 \frac{\text{MMBtu}}{\text{yr}}$$

$$@\ 70\% \text{ efficiency } 24 \frac{\text{MMBtu}}{\text{yr}} \div 0.7 = 34 \frac{\text{MMBtu}}{\text{yr}}$$

Improve showerhead flow to 2 gal/min:

$$390\,\frac{\text{showers}}{\text{wk}} \times 2\,\frac{\text{gal}}{\text{min}} \times 4\,\frac{\text{min}}{\text{shower}} = 3{,}120\,\frac{\text{gal}}{\text{wk}}$$

$$3{,}120\,\frac{\text{gal}}{\text{wk}} \div 7\,\frac{\text{days}}{\text{wk}} = 446\,\frac{\text{gal}}{\text{day}}\text{, or for 92 days, } 41{,}006\,\frac{\text{gal}}{\text{yr}}$$

$$446\,\frac{\text{gal}}{\text{day}} \times 8.34\,\frac{\text{lb}}{\text{gal}} \times (110-55)°\text{F} = 204{,}449\,\frac{\text{Btu}}{\text{day}} \text{ or } 0.2044\,\frac{\text{MMBtu}}{\text{day}}$$

$$0.2044\,\frac{\text{MMBtu}}{\text{day}} \times 92\,\frac{\text{days}}{\text{yr}} = 19\,\frac{\text{MMBtu}}{\text{yr}}$$

$$\text{@ 70\% efficiency } 19\,\frac{\text{MMBtu}}{\text{yr}} \div 0.7 = 27\,\frac{\text{MMBtu}}{\text{yr}}$$

Laundry: Assume that each person washes two loads of laundry once per week.

$$130\text{ people} \times 0.14\,\frac{\text{days}}{\text{wk}} \times 2\,\frac{\text{loads}}{\text{person}} = 37\,\frac{\text{loads}}{\text{day}}$$

Water demand:

$$23\,\frac{\text{gal}}{\text{load}} \times 37\,\frac{\text{loads}}{\text{day}} = 854\,\frac{\text{gal}}{\text{day}}$$

$$854\,\frac{\text{gal}}{\text{day}} \times 92\,\frac{\text{days}}{\text{yr}} = 78{,}594\,\frac{\text{gal}}{\text{yr}}$$

DHW load:

$$854\,\frac{\text{gal}}{\text{day}} \times 8.34\,\frac{\text{lb}}{\text{gal}} \times (100-55)°\text{F} = 320{,}613\,\frac{\text{Btu}}{\text{day}},\text{ or } 0.3206\,\frac{\text{MMBtu}}{\text{day}}$$

$$0.32061\,\frac{\text{MMBtu}}{\text{day}} \times 92\,\frac{\text{days}}{\text{yr}} = 29.5\,\frac{\text{MMBtu}}{\text{yr}}$$

$$\text{@ 70\% efficiency } 29.5\,\frac{\text{MMBtu}}{\text{yr}} \div 0.7 = 42.1\,\frac{\text{MMBtu}}{\text{yr}}$$

Improve this to 13 gal/load:

$$483\,\frac{\text{gal}}{\text{day}} \times 8.34\,\frac{\text{lb}}{\text{gal}} \times (100-55)°\text{F} = 181{,}216\,\frac{\text{Btu}}{\text{day}},\text{ or } 0.18122\,\frac{\text{MMBtu}}{\text{day}}$$

$$0.18122\,\frac{\text{MMBtu}}{\text{day}} \times 92\,\frac{\text{days}}{\text{yr}} = 16.7\,\frac{\text{MMBtu}}{\text{yr}}$$

$$\text{@ 70\% efficiency } 29.5\,\frac{\text{MMBtu}}{\text{yr}} \div 0.7 = 23.8\,\frac{\text{MMBtu}}{\text{yr}}$$

Washers' electric demand: each machine draws 500 watts.

$$500\text{ watts} \times 0.83\,\frac{\text{hrs}}{\text{load}} \times 37\,\frac{\text{loads}}{\text{day}} = 15{,}476\,\frac{\text{Wh}}{\text{day}}\text{, or } 15.5\,\frac{\text{kWh}}{\text{day}}$$

$$15.5\,\frac{\text{kWh}}{\text{day}} \times 92\,\frac{\text{days}}{\text{yr}} = 1{,}423.8\,\frac{\text{kWh}}{\text{yr}}$$

Improve washers' electric demand to 250 watts but increase the time to 1.32 hrs./load:

$$250\text{ watts } \times 1.32\,\frac{\text{hrs}}{\text{load}} \times 37\,\frac{\text{loads}}{\text{day}} = 12{,}226\,\frac{\text{Wh}}{\text{day}}, \text{or } 12.2\,\frac{\text{kWh}}{\text{day}}$$

$$12.2\,\frac{\text{kWh}}{\text{day}} \times 92\,\frac{\text{days}}{\text{yr}} = 1{,}124.8\,\frac{\text{kWh}}{\text{yr}}$$

Dryers' electric demand: each machine draws 4,500 watts; one dryer is used for two loads of laundry

$$4{,}500\,\frac{\text{watts}}{\text{dryer}} \times 0.75\,\frac{\text{hrs}}{\text{load}} \times 18.6\,\frac{\text{loads}}{\text{day}} = 62{,}679\,\frac{\text{Wh}}{\text{day}}, \text{or } 62.7\,\frac{\text{kWh}}{\text{day}}$$

$$62.7\,\frac{\text{kWh}}{\text{day}} \times 92\,\frac{\text{days}}{\text{year}} = 5{,}766.4\,\frac{\text{kWh}}{\text{yr}}$$

Improve dryers' electric demand to 2,000 watts/dryer and reduce drying time to 0.58 hrs./load:

$$2{,}000\,\frac{\text{watts}}{\text{dryer}} \times 0.58\,\frac{\text{hrs}}{\text{load}} \times 18.6\,\frac{\text{loads}}{\text{day}} = 21{,}667\,\frac{\text{Wh}}{\text{day}}, \text{or } 21.7\,\frac{\text{kWh}}{\text{day}}$$

$$21.7\,\frac{\text{kWh}}{\text{day}} \times 92\,\frac{\text{days}}{\text{year}} = 1{,}993\,\frac{\text{kWh}}{\text{yr}}$$

For the Winter and Winfly seasons these numbers are duplicated except for the population (max 28 people and 62 people), and the numbers of days (136 and 137 days long). The outside air temperature difference (ΔT) does not affect water intake ΔT.

<u>Mainbody Ventilation</u>: population 130 max; 92 days/year

Laundry room ventilation: Assume each dryer requires 150 ft^3/min. Each person runs one 45-minute dryer for their two loads of weekly laundry. The average outside temperature for Mainbody is 30°F, for Winter it is -14 °F, and for Winfly it is -2 °F. Temperature for a hot dryer is 135 °F.

$$150\ \frac{\text{ft}^3}{\text{min}} \times\ 1.08\frac{\text{Btu}}{\text{lb°F}} \times (135-30)\text{°F} = 17{,}010\frac{\text{Btu}}{\text{hr}}$$

$$17{,}010\frac{\text{Btu}}{\text{hr}} \times 0.75\frac{\text{hr}}{\text{load}} \times 18.6\frac{\text{loads}}{\text{day}}\ = 236{,}925\frac{\text{Btu}}{\text{day}}, \text{or } 0.24\frac{\text{MMBtu}}{\text{day}}$$

$$0.24\frac{\text{MMBtu}}{\text{day}} \times 92\frac{\text{days}}{\text{yr}} = 22\frac{\text{MMBtu}}{\text{yr}}$$

Improve the drying time to 35 minutes/load:

$$150\ \frac{\text{ft}^3}{\text{min}} \times\ 1.08\frac{\text{Btu}}{\text{lb°F}} \times (135-30)\text{°F} = 17{,}010\ \text{Btu/hr}$$

$$17{,}010\frac{\text{Btu}}{\text{hr}} \times 0.58\frac{\text{hr}}{\text{load}} \times 18.6\frac{\text{loads}}{\text{day}}\ = 184{,}275\frac{\text{Btu}}{\text{day}}, \text{or } 0.18\frac{\text{MMBtu}}{\text{day}}$$

$$0.18\frac{\text{MMBtu}}{\text{day}} \times 92\frac{\text{days}}{\text{yr}} = 17\frac{\text{MMBtu}}{\text{yr}}$$

Whole building ventilation (excludes Laundry): Assume rates using ASHRAE Std. 62.1-2013 for outside air rates (see 1.4.2.2). Desired inside temperature is 72°F.

$$2{,}087\ \frac{\text{ft}^3}{\text{min}} \times 1.08\frac{\text{Btu}}{\text{lb°F}} \times (72-30)\text{°F} = 94{,}672\frac{\text{Btu}}{\text{hr}}, \text{or } 0.0947\frac{\text{MMBtu}}{\text{hr}}$$

$$0.0947\frac{\text{MMBtu}}{\text{hr}} \times 24\frac{\text{hr}}{\text{day}} = 2.27\frac{\text{MMBtu}}{\text{day}}$$

$$2.27\frac{\text{MMBtu}}{\text{day}} \times 92\frac{\text{days}}{\text{yr}} = 209\frac{\text{MMBtu}}{\text{yr}}$$ (note: Mainbody only)

Table 9: Summary of totals for energy consumption for the base case dorm and the improved version. These represent a yearly total. Numbers below the solid line were calculated separately and included for the total. The savings are 21%.

	BASECASE			IMPROVED			
	Electricity MMBTU	JP-5 MMBTU	Total MMBTU	Electricity MMBTU	JP-5 MMBTU	Total MMBTU	% Difference
AREA LIGHTS	321	0	**321**	321	0	**321**	
MISC EQUIPMT	493	0	**493**	493	0	**493**	
SPACE HEAT	31	1,425	**1,456**	25	956	**980**	**33%**
PUMPS & MISC	9	0	**9**	7	0	**7**	
VENT FANS	34	0	**34**	41	0	**41**	
SHWR DHW	0	68	**68**	0	54	**54**	**21%**
WSHR DHW	0	85	**85**	0	48	**48**	**44%**
LAUND	50	0	**50**	22	0	**22**	**57%**
BLDG VENT	0	1,147	**1,147**	0	918	**918**	**20%**
LAUND VENT	0	46	**52**	0	36	**40**	**23%**
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TOTAL	937	2,771	**3,714**	907	2,012	**2,923**	**21%**
EUI			**153**			**121**	

APPENDIX P

SURVEYS

Overview of Survey Data

During the 2009 and 2010 site visits, the author was able to distribute surveys to contract workers at the station.[484] Some had just completed a winter season and had been at the station since 8-12 months. Others had just arrived at Winfly, either for the very first time or for another season. The sample size for these surveys was limited to day-shift workers, but they still offer useful information about the people who keep the station working 24/7. For the purposes of this study, these surveys will be referred to as the Winfly surveys.

Supplementing the author's data is a survey Raytheon commissioned through a company called GreenPlay, LLC[485] to conduct in order to determine areas for improving recreational offerings for USAP stations and vessels. In addition to the GreenPlay survey and report, which was made available in January 2010 and drew nearly 1,000 responses from across the continent, a representative from GreenPlay made a 10-day visit to both McMurdo and South Pole Station to lead focus groups and hold informal "chats" with employees.

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[484] These surveys were reviewed and certified in accordance with IRB approval IRB2010-0437 and 2009-0552.

[485] Founded in Colorado, this is a consulting firm that focuses on the management of parks, recreation, and open spaces. GreenPlay's Recreation and Wellness Master Plan for the USAP contains both short and long-term recommendations; the surveys were conducted by the NRC.

The GreenPlay survey and report covered not just McMurdo Station but South Pole, Palmer, some field camps, and research vessels, meaning that it represents "…excellent cross-section of participant experience, job functions, and background" of the USAP community (GreenPlay, 2010, p. ii). The report was released in April 2010. For the purposes of this study, the findings will be referred to as the GreenPlay report, with any information directly out of the surveys attributed to the NRC, i.e., "NRC, 2010."

Profile Information Findings

Of the respondents to the Winfly surveys, roughly two-thirds were male and one-third female, nearly the same proportion reported in the GreenPlay surveys. In the Winfly surveys, two-thirds of respondents were between the ages of 30 and 45; in a similar fashion, the GreenPlay surveys showed 58% were between the ages of 25 and 45. These numbers fit into the picture of a historically male-dominated location and the long-term commitment requirement.[486] Additionally, the physical demands of many Antarctic jobs and the basic medical exam required eliminate older people and anyone with any chronic or permanent physical disability.

For both surveys, a clear majority had logged "Ice Time" only or most recently at McMurdo Station, a testament to its size. According to the GreenPlay survey, 33% were in Antarctica for the first time and 16% were returning after their first season. Very few people reported having spent more than 3-4 seasons "on the ice;" however, a small

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[486] Should the station ever shift towards a colony with families, this imbalance would probably shift.

percentage claimed over 10 and up to 25 seasons. Over three-quarters of the GreenPlay respondents reported having a degree higher than a high school diploma. Only half stated they were "very likely" to return to Antarctica if they had the opportunity to do so.

Samples of the Surveys

Questionnaire: Development of an Off-Grid, Large-Scale Research Station in Antarctica

Questions for Win-Fly

ID: ________________________________

Date: ________________________________

Please answer the following questions as completely as possible. All responses will be kept confidential.

<u>Section 1</u>

1. Sex: (Circle one) **Male** **Female**
2. Age: (Circle one) **18-29** **30-45** **46-65**
3. What is your role at the station? (Please describe).

   a. Which shift do you work? (Circle one) **Dayshift** **Nightshift** **Varies**

4. Is this your first deployment to McMurdo? (Circle one) **Yes** **No**
   a. If this is not your first time in **McMurdo**, how many times have you been here before, and at what time of year?

5. Is this your first time in **Antarctica**? (Circle one) **Yes** **No**

a. If you have worked elsewhere in Antarctica, where were you, and for how long?

6. Is this the first time you have been here at **WinFly**? (Circle one) **Yes** **No**

Section 2

1. Do you feel the built environment (the buildings that comprise the station) provides a comfortable environment that promoted a sense of physical and emotional well-being? (Circle one) **Yes** **No** **Don't Know**
   a. Rate your ability to find comfortable places to socialize since you have arrived. (1 = not a problem, 5 = often a problem)
      1 2 3 4 5
   b. Rate your ability to find comfortable places for privacy since you have arrived. (1 = not a problem, 5 = often a problem)
      1 2 3 4 5
2. Rate your difficulty sleeping since you have arrived.
   (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
3. Rate difficulty encountered when moving between buildings since you have arrived.
   (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
   a. If there are problems, please describe them.
4. How often does the low relative humidity keep you from feeling comfortable?
   (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
   a. If there are problems, please describe them.
5. How often does the low temperature keep you from feeling comfortable?
   (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
   a. If there are problems, please describe them.

<u>Section 3</u>

1. Since you have arrived, do you feel you get adequate physical exercise each day?

   (Circle one) **Yes** **No** **Don't Know**

   a. Do you feel there are there enough opportunities for physical exercise in McMurdo? (Circle one) **Yes** **No** **Don't Know**

   b. If you do exercise, where do you go and what activity/activities do you engage in?

   c. Do you feel you have adequate access to recreational equipment in McMurdo? (Circle one) **Yes** **No** **Don't Know**

   d. Do you feel there are there enough opportunities for excursions off-base?

      (Circle one) **Yes** **No** **Don't Know**

   e. Have you taken one of the provided hiking trails near McMurdo Station?

      (Circle one) **Yes** **No**

   f. If you have taken one of the provided hiking trails, how satisfied were you with them? (1 = very satisfied, 5 = very unsatisfied)

      1 2 3 4 5 N/A

2. Does your daily routine require that you spend time outside?

   (Circle one) **Yes** **No**

   a. Do you like or dislike being outdoors in McMurdo Station?

      (Circle one) **Like** **Dislike** **Don't Know**

   b. Do you like or dislike going outside to travel between buildings?

      (Circle one) **Like** **Dislike** **Don't Know**

   c. Do you like or dislike being outdoors away from McMurdo Station?

      (Circle one) **Like** **Dislike** **Don't Know**

3. What percentage of your work day is spent outside?

(Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

   a. What percentage of this time is spent off the base (on the sea ice or elsewhere)?

      (Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

4. What percentage of your free time is spent outside?

      (Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

   a. What percentage of this time is outdoors in town and how much is spent off the base (on the sea ice or elsewhere)?

      (Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

5. Describe your place of work:

   a. What is the building name?

   b. Where is this building located?

   c. How conveniently located is this building, relative to other buildings you frequent on a typical day? (1 = very convenient, 5 = inconvenient)

      1 **2** **3** **4** **5**

   d. Is there any natural daylighting (through windows or skylights)?

      (Circle one) **Yes** **No** **Don't Know**

   e. In general, what is the noise level like?

      (1= very quiet, 5 = unpleasantly loud) **1** **2** **3** **4** **5**

   f. Does there seem to be adequate ventilation?

      (Circle one) **Yes** **No** **Don't Know**

   g. Is the temperature generally comfortable to you?

      (Circle one) **Yes** **No** **Sometimes**

6. How important is occasional access to Scott Base?

   (1= very important, 5 = not very important) **1** **2** **3** **4** **5**

a. When it is open, about how many times per month do you go there?

7. Does the ship's store (in Building 155) provide most of what you need?

   (Circle one) **Yes** **No**

   a. If not, what would you like to see changed?

8. How important is the Internet to your daily life here in McMurdo?

   (1= very important, 5 = not very important) **1** **2** **3** **4** **5**

9. How satisfied are you with your Internet access?

   (1= very satisfied, 5 = very unsatisfied) **1** **2** **3** **4** **5**

10. Are you satisfied with your voice/telephone access?

    (1= very satisfied, 5 = very unsatisfied) **1** **2** **3** **4** **5**

    a. If not, what would you like to see changed?

11. Do you miss a normal light cycle (periods of daylight and darkness)?

    (Circle one) **Yes** **No** **Don't Know**

    a. Have you done anything to simulate a day/night cycle? If so, what?

12. Do you miss green vegetation?

    (Circle one) **Yes** **No** **Don't Know**

    a. Have you done anything to simulate having vegetation? If so, what?

    (Circle one) **Yes** **No** **Don't Know**

13. Are you able to work flexible hours to accomplish your job?

    (Circle one) **Yes** **No** **Don't Know**

    a. Is having flexible work hours important to you?

       (Circle one) **Yes** **No** **Don't Know**

    b. Would flexible hours make you feel more comfortable in your job?

       (Circle one) **Yes** **No** **Don't Know**

<u>Section 4</u>

1. Do you or will you have a roommate?

   (Circle one) **Yes** **No** **Don't Know**

   a. Is this by choice? (Circle one) **Yes** **No** **N/A**
   b. How many roommates do you have at the moment?
   c. Does your roommate have the same or similar work hours as you?

      (Circle one) **Yes** **No** **Don't Know**
   d. Did you know your roommate(s) before they arrived?

      (Circle one) **Yes** **No**
   e. How important to you are private rooms in McMurdo during Win-Fly?

      (1 = very important, 5 = not very important) **1 2 3 4 5**
2. Do you have access to a private or semi-private shower/bathroom?

   (Circle one) **Yes** **No**

   a. How important do you think private or semi-private bathrooms are in McMurdo?

   (1= very important, 5 = not very important) **1 2 3 4 5**
3. About how many hours per day do you spend in your room?

   (Circle one) **1-4 hours** **5-9 hours** **10-14 hours** **more than 14 hours**

4. Aside from your room and your place of work, where do you spend the most time, and why?

5. Describe your room:

   a. What is the building name?
   b. What is this building's location?
   c. How conveniently located is this building, relative to other buildings you frequent on a typical day? (1 = very convenient, 5 = inconvenient)

      1 2 3 4 5

   d. How many windows are there?

e. What is the view out the window (if present)?

f. In general, what is the noise level?
(1= very quiet, 5 = unpleasantly loud) **1** **2** **3** **4** **5**

g. Is the temperature comfortable to you?
(Circle one) **Yes** **No** **Sometimes**

h. If you had the means, how would you make your room more comfortable?

<u>Section 5</u>

1. When you leave McMurdo, will you return directly home or will you travel first?
(Circle one) **Home** **Travel** **Don't Know**
2. Given the option, would you return to McMurdo (or elsewhere in Antarctica)?
(Circle one) **Yes** **No** **Don't Know**
   a. What would keep you from returning?

Questionnaire: Development of an Off-Grid, Large-Scale Research Station in Antarctica

Questions for Winter-Overs

ID: ____

Date: ____

Please answer the following questions as completely as possible. All responses will be kept confidential.

Section 1

7. Sex: (Circle one) **Male** **Female**
8. Age: (Circle one) **18-29** **30-45** **46-65**
9. What is your role at the station? (Please describe).
   a. Which shift do you work? (Circle one) **Dayshift** **Nightshift** **Varies**
10. Was this your first deployment to McMurdo? (Circle one) **Yes** **No**
    a. If this was not your first time in **McMurdo**, how many times have you been here before, and at what time of year?
    b. How long have you been here? (Circle one) **6-9 months** **More than 9 months**
11. Was this your first time in **Antarctica**? (Circle one) **Yes** **No**
    a. If you have worked elsewhere in Antarctica, where were you, and for how long?
12. Was this your first **winter** in McMurdo? (Circle one) **Yes** **No**
    a. If not, where else have you wintered in Antarctica?

Section 2

6. (Circle one) Over the winter, did you **(A)** form a social bond with the people around you, or **(B)** did you tend to spend time alone?
   a. Did this change as the winter progressed? (Circle one) **Yes** **No**
7. Do you feel the built environment (the buildings that comprise the station) provided a comfortable place that promoted a sense of physical and emotional well-being? (Circle one) **Yes** **No** **Don't Know**
   a. Rate your ability to find comfortable places to socialize during the winter. (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
   b. Rate your ability to find comfortable places for privacy during the winter. (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
8. Rate your difficulty sleeping during the winter. (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
9. Rate difficulty encountered when moving between buildings during the winter. (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
   a. If there were problems, please describe them.
10. How often did the low relative humidity keep you from feeling comfortable? (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
    a. If there were problems, please describe them.
11. How often did the low temperatures keep you from feeling comfortable? (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
    a. If there were problems, please describe them.

Section 3

1. Did everyone have their room in one building during the winter? (Circle one) **Yes** **No** **Don't Know**

a. Would it be preferable having everyone in one building during the winter? (Circle one) **Yes** **No** **Don't Know**

2. How many times have you changed rooms or moved to a different building since you arrived? (Circle one) **0-1** **2-3** **More than 3 times**
   a. Would staying in one place during your deployment be preferable? (Circle one) **Yes** **No** **Don't Know**
3. During the winter, did you have a roommate? (Circle one) **Yes** **No**
   a. Was this by choice? (Circle one) **Yes** **No**
   b. How important is having a private room in McMurdo during the winter? (1 = very important, 5 = not very important) **1** **2** **3** **4** **5**
4. During the winter, did you have a private/semi-private bathroom? (Circle one) **Yes** **No**
   a. How important is having a private or semi-private bathroom in McMurdo? (1 = very important, 5 = not very important) **1** **2** **3** **4** **5**
5. About how many hours per day did you spend in your room? **(Circle one) 1-4 hours 5-9 hours 10-14 hours more than 14 hours**
6. Aside from your room and your place of work, where did you spend the most time, and why?

<u>Section 4</u>

14. During the winter, did you feel you got adequate physical exercise each day? (Circle one) **Yes** **No** **Don't Know**

a. Do you feel there are there enough opportunities for physical exercise in McMurdo? (Circle one) **Yes** **No** **Don't Know**

b. If you do exercise, where do you go and what activity/activities do you engage in?

c. Do you feel you have adequate access to recreational equipment in McMurdo? (Circle one) **Yes** **No** **Don't Know**

d. Do you feel there are there enough opportunities for excursions off-base? (Circle one) **Yes** **No** **Don't Know**

e. Have you ever taken one of the provided hiking trails near McMurdo Station? (Circle one) **Yes** **No**

f. If you have taken one of the provided hiking trails, how satisfied were you with them? (1 = very satisfied, 5 = very unsatisfied)

1 2 3 4 5 N/A

15. Did your daily routine require that you spend time outside?
(Circle one) **Yes** **No**

a. Do you like or dislike being outdoors in McMurdo Station?
(Circle one) **Like** **Dislike** **Don't Know**

b. Do you like or dislike going outside to travel between buildings?
(Circle one) **Like** **Dislike** **Don't Know**

c. Do you like or dislike being outdoors away from McMurdo Station?
(Circle one) **Like** **Dislike** **Don't Know**

16. What percentage of your work day was spent outside?
(Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

a. What percentage of this time is outdoors in town and how much is spent off the base (on the sea ice or elsewhere)?

   (Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

17. What percentage of your free time was spent outside?

   (Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

   a. What percentage of this time is outdoors in town and how much is spent off the base (on the sea ice or elsewhere)?

   (Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

18. Describe your place of work:

   a. What is the building name/number?

   b. How conveniently located is this building, relative to other buildings you frequent on a typical day? (1 = very convenient, 5 = inconvenient)

   1 2 3 4 5

   c. Is there any natural daylighting (through windows or skylights)?

   (Circle one) **Yes** **No** **Don't Know**

   d. In general, what is the noise level like?

   (1= very quiet, 5 = unpleasantly loud) **1 2 3 4 5**

   e. Does there seem to be adequate ventilation?

   (Circle one) **Yes** **No** **Don't Know**

   f. Is the temperature generally comfortable to you?

   (Circle one) **Yes** **No** **Sometimes**

19. How important is occasional access to Scott Base?

   (1= very important, 5 = not very important) **1 2 3 4 5**

   a. When it is open, about how many times per month do you go there?

20. Does the ship's store (in Building 155) provide most of what you need?

(Circle one) **Yes** **No**

a. If not, what would you like to see changed?

21. How important is the Internet to your daily life here in McMurdo?

(1= very important, 5 = not very important) **1 2 3 4 5**

22. How satisfied are you with your Internet access?

(1= very satisfied, 5 = very unsatisfied) **1 2 3 4 5**

23. Are you satisfied with your voice/telephone access?

(1= very satisfied, 5 = very unsatisfied) **1 2 3 4 5**

a. If not, what would you like to see changed?

24. Do you miss a normal light cycle (day/night)?

(Circle one) **Yes** **No** **Don't Know**

a. Have you done anything to simulate a day/night cycle? If so, what?

25. Do you miss green vegetation?

(Circle one) **Yes** **No** **Don't Know**

a. Have you done anything to simulate having vegetation? If so, what?

(Circle one) **Yes** **No** **Don't Know**

26. During the Winter were you able to work flexible hours to accomplish your job?

(Circle one) **Yes** **No** **Don't Know**

a. Is having flexible work hours important to you?

(Circle one) **Yes** **No** **Don't Know**

b. Would flexible hours make you feel more comfortable in your job?

(Circle one) **Yes** **No** **Don't Know**

Section 5

6. Now that the station is open (Win-Fly), do you or will you have a roommate?

   (Circle one) **Yes** **No** **Don't Know**

   a. Is this by choice? (Circle one) **Yes** **No** **N/A**
   b. How many roommates do you have at the moment?
   c. Does your roommate have the same or similar work hours as you?

      (Circle one) **Yes** **No** **Don't Know**
   d. Did you know your roommate(s) before they arrived?

      (Circle one) **Yes** **No**
   e. How important to you are private rooms in McMurdo during Win-Fly?

      (1 = very important, 5 = not very important) **1** **2** **3** **4** **5**
7. Do you have access to a private or semi-private shower/bathroom?

   (Circle one) **Yes** **No**

   a. How important do you think private or semi-private bathrooms are in McMurdo?

   (1= very important, 5 = not very important) **1** **2** **3** **4** **5**
8. During Win-Fly, about how many hours per day do you spend in your room?

   (Circle one) **1-4 hours** **5-9 hours** **10-14 hours** **more than 14 hours**

9. Aside from your room and your place of work, where do you spend the most time, and why?
10. Describe your room:
    a. What is the building name?

    b. What is this building's location?

c. How conveniently located is this building, relative to other buildings you frequent on a typical day? (1 = very convenient, 5 = inconvenient) **1** **2** **3** **4** **5**

d. How many windows are there?

e. What is the view out the window (if present)?

f. In general, what is the noise level?
(1= very quiet, 5 = unpleasantly loud) **1** **2** **3** **4** **5**

g. Is the temperature comfortable to you?
(Circle one) **Yes** **No** **Sometimes**

h. If you had the means, how would you make your room more comfortable?

<u>Section 6</u>

3. When you leave McMurdo, will you return directly home or will you travel first?
(Circle one) **Home** **Travel** **Don't Know**
4. Given the option, would you return to McMurdo (or elsewhere in Antarctica)?
(Circle one) **Yes** **No** **Don't Know**
   a. What would keep you from returning?

Questionnaire: Development of an Off-Grid, Large-Scale Research Station in Antarctica

Questions for Win-Fly

ID: ____

Date: ____

Please answer the following questions as completely as possible. All responses will be kept confidential.

Section 1

13. Sex: (Circle one) **Male** **Female**

14. Age: (Circle one) **18-29** **30-45** **46-65**

15. What is your role at the station? (Please describe).

    a. Which shift do you work? (Circle one) **Dayshift** **Nightshift** **Varies**

16. Is this your first deployment to McMurdo? (Circle one) **Yes** **No**

    a. If this is not your first time in **McMurdo**, how many times have you been here before, and at what time of year?

17. Is this your first time in **Antarctica**? (Circle one) **Yes** **No**

    a. If you have worked elsewhere in Antarctica, where were you, and for how long?

18. Is this the first time you have been here at **WinFly**? (Circle one) **Yes** **No**

Section 2

12. Do you feel the built environment (the buildings that comprise the station) provides a comfortable environment that promoted a sense of physical and emotional well-being? (Circle one) **Yes** **No** **Don't Know**
    a. Rate your ability to find comfortable places to socialize since you have arrived. (1 = not a problem, 5 = often a problem)
       1 2 3 4 5
    b. Rate your ability to find comfortable places for privacy since you have arrived. (1 = not a problem, 5 = often a problem)
       1 2 3 4 5
13. Rate your difficulty sleeping since you have arrived.
    (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
14. Rate difficulty encountered when moving between buildings since you have arrived.
    (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
    a. If there are problems, please describe them.

15. How often does the low relative humidity keep you from feeling comfortable?
    (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
    a. If there are problems, please describe them.

16. How often does the low temperature keep you from feeling comfortable?
    (1 = not a problem, 5 = often a problem) **1 2 3 4 5**
    a. If there are problems, please describe them.

Section 3

27. Since you have arrived, do you feel you get adequate physical exercise each day?
    (Circle one) **Yes** **No** **Don't Know**
    a. Do you feel there are there enough opportunities for physical exercise in McMurdo? (Circle one) **Yes** **No** **Don't Know**

b. If you do exercise, where do you go and what activity/activities do you engage in?

c. Do you feel you have adequate access to recreational equipment in McMurdo? (Circle one) **Yes** **No** **Don't Know**

d. Do you feel there are there enough opportunities for excursions off-base? (Circle one) **Yes** **No** **Don't Know**

e. Have you taken one of the provided hiking trails near McMurdo Station? (Circle one) **Yes** **No**

f. If you have taken one of the provided hiking trails, how satisfied were you with them? (1 = very satisfied, 5 = very unsatisfied)

1 2 3 4 5 N/A

28. Does your daily routine require that you spend time outside?

(Circle one) **Yes** **No**

a. Do you like or dislike being outdoors in McMurdo Station?
(Circle one) **Like** **Dislike** **Don't Know**

b. Do you like or dislike going outside to travel between buildings?
(Circle one) **Like** **Dislike** **Don't Know**

c. Do you like or dislike being outdoors away from McMurdo Station?
(Circle one) **Like** **Dislike** **Don't Know**

29. What percentage of your work day is spent outside?

(Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

a. What percentage of this time is spent off the base (on the sea ice or elsewhere)? (Circle one)

0% - 25% **25%-50%** **50%-75%** **more than 75%**

30. What percentage of your free time is spent outside?

(Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

a. What percentage of this time is outdoors in town and how much is spent off the base (on the sea ice or elsewhere)?

(Circle one) **0% - 25%** **25%-50%** **50%-75%** **more than 75%**

31. Describe your place of work:

a. What is the building name?

b. Where is this building located?

c. How conveniently located is this building, relative to other buildings you frequent on a typical day? (1 = very convenient, 5 = inconvenient)

1 2 3 4 5

d. Is there any natural daylighting (through windows or skylights)?

(Circle one) **Yes** **No** **Don't Know**

e. In general, what is the noise level like?

(1= very quiet, 5 = unpleasantly loud) **1 2 3 4 5**

f. Does there seem to be adequate ventilation?

(Circle one) **Yes** **No** **Don't Know**

g. Is the temperature generally comfortable to you?

(Circle one) **Yes** **No** **Sometimes**

32. How important is occasional access to Scott Base?

(1= very important, 5 = not very important) **1 2 3 4 5**

a. When it is open, about how many times per month do you go there?

33. Does the ship's store (in Building 155) provide most of what you need?

(Circle one) **Yes** **No**

a. If not, what would you like to see changed?

34. How important is the Internet to your daily life here in McMurdo?

(1= very important, 5 = not very important) **1** **2** **3** **4** **5**

35. How satisfied are you with your Internet access?

(1= very satisfied, 5 = very unsatisfied) **1** **2** **3** **4** **5**

36. Are you satisfied with your voice/telephone access?

(1= very satisfied, 5 = very unsatisfied) **1** **2** **3** **4** **5**

a. If not, what would you like to see changed?

37. Do you miss a normal light cycle (periods of daylight and darkness)?

(Circle one) **Yes** **No** **Don't Know**

a. Have you done anything to simulate a day/night cycle? If so, what?

38. Do you miss green vegetation?

(Circle one) **Yes** **No** **Don't Know**

a. Have you done anything to simulate having vegetation? If so, what?

(Circle one) **Yes** **No** **Don't Know**

39. Are you able to work flexible hours to accomplish your job?

(Circle one) **Yes** **No** **Don't Know**

a. Is having flexible work hours important to you?

(Circle one) **Yes** **No** **Don't Know**

b. Would flexible hours make you feel more comfortable in your job?

(Circle one) **Yes** **No** **Don't Know**

<u>Section 4</u>

11. Do you or will you have a roommate?

(Circle one) **Yes** **No** **Don't Know**

a. Is this by choice? (Circle one) **Yes** **No** **N/A**

b. How many roommates do you have at the moment?

c. Does your roommate have the same or similar work hours as you?

(Circle one) **Yes** **No** **Don't Know**

d. Did you know your roommate(s) before they arrived?

(Circle one) **Yes** **No**

e. How important to you are private rooms in McMurdo during Win-Fly?

(1 = very important, 5 = not very important) **1** **2** **3** **4** **5**

12. Do you have access to a private or semi-private shower/bathroom?

(Circle one) **Yes** **No**

a. How important do you think private or semi-private bathrooms are in McMurdo?

(1= very important, 5 = not very important) **1** **2** **3** **4** **5**

13. About how many hours per day do you spend in your room?

(Circle one) **1-4 hours** **5-9 hours** **10-14 hours** **more than 14 hours**

14. Aside from your room and your place of work, where do you spend the most time, and why?

15. Describe your room:

a. What is the building name?

b. What is this building's location?

c. How conveniently located is this building, relative to other buildings you frequent on a typical day? (1 = very convenient, 5 = inconvenient)

1 **2** **3** **4** **5**

d. How many windows are there?

e. What is the view out the window (if present)?

f. In general, what is the noise level?
(1= very quiet, 5 = unpleasantly loud) **1** **2** **3** **4** **5**

g. Is the temperature comfortable to you?
(Circle one) **Yes** **No** **Sometimes**

h. If you had the means, how would you make your room more comfortable?

<u>Section 5</u>

5. When you leave McMurdo, will you return directly home or will you travel first?
(Circle one) **Home** **Travel** **Don't Know**
6. Given the option, would you return to McMurdo (or elsewhere in Antarctica)?
(Circle one) **Yes** **No** **Don't Know**
a. What would keep you from returning?

Summary of Survey Responses

This section includes a written summary of the most important information from the surveys, as well as a series of graphics showing individual responses. There is a focus on housing over work spaces.

Demographic Data

Survey responses from the mid-August-October time frame showed a roughly two-thirds majority of males to females (65% vs 35%). Most (61%) of these people were between 30 and 45 years of age, with a roughly equal split between those older (23% age 46-65) and younger (18% age 18-29). Of this group, 17% were in Antarctica and McMurdo Station for the first time; 34% of those surveyed had stayed previously at other Antarctic Stations (i.e., South Pole or Palmer).

Housing

Of those surveyed, 45% lived in either Dorm 210 or 211, standard facilities for contract workers. Three quarters (76%) reported sharing similar work hours with their roommate, and 88% wrote they knew their roommate before they moved in. While a few (30%) still had no roommate (this would definitely change during Mainbody), 57% reported having one roommate and a smaller number (13%) had three roommates. Those living in four-bedroom quarters were all in Dorm 211, but others in the same dorm reported only one roommate (at the time). Those living in 155 (18%) reported having no windows in their room.

On a 1-5 scale (with one being very important and 5 not important), respondents rated the importance of having a single room during the WinFly season as two on average. Of six questions on their experience, four are ranked as three on a 1-5 scale: the ability of the respondents to find places to socialize and places for privacy (one is not a problem, five is a problem); and problems with low outside temperatures and low relative humidity. Nearly 62% of respondents report they have put up pictures of natural scenes or “greenery” in their room or shared bathroom. Nearly the same number (52% report either actively blacking out their room in the evening or visiting the greenhouse when possible.

Living Conditions

Outside of rooms, respondents were asked where they spent most of their time. Answers were written in, and some people gave more than one location. “Coffee House” was listed 13 times; “155” or “the Galley” appeared 12 times; “gym” appeared give times; “the chapel,” “bars,” and “library” were named three times each; “outside” or “hiking” appeared twice; and “dorm lounge,” “the craft room,” and “internet kiosk” appeared once each. Another question about access for daily exercise showed that 48% felt it was adequate, and that 96% had at some point taken the hiking trails provided around the station.

Other Findings

At the time of the survey, 70% of respondents indicated their desire to return given the chance, with 87% planning on traveling somewhere before returning. Of just those who wintered over, 9% thought it would be preferable for everyone to be in one building during winter, and all of them would have preferred not to have change rooms during their stay. This can be understood when 54% of those who wintered over reported having had to have move two or more times during their stay. Of those who wintered over, 82% ranked keeping their single room as being a one (most important) on a scale of 1-5.

In a write in section asking how respondents’ rooms could be improved, temperature came up the most, with 61% of everyone surveyed indicating their room was either too hot or too cold, and that the control of the temperature did not seem to work. Better windows (for more light and less draft) and more lighting choices (including a sun lamp) were mentioned in 26% of the answers. Improving the comfort and feel of the furniture and décor could be improved in the opinion of 30% of respondents. Regrettably, none of the respondents were on the night shift, but it should be noted that during the winter there is no night shift unless one works at the power plant.

Findings of the GreenPlay Report

The GreenPlay report notes important ideas which may have been known qualitatively for years but never quantified or presented in an official report undertaken by a third party.[487] Although a large section of the report is highly generalized, it does offer some specific recommendations, even if they do not "have teeth" or have very little chance of implementation in the face of recent budget cuts (e.g., hydrotherapy pools).

The GreenPlay report focus on improvements to recreation, which is describes as "… all activities and spaces that help rejuvenate body, mind, and spirit" (GreenPlay, 2010, i). Three of the report's key findings include:

a. Recreation is essential to maintaining productivity, retention, and quality of life.
b. Recreation keeps participants healthy and fully functional during deployment, but it is also necessary to remember that safety and preservation of the environment also hold high priority.

[487] "One of the initial key findings [of the GreenPlay report] is that there are … suspicions and accusations that the administrators for the contractor, USAP, and NSF are 'not listening' and that there may be inherent bias in this project (GreenPlay, 2010, p.25). This is symptomatic of distrust of a large bureaucracy, one that is seen to have a long arm that can retaliate with docked pay or even banishment from the continent.

c. Housing affects the needs for recreation: the dorm-style living arrangements make single rooms highly desirable; the design and availability of private and public space outside the room are also important.

These findings seemingly come from data other than the surveys, since there were no questions about housing and no physical tests of the participants. However, these conclusions are easily found to be true in many remote locations, physically confined locations, McMurdo Station included.

In the GreenPlay report, it is noted that people working at the station were generally "web savvy and digitally connected" and had adventuresome personalities (GreenPlay, 2010, ii).[488] This is meant to highlight the limitation of the station's current access to the Internet. To some, that there is an Internet connection at all is still amazing (and sometimes something of an intrusion), but clearly its expansion will be beneficial to all at the station wishing to connect with the outside world and with friends and family back home.

These descriptions (based on self-reported information) help create a more accurate picture of those who will use the facilities at the station most: the contract employees.[489] Other points that became clear after (it is assumed) the site visit and participation in group discussions, is that access not only to activity areas and gym-type facilities is very important. Prized over anything else are recreational trips away from the station –the so-called "jolly" or "boondoggle." Also ranked highly are among USAP

[488] "Adventure" and "Antarctic experience" were rated "Essential" by 45% and 50%, respectively, of respondents (Greenplay, 2010).

[489] While science groups also need access to recreational facilities, the fact is that they are generally present for less time and sometimes spend most of their time in remote field camps.

recreational amenities are libraries, coffee houses, bowling alleys, availability of warm water, and music/live social events (GreenPlay, 2010, ii). The sedentary lifestyle experienced by many who find themselves working mostly inside can be a reversal for those used to a more active lifestyle or those expecting a more physically demanding outdoor experience in Antarctica.

The GreenPlay report makes an interesting note one regarding "non-sanctioned" behavior. The top three reported non-sanctioned behaviors all seem to stem from a primal need to relieve stress or boredom: drinking (alcohol), sexual contact, and hot water (i.e., improvised hot tubs). The report refers to this latter behavior as a way for people to "…[seek] physical solace and rejuvenation from hot water" (GreenPlay, 2010, ii). These may be considered "non-sanctioned," but at least at McMurdo Station, there has long been an acceptance of these needs and no effort to eliminate them, as long as carried out responsibly.[490]

The report also mentions other types of behavior that can be found in many extreme and remote environments: the need for balance between increased caloric intake and the risk of gaining too much weight, the balance between offering alcohol and the risk of it being abused, and the "scarcity complex" (another primal instinct to hoard items when resources appear to run low). These may have some architectural

[490] Two exceptions: hard liquor and saunas. While the former can be found at South Pole, it is no longer sold in McMurdo Station. As for the latter, the availability of saunas or even substantial, hot shower is severely limited. The GreenPlay report may be the first USAP report to recommend the installation of a "[h]ydrotherapy area with two hot spas and one recirculating warm water pool (GreenPlay, 2010, iv). Amundsen and his crew reportedly benefited greatly from having their own sauna.

implications (especially when it comes to designs for "active living,") but most of these are outside the scope of this work, as are proposals for increased outdoor activities.

Although the GreenPlay report did take on some selected architectural issues, it covered mostly the availability and quality of spaces for indoor activities. The report listed every space on the station used for communal activities and comments on their strengths and weaknesses. For instance, the Coffee House was described as "cozy" and quieter than the two other bars, but is threatened with demolition because it is very old and falling apart. However, earlier in the report it was noted that,

> Recent discussions about potential movement of spaces like the library, cardio (gerbil) gym, and weight room have elicited very strong responses. Movement of such spaces should be delayed until a wide communication and a well-defined plan for improved replacement that involves community input has been achieved. *Participants are very protective of their favorite places*. (GreenPlay, 2010, p. 23, italics added).

The author found that there were similar sentiments about the Coffee House, with WinFly survey responses listing it as the second most frequented space besides the dorm room, trailing only Building 155 (where all meals are served). The GreenPlay report provided no designs for a renovation or replacement of the coffee house, but a café setting is included in the program of a recreational facility proposal that consists of one large multi-purpose building.[491]

When it comes to dormitories, lounges are singled out for being grossly inadequate. This is because they are poorly sized and unfortunately placed in areas under 24-hr quiet hour rules (because day sleepers are mixed in with the general population). Community furniture is often swapped for lower-quality room furniture, and the amenities are limited and not equitable. In general, they are poorly maintained (because it is left up to residents to do so). During the two site visits by the author this was also found to be the case, especially the noise issue.

As for the availability of saunas, at the time of the report all but one in Building 155 had been closed because of high energy cost. During the author's 2009 and 2010 site visits, this was also found to be the case. The GreenPlay report noted that gym facilities were also severely undersized and inefficient; the author found that during normal working hours it was easy to find an open machine, but that after 5:00 pm the facilities were crowded, with the problem only worsening as more people arrived at the station. Overall, the GreenPlay report ranks McMurdo Station's recreational facilities as being of "poor to marginal quality" (GreenPlay, 2010, p.33).

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[491] The OZ proposal converts the NSF chalet into the new Coffee House. This increases the square footage somewhat and keeps the café set in a wood-paneled structure. It would also have a balcony with one of the best views in the station out to the ocean and mountains to the south.

APPENDIX Q

NOMENCLATURE

A&E	Architecture and Engineering
AIAS	American Institute of Architecture Students, formerly the Associated Student Chapters of the AIA.
Aerogel	An open-celled, mesoporous, solid foam that is composed of a network of interconnected nanostructures and that exhibits a porosity (non-solid volume) of no less than 50%. (http://www.aerogel.org).
Ablation	"The removal of material from a glacier, melting, evaporation, or calving (bits dropping off the end into the sea to form icebergs). Opposite of 'accumulation.'" (n.d.) In "Antarctic Appendix Q of Terms." Retrieved from *http://www.coolantarctica.com*
AAD	Australian Antarctic Division.
ACI	American Concrete Institute
Air, entrained	"…microscopic bubbles intentionally incorporated in mortar or concrete during mixing…" This process usually involves an admixture that causes these bubbles to develop, with the goal of "increas[ing] [the concrete's] workability and resistance to

freezing and thawing" (Specifications for Structural Concrete, ACI 301-05, 2005, p. 52).

ASA — *Antarctic Support Associates*, contract holder from 1990-2000. See timeline

ASHRAE — American Society of Heating, Refrigeration, Air-Conditioning Engineers

Barometric damper — "Counterweighted damper set so that variations in chimney barometric pressure will cause the damper to open or close gradually to maintain a constant draft directly upstream of the damper" (ASHRAE Technical Committee 1.6, Terminology; *http://wiki.ashrae.org/*)

Big eye (n., slang) — (1) "Insomnia caused by changes in the length of daylight." (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com.* (2) "… sleep disturbance…" (Oliver, 1991, p. 224).

BFC — Berg Field Center. Renamed after geologist Thomas Berg, who died in a helicopter crash, in 1969. Described as "the REI of McMurdo," (http://www.sandwichgirl.com), this the central storage location for all field equipment. Nothing is sold there, but equipment is tested and packed for all parties needing it for the field. There is also a food storage area for field camps of all sizes.

Blizzie — (n., slang) Australian term for a blizzard

Bolo — (n., slang) (*Australia)*: "Burnt-out-left-over." An expeditioner [sic] who has been in the Antarctic for too long." (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*

BUMED — The Navy Bureau of Medicine and Surgery in Virginia is the headquarters command for Navy Medicine. Under the leadership of the Navy Surgeon General, Navy Medicine provides health care to beneficiaries in both wartime and peacetime. *http://www.med.navy.mil*

C-17 — Boeing C-17 Globemaster III. Large transporter aircraft developed in the 1980s and 90s by McDonnell Douglas. It is 174 feet (53 m) long and has a wingspan of about 170 feet (52 m). It can carry about 121,254 lbs. (55,000 kg.). In McMurdo these aircraft tend to land on the Pegasus prepared-glacier runway (as opposed to the sea-ice runway; see "Pegasus.") If the sea ice runway (closer to the station) is at least 2 meters thick, the planes may land there (nsf.gov).

Capsule Environment — Typically, capsule environments are remote from other communities, are located in places where the physical parameters are inimical to human life, and are difficult to enter or leave. They are inhabited by artificially composed groups of people who are removed from their normal social networks and who carry out

	specific tasks and procedures. Excursions into the surrounding environment are relatively rare, usually uncomfortable, and frequently dangerous. The capsule therefore has to contain workspaces and living quarters, as well as facilities for recreation, health maintenance, medical treatment, sanitation, food preparation and consumption, and communication" (Suedfeld & Steel, 2000, p. 228-229).
Centria	A company formed in 1996 from H.H. Robertson, E.G. Smith, and Steelite, all companies that had previously worked with steel and foam composite wall systems. Building plans from the late 1980s for McMurdo's three-story dorms label the siding material as "Robertson Versawall Panels." Today a search for "Versawall" leads to the Centria website.
City Mice	(n., slang) :"Support personnel whose duties force them to remain at McMurdo Station." (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*
CCHRC	Cold Climate Housing Research Center located in Fairbanks, Alaska.
CONUS	Continental United States (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*
CDD	Cooling Degree Day. "Annual cooling degree days are the sum of the degree days over a calendar year." (http://wiki.ashrae.org)

These are "…summations of positive differences between the mean daily temperature and the [65°F base]" (NWS, n.d.).

Country Mice	(n., slang): "Scientists and their assistants who get to travel to camps around Antarctica."
Critical	(1) : of sufficient size to sustain a chain reaction —used of a mass of fissionable material <*a critical mass*>; (2): sustaining a nuclear chain reaction <the reactor went *critical*> (n.d.) Retrieved from *http://www.merriam-webster.com*
CRREL	Cold Regions Research Lab located in Hanover, NH.
Crud, the	(n., slang): "Common name for colds/flu contracted by new arrivals to the U.S. McMurdo base. Most common with a large entry of new people bringing a large influx of fresh germs. Any germ-related illnesses in Antarctica are rare in the winter as the base personnel have either had the illnesses by then or are immune to them." (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*
Degomble	(v., slang): "… process of removing … loosely attached snow [on one's clothing] before going indoors into a hut, base-building or tent where it would melt and make life more unpleasant." (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*

DMJM	Daniel, Mann, Johnson & Mendenhall, once located in Arlington, VA. (now a part of AECOM).
Donga	(n., slang): Australian term for a room in the Antarctic, although this terms usually refers to an improvised shelter.
Driftiness	(n.): "… impaired cognition…" usually associated with winter-over syndrome. (Oliver, 1991, p. 24)
EEM	energy efficiency measure(s)
EG&G	Edgerton, Germeshausen, and Grier, Inc. The three men partnered while at MIT and developed a high-speed photography technique which was later used to image nuclear weapon detonation during the Manhattan Project. During the 1970s and 80s they were located in Massachusetts. In 2002 the company was acquitted by the URS Corporation, located in Maryland.
EPA	Environmental Protection Agency
EUE	Extreme and unusual environment. Nearly any environment may be this way to those unaccustomed to it, but this phrase indicates something beyond simply feeling out of place. "The term extreme [indicates] physical parameters that are substantially outside the optimal range for human survival (even though some groups may exist in them) and the term unusual [denotes] conditions that deviate seriously from the accustomed milieu [sic] of most (but not necessarily all) human communities. Some environments

qualify as EUEs only during temporary disruption, such as natural or industrial disasters or war." (Suedfeld & Steel, 2000, p.228)

ERV — Energy Recovery Ventilation is a process in which energy is recovery through the heat exchange of energy embodied in exhausted building air. In the case of a cold, dry climate, the heat recovery preconditions the incoming outdoor air, heating it (e.g., from -70°F to just over 0°F) before it is fully heated by the rest of the system. In cold, dry climates, ERVs also humidify the air. See also HRV.

Fan-assisted combustion system — "An appliance equipped with an integral mechanical means either to draw or force products of combustion through the combustion chamber or heat exchanger" (ICC, 2012).

Freshies — (n., slang): "Fresh fruit and vegetables brought in by air or ship." At the end of the winter, the first flights into McMurdo usually bring "freshies" which are reserved for those who have wintered over. (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com* *note:* The McMurdo greenhouse sometimes provides some fresh produce during the winter, but not on a large scale or reliable schedule.

Galbestos — (n.): " Galbestos panels consist of two metal sheets with an intervening layer of insulating fiber glass. The trade name derives from the treatment of the metal surfaces, which by a special process are galvanized and impregnated with asbestos fibers" (Barber, 1968, p. 140). "Profiled metal sheeting with asbestos felt on both sides coated with either bitumen or polyester resin" ("Trade Names," Asbestos Information Center). "Galbestos is a protected metal perfected by the H.H. Robertson Company, pioneers in protected metal manufacture. It consists of a steel core to which an asbestos felt is bonded by means of a zinc alloy adhesive. This asbestos felt is saturated with an asphaltic compound to increase its waterproof qualities." (cite from "Galbestos HH books"). Galbestos contains 7%, chrysotile asbestos. It "…consists of sheet steel which is first dipped in a bath of molten zinc. Immediately, a layer of asbestos felt is applied under great pressure and bonded to the zinc coat. The felt is them impregnated with asphalt, and finally a touch waterproof colored coating is applied to both sides. Galbestos sheets are available in widths of 30 and 33 inches, lengths up to 12 feet" (Salvan, 2000, p. 536).

Greenout (n., slang): "The emotion felt on seeing and smelling green things (plants) again after an extended period on the ice." (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*

Gypsum board, Type X "ASTM C 36 designates two types of gypsum board, regular and Type X. Type X gypsum board… is formulated by adding noncombustible fibers to the gypsum. These fibers help maintain the integrity of the core as shrinkage occurs, providing greater resistance to heat transfer during fire exposure" (http://www.national gypsum.com/). In essence, the Type X designation means that a 5/8" board on both sides of a load-bearing framing provides a one-hour fire resistance rating.

H&N Holmes and Narver, first Antarctic contract holder, from 1968-1980. Based in Orange CA, they are now a part of AECOM.

Happy Camper Survival training for people in McMurdo who are required to work beyond the boundaries of the station.

HDD Heating Degree Day. "For any one day, when the mean temperature is less than 65°F (18°C), there are as many degree days as degrees Fahrenheit (Celsius) temperature difference between the mean temperature for the day and 65°F (18°C). Annual heating degree days (HDDs) are the sum of the degree days over a calendar year." (http://wiki.ashrae.org) These are

	"…summations of negative differences between the mean daily temperature and the 65°F base…" (NWS, n.d.).
Herbie	(n., slang): Term used to describe a type of particularly powerful and (potentially) dangerous storms that affect the U.S. McMurdo base coming from the South, through "Herbie Alley" winds can be in excess of 100 knots (115 mph). Exact origin unknown, possible adapted from a New Zealand term meaning "powerful." Sometimes known as a "hooley" on British bases. (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*
Herbie Alley	The area between White Island and Black Island, two island just south of McMurdo Station. Strong storm winds are often funneled through this area (Figure 10).
HIPAA	"The federal Health Insurance Portability and Accountability Act of 1996. The primary goal of the law is to make it easier for people to keep health insurance, protect the confidentiality and security of healthcare information and help the healthcare industry control administrative costs." (http://health.state.tn.us/hipaa/)
HoCal	abbreviation for Hotel California (formerly Building 166), an 8,160 ft^2 dormitory from 1968 (refurbished 1986). Probably refers to the song released by the *Eagles* in 1976, which describes a fictional hotel (or a state of mind) where "you can check out any time you like / but you can never leave." This sentiment may be

	felt by those who wish to leave Antarctica in the middle of a long deployment.
HRV	Heat Recovery Ventilation (a.k.a. mechanical ventilation heat recovery/MVHR), is an energy recovery ventilation system (see ERV) that uses a heat recovery ventilator which employs a counter-flow heat exchanger between the inbound and outbound air flow. Unlike ERVs, HRVs do not transfer latent heat.
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Association, located in Vienna, Austria. This agency was born out of President Eisenhower's Atoms for Peace address to the US in 1953.
ICE	*Isolated and confined environment*. An ICE is a type of EUE with the additional characteristics of "…physical remoteness or lack of access from accustomed locales and a circumscribed spatial range." (Suedfeld & Steel, 2000).
Ice sheet	(n.): See *ice shelf*.
Ice shelf	(n.): Ice shelves are glaciers which have flowed down a coastline and met the ocean; ice sheets are large glaciers over land, sometimes called continental glaciers. One example of an ice shelf is the Ross Ice Shelf, which covers much of the Ross Sea. On the other hand, much of Greenland is covered by an ice sheet.

Iceport	(n.): "The term iceport was first suggested by the Advisory Committee on Antarctic Names in 1956 to denote ice shelf embayments … subject to configuration changes, which may offer anchorage or possible access to the upper surface of an ice shelf via ice ramps along one or more sides of the feature." These features are generally not stable in the long term, as calving events can deny access to the iceport. USGS. (n.d.) Retrieved from *http://geonames.usgs.gov*
Ice time	The number of months one has spent "on the Ice," or in Antarctica. (It does not matter whether or not it was only at a station or in a field camp.) This number is sometimes used as a quick way of establishing seniority, especially when determining housing preferences.
IECC	International Energy Conservation Code, put out by the International Code Council (ICC).
IGCC	International Green Construction Code, put out by the ICC
IGY	*International Geophysical Year*. An 18-month international scientific endeavor that began July 1, 1957, and ended December 31, 1958. It was intended to promote international scientific cooperation, including in Antarctica.
ITT	ITT Antarctic Services, Antarctic contract holder from 1980-1990.

Katabatic	(adj.): Relating to or being a wind produced by the flow of cold dense air down a slope (as of a mountain or glacier) in an area subject to radiational cooling. Origin: Greek *katabatos* descending, verbal of *katabainein* to go down, from kata- *cata-* + *bainein* to go. First known use: 1918. (n.d.) Retrieved from *http://www.merriam-webster.com. Extraordinary katabatic wind*: "Katabatic wind that is particularly long-lasting (days to even weeks) and remains fairly constant in strength during that time." (n.d.) In "Antarctic Appendix Q of Terms." Retrieved from *http://www.coolantarctica.com*
LC-130	ski-equipped variant of the C-130 Hercules. An LC-130 aircraft has "…a cargo area of 12 by 3 by 3 meters [40 x 9.8 x 9.8ft]. It can … carry 12,200 kilograms [26,896 lbs.] of people and/or cargo from McMurdo to South Pole (728 nautical miles or 840 statue [sic] miles), then return to McMurdo without refueling. It cruises at 275 knots [316 mph]. Wingspan is 40 meters [131 ft.]; length overall, 30 meters [98 ft.] (NSF.gov).
Lockheed	*Lockheed Martin.* Current Antarctic contract holder, starting in 2012. See timeline. In 1912, Glenn L. Martin established the Glenn L. Martin Company in Los Angeles, California. The same year, Allan and Malcolm Lougheed (pronounced "Lockheed") founded the Alco

Hydro-Aeroplane Company, which they later renamed the Lockheed Aircraft Company.

In 1928 Captain George Hubert Wilkins (for whom many geographic/ topographic features are now named) flew a Lockheed Vega seaplane over parts of Antarctica. He named the Lockheed Mountains after the makers of his aircraft and Hearst Island after his sponsor (the newspaperman W.R. Hearst).

In 1930 Lockheed (still a separate organization), built the C-130 Hercules, an aircraft that would play a huge role in Antarctic logistics, even today.

In 1961 the Martin Company and American-Marietta Corporation (which sold building products like construction materials, paints, and chemicals) merged to form the Martin Marietta Corporation.

In the late 1950s/early 1960s the American Locomotive Company ("Alco," not to be confused with the predecessor to Lockheed) and Martin Marietta designed and built the remote nuclear power systems used in Camp Century, Greenland, and McMurdo Station, Antarctica.

Lockheed products include the Trident missile, P-3 Orion, F-16 Fighting Falcon, F-22 Raptor, A-4AR Fightinghawk, and the DSCS-3 satellite.

Martin Marietta products included Titan rockets, the Space Shuttle External Tank, the Viking 1 and Viking 2 landers, and various satellite models.

The two companies merged in 1995 to becomes one of the largest aerospace, defense, and technology companies: Lockheed Martin. In 2012 they secured the contract to support the U.S. Antarctic Program.

Long eye	(n., slang): A fugue state also known as "…the 20-foot stare in the 10-foot room…" that is a symptom of "winter-over syndrome. (Suedfeld, 2000, p.11)
LRDP	Long Range Development Plan
Mainbody	(n.): One of the three main seasons of the Antarctic year. At McMurdo, Mainbody usually lasts from about October 1 until the last flight before Winter Season, which begins in late February or early March. (n.d.) In "Antarctic Slang." Retrieved from *http://www.coolantarctica.com*
MMBtu	One million British Thermal Units.
MMI	abbreviation for Mammoth Mountain Inn (Building 188), constructed in the late 1960s.
Milvan	(n.): A standardized, modular shipping container such as those used on container ships. Sometimes referred to as a "Conex box."

Nacreous Clouds	"Clouds of unknown composition that have a soft, pearly luster and that form at altitudes about 25 to 30 km above the Earth's surface. They are also called "'mother-of-the-pearl clouds.'" *n.d. Retrieved from the National Weather Service, www.weather.gov* The unusual color is best seen at high latitudes.
NAF McMurdo	Naval Air Facility, McMurdo Sound
NASA	National Aeronautics and Space Administrations
NCDC	National Climatic Data Center
NCEL	Navy's Civil Engineering Laboratory
NFPA	National Fire Protection Agency, established in 1896. Its mission "… is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education." *(n.d.).* Retrieved from *http://www.nfpa.org*
NHRC	U.S. Naval Health Research Center
NOAA	National Oceanic and Atmospheric Administration
NRC	(1): "The NRC is a single-number index determined in a lab test and used for rating how absorptive a particular material is. This industry standard ranges from zero (perfectly reflective) to 1 (perfectly absorptive). It is simply the average of the mid-frequency sound absorption coefficients (250, 500, 1000 and 2000

Hz) rounded to the nearest 5%." (http://www.nrcratings.com/; accessed 11-17-2013). (2): National Research Council

NRCC — National Research Council (Canada)

NREL — National Renewable Energy Lab

NSF — National Science Foundation, founded in 1950 during a post-WWII wave of enthusiasm for science (Belanger, 2006, p. 30).

Nunatuk — (n.): An Inuit word meaning "a hill or mountain completely surrounded by glacial ice." The Inuit people are indigenous to the world's Arctic regions. (n.d.) Retrieved from *http://www.merriam-webster.com*

OAC — OPP External Advisory Committee

OPP — Office of Polar Programs is the primary U.S. supporter of fundamental research in polar regions.

Outfall — (n.) The place where a river, drain, or sewer empties into the sea, river, or lake.

Pegasus — Pegasus Field is a 10,000 ft. hard ice runway suitable for large, wheeled aircraft such as a C-17 or Airbus. It is located on the McMurdo Ice Shelf and was named after the C-121 Lockheed Constellation Pegasus that crashed nearby in 1970. Part of the plane is still visible. Because Pegasus is located in an area of surface ice ablation, there have been problems maintaining the surface of the runway during the summer. A new permanent

	runway for wheeled aircraft is planned closer to McMurdo that will replace Pegasus in 2017.
POE	post-occupancy evaluation
Polar Plateau	"The relatively flat, high altitude central region of the East Antarctic Ice Sheet. The plateau has an average height of 2000 meters (about one mile) above sea level and a smooth surface with a small slope towards the coast in all directions." (n.d.) In "Antarctic Appendix Q of Terms." Retrieved from *http://www.coolantarctica.com*
Polystyrene	"Expanded polystyrene (EPS) foam is a closed-cell insulation manufactured by 'expanding' a polystyrene polymer; the appearance is typically a white foam plastic insulation material … . Extruded polystyrene (XPS) foam is a rigid insulation also formed with polystyrene polymer, but manufactured using an extrusion process, and is often manufactured with a distinctive color to identify product brand." Retrieved from *http://www.buildings.com*.
RO	reverse osmosis is a process in which pressure is used to push salt water through a membrane which filters out salt and other minerals. It is used to desalinate ocean water to make it potable (it is often fortified with beneficial minerals after being desalinated).

RPSC	Raytheon Polar Services Company, Antarctic contract holder from 2000-2011. See timeline
RSA	RSA Engineering
Shore-fast ice	Ice that is attached or fastened to the shore and does not move with winds or currents, unlike drift or pack ice.
SPAWAR	"The *Space and Naval Warfare Systems Command* is the Navy's Information Dominance Systems Command. SPAWAR is fully committed to supporting the achievement of the Navy's mission and is dedicated to serving the Fleet. As one of three Department of Navy major acquisition commands, this means acquiring, installing, delivering and maintaining advanced information technology capabilities to the fleet, regardless of platform, to keep warfighters one step ahead of adversaries." (n.d.). Retrieved from http://www.public.navy.mil/
SOPP	SPAWAR Office of Polar Programs
Spindrift	(n.): Originally a nautical term used to describe sea spray in a gale, this term is here used to mean "fine wind-borne snow or sand." It is fine enough to work its way through tiny cracks in buildings or vehicles. *(n.d.)* Retrieved from *http://www.merriam-webster.com*
SSC	Science Support Center (a new building in McMurdo Station).

Subnivean	(adj.): Referring to objects or actions occurring in places buried by snow, e.g., a structure that is no longer visible because it is now completely covered by snow.
USN	United States Navy
VFD	variable frequency drive
VMF	Vehicle Maintenance Facility
White-out	"A weather condition in which the horizon cannot be identified and there are no shadows. The clouds in the sky and the white snow on the ground blend - described as like walking along inside a ping-pong ball. White out conditions are potentially dangerous because it is difficult to find a point of reference and it is very easy to walk over a cliff or fall down a crevasse in such conditions." (n.d.) In "Antarctic Appendix Q of Terms." Retrieved from *http://www.coolantarctica.com*
Williams Field	About half as far as Pegasus Field, "Willy Field" is used for ski-equipped planes. Its location on the Ross Ice Shelf makes it most useful when the annual ice runways become too unstable (usually after December). The runway is named after a naval equipment operator who died in 1956 after his D-8 tractor broke through thin ice.
Wind chill	(n.): "A way of describing the temperature that takes into consideration the effect of the wind speed in the temperature reported. Wind makes any temperature feel colder and wind chill

factor is a way of expressing how cold the wind might make the temperature feel. First described after experiments by the American scientist Paul Siple and Charles Passel on baked bean cans containing water and a thermometer left in the wind." (n.d.) In "Antarctic Appendix Q of Terms." Retrieved from *http://www.coolantarctica.com*

WinFly *Winter Fly-In*. A period of time between Winter season and Main Body, when the first few waves of relief personnel, supplies, fuel, food, and sometimes science groups arrive at the station. It usually starts in late August but with the advent of night-vision flights has been known to begin mid-month.

Winter-over syndrome Emotional and physical side effects of wintering over in Antarctica, usually in an isolated base or field camp with an unchanging population. Affecting everyone differently, it is often characterized by depression, hostility, sleep disturbance, and impaired cognition. Strange & Klein, 1974, p.411

APPENDIX R

ADDITIONAL FIGURES

Figure 9: Map showing Antarctica in context. McMurdo Station indicated, along with the 60°S latitude line, also known as the Antarctic Circle. Islands designated as "sub-Antarctic" are also included.

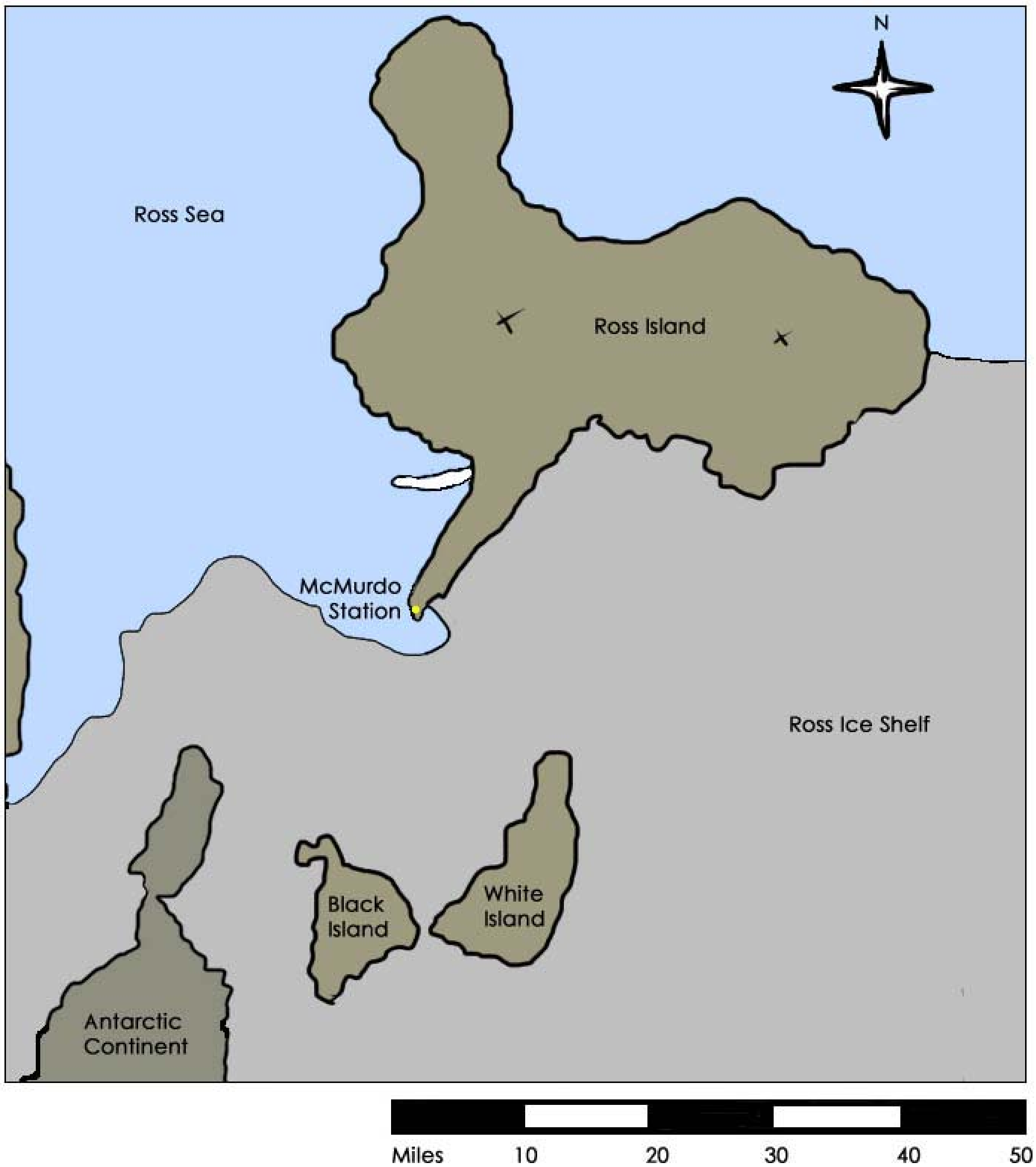


Figure 10: Ross Island in relation to the Ross ice Shelf an, White and Black Islands, and the continent mainland.

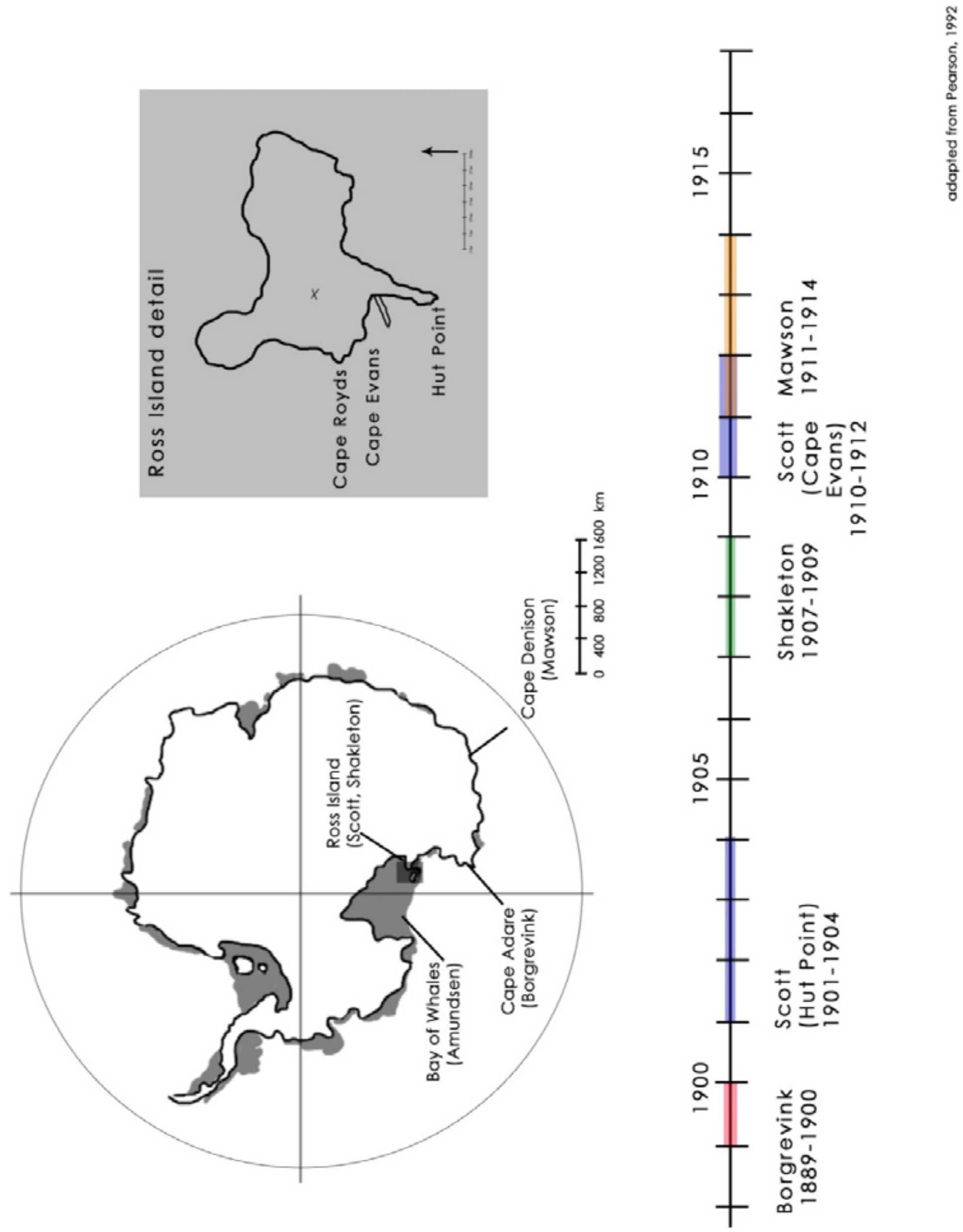


Figure 11: Timeline of Heroic Era explorers.

Figure 12: “The first building in Antarctica.” Reprinted with permission from *Icy heritage*, by David L. Harrowfield, 1995, Antarctic Heritage Trust: Christchurch. Copyright 1995 by Name of David L. Harrowfield.

Figure 13: Amundsen’s base, Framheim, at the Bay of Whales. Photo from The South Pole, by Roald Amundsen, 1931, p. 206. Public Domain.

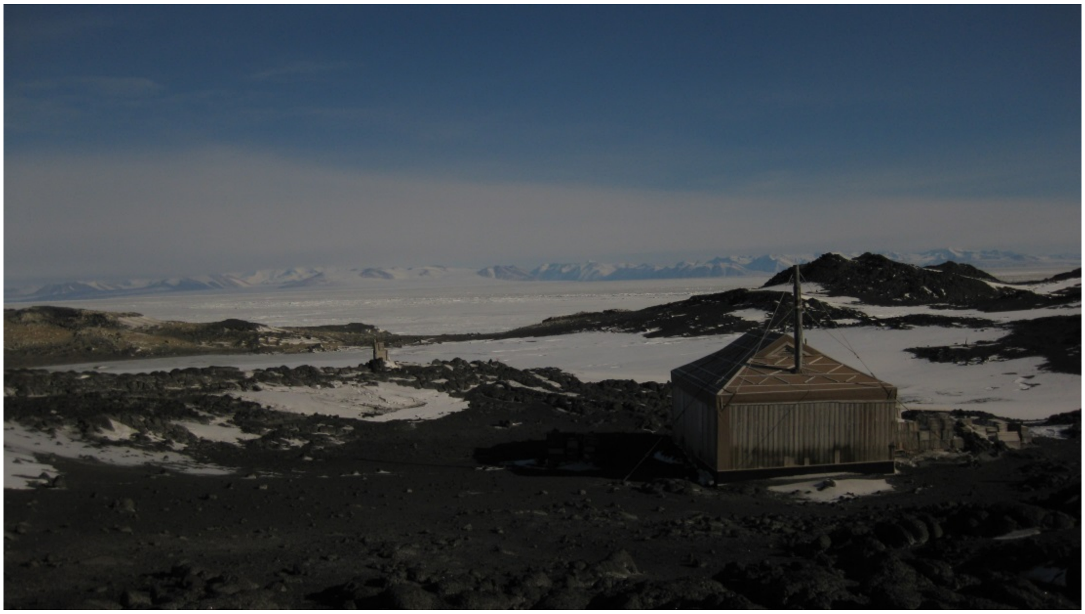


Figure 14: Shackleton's hut at Cape Royds. Photo by author, 2009.

Figure 15: Scott's hut at Cape Evans. Photo by author, 2009.

Figure 16: Scott's Discovery hut, Hut Point, Ross Island (foreground), and McMurdo Station (background). Between them is Winter Quarter's Bay. Photo by D. Williams, 2009.

Figure 17: Mawson's hut at Cape Denison. Image shows enclosed verandah. Public Domain.

Figure 18: Interior of Shackleton's Hut at Cape Royds. Photo by author, 2009.

Figure 19: the Science Support Center (SSC), built 2004. Photo by author, 2009.

Figure 20: Nacreous clouds, looking from a dormitory out to Hut Point and beyond. Photo by author, 2009.

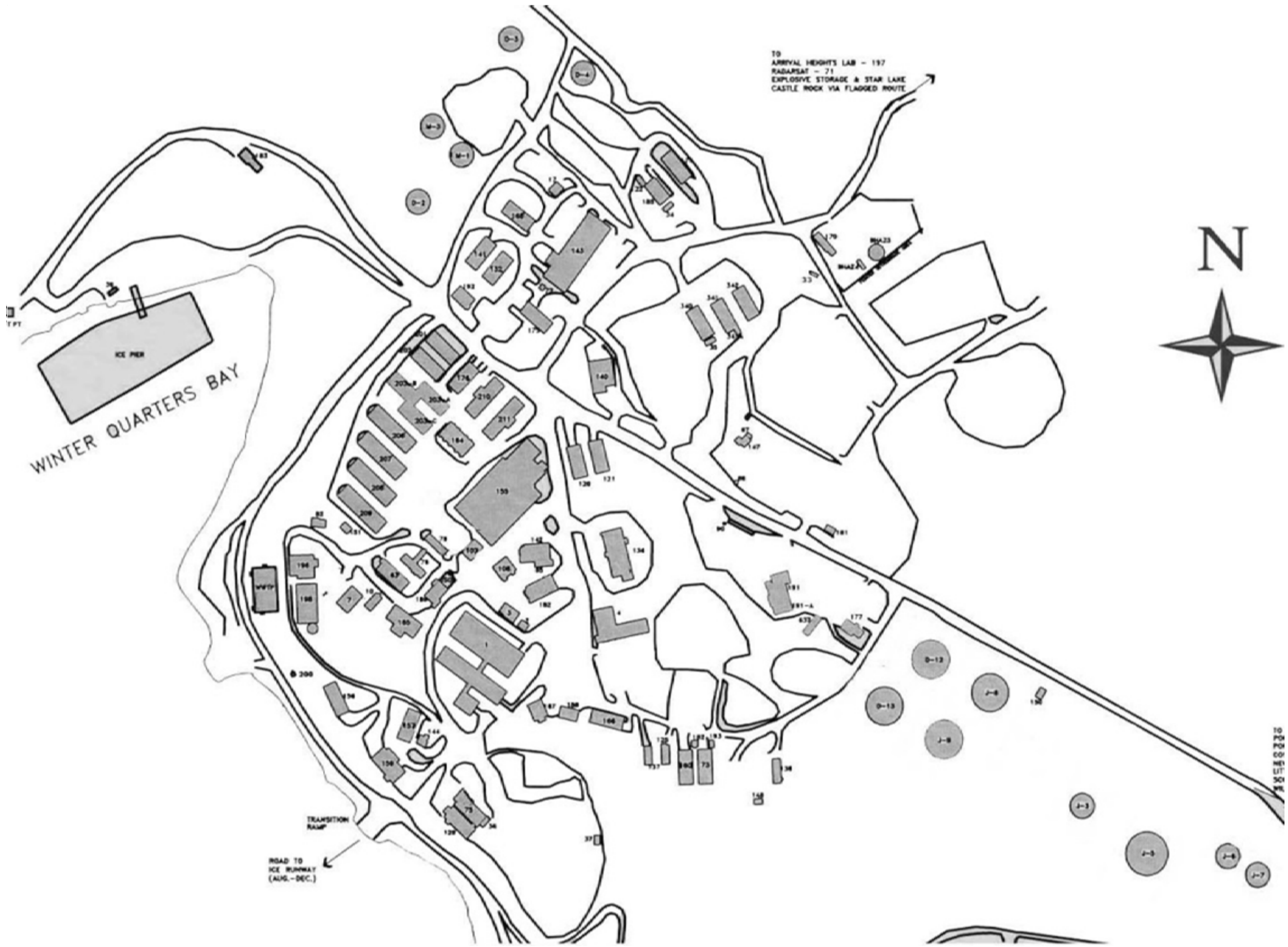


Figure 21: map of McMurdo Station building and roads.

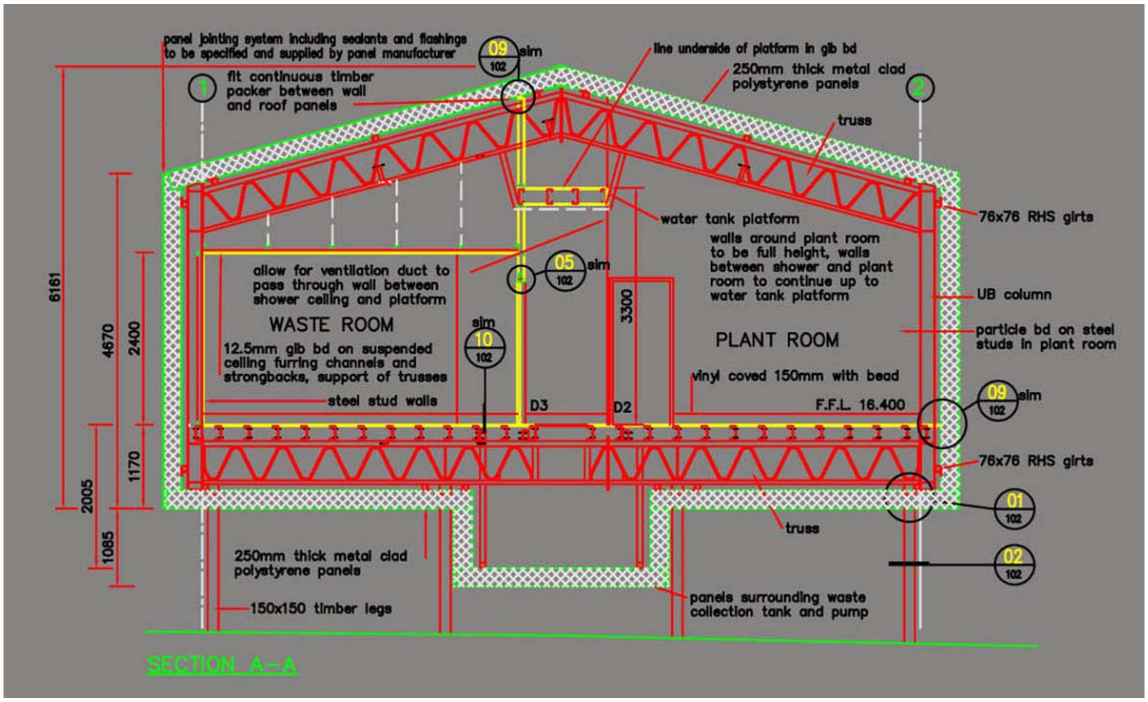


Figure 22: a Plan for an “ablutions building” at Scott Base, showing the full-building wrap design.

Figure 23: Map showing McMurdo Station and its drainage patters. Adapted. Courtesy of U.S. National Archives, College Park, MD.

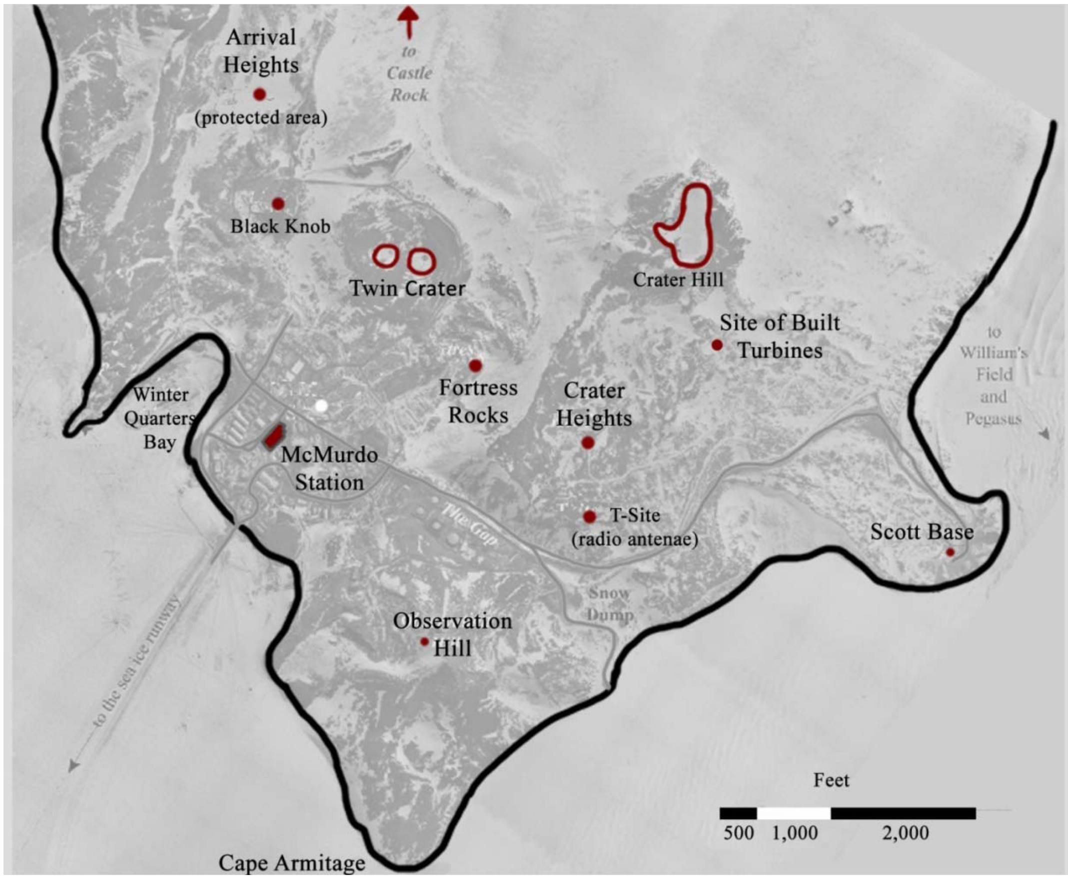


Figure 24: Map showing relevant political and geological features at the tip of the Hut Point Peninsula. Adapted from Klein, et al., 2008.

Figure 25: A McMurdo fuelie refills the fuel tank alongside one of the uppercase dorms. The type of truck is a "gasshopper." Photo by author, 2009.

Figure 26: Vehicles left idling in the area between the dorms and Building 155 during the lunch hour. Photo by author, 2010.

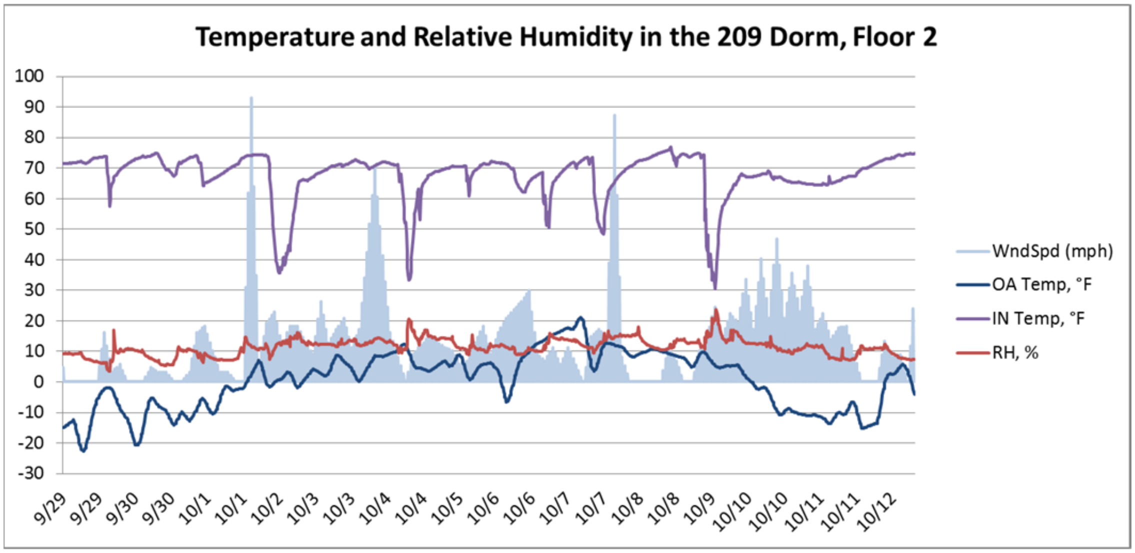


Figure 27: Temperature and relative humidity readings in a dorm room on the second floor of Building 209 (identical and adjacent to Building 209) over the same two weeks, overlaid with outside conditions. The downward spikes in interior temperature show moments when the room occupants opened a window as relief from a perceived too-hot indoor temperature (highest temperature is nearly 77°F).

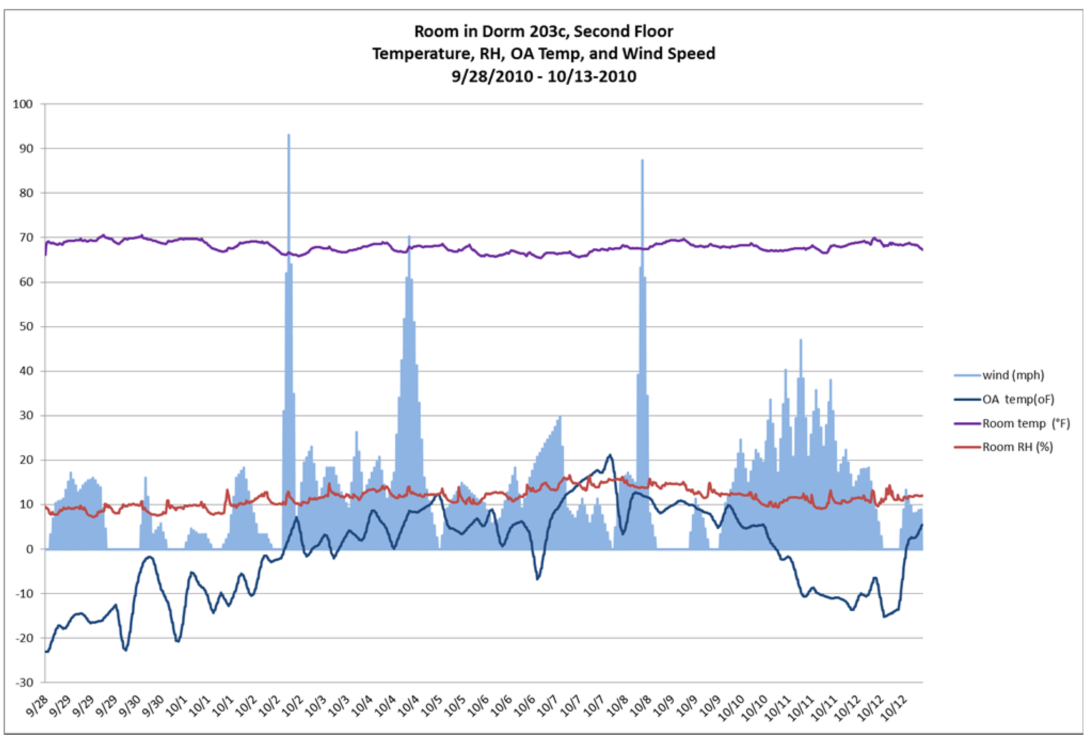


Figure 28: Temperature and relative humidity readings readings in a dorm room on the second floor of Building 203c, overlayed with outside conditions. The temperature remained fairly constant over two weeks (highest temperature is 71°F).

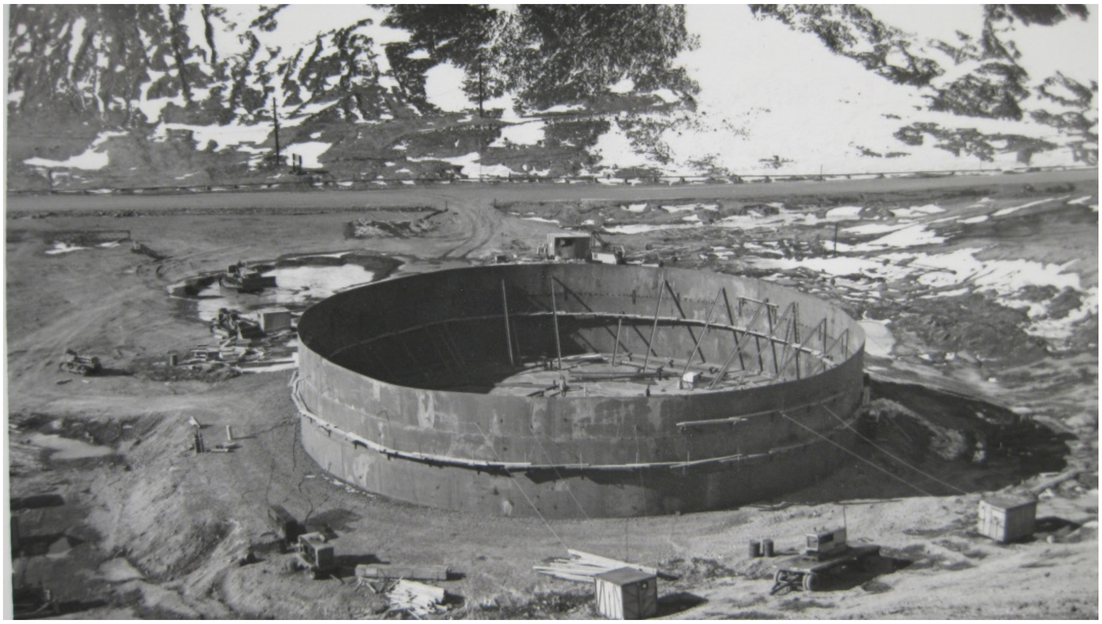


Figure 29: A view of the two million gallon tank under construction. Dec. 12, 1969. Courtesy U.S. National Archives Branch, College Park, MD.

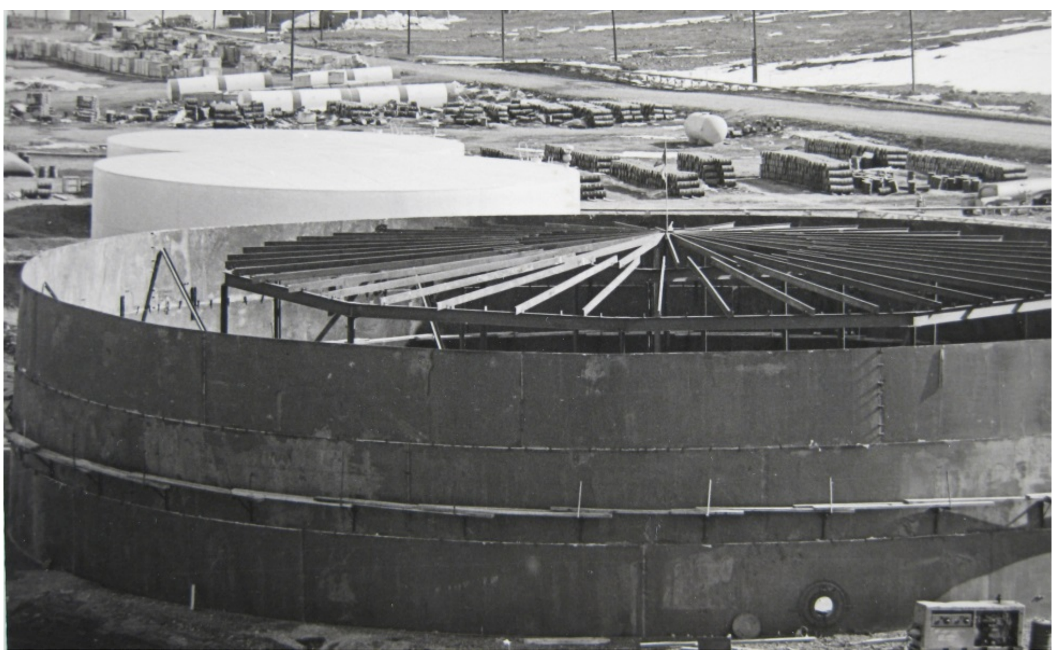


Figure 30: A second view of the two million gallon tank under construction by the Construction Battalion Unit 201 in the pass below Observation Hill at McMurdo Station. Courtesy U.S. National Archives Branch, College Park, MD.

Figure 32: Generators in their new housing facilities in McMurdo Station, 2009. Photo by author, 2009.

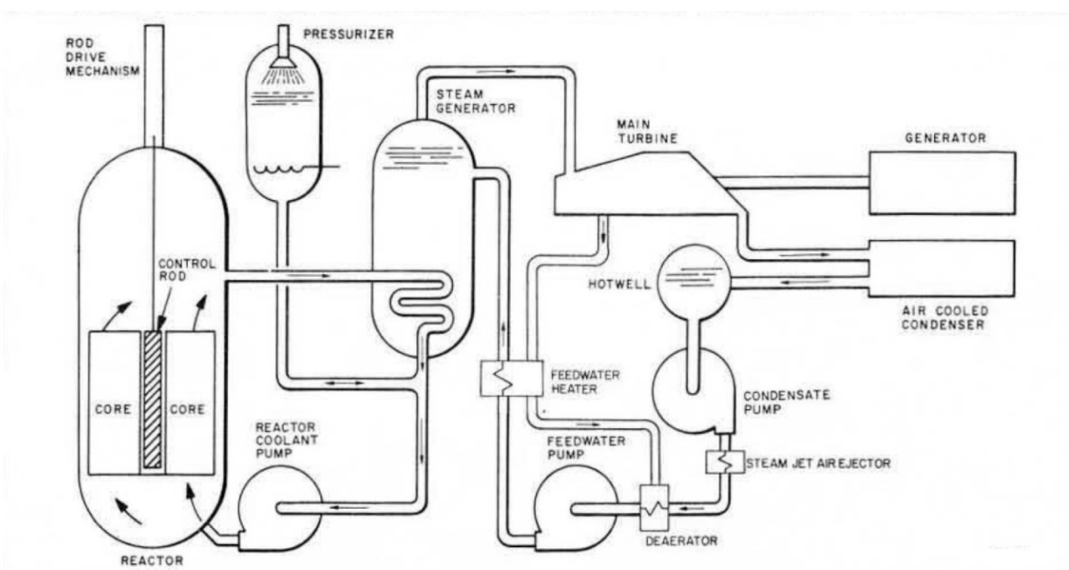


Figure 31: Diagram showing the three water loops which were a part of the nuclear power generator: water cooled the reactor (gaining heat) and then passed to the steam generator (loses heat) in a second loop. That steam powers a turbine, but also made low-pressure steam for the old water-distillation plant in the third loop. (USN, 1968, p. 37).

Figure 34: Scott Base turbines, 2014. Photo by R. Davis.

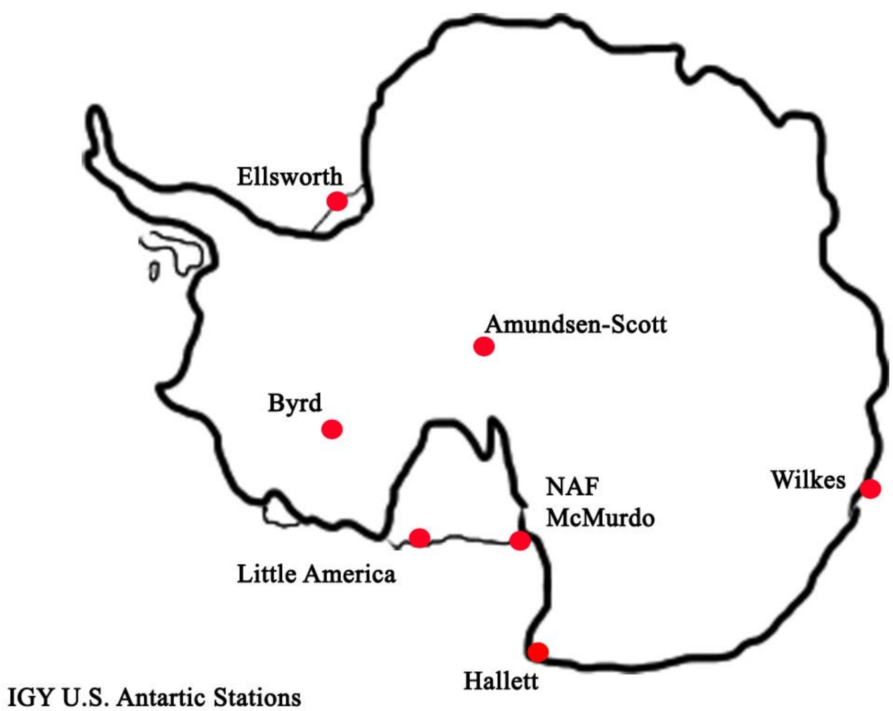


Figure 33: the original seven US stations during Operation Deep Freeze. NRC, 1957. Plate 1. Adapted.

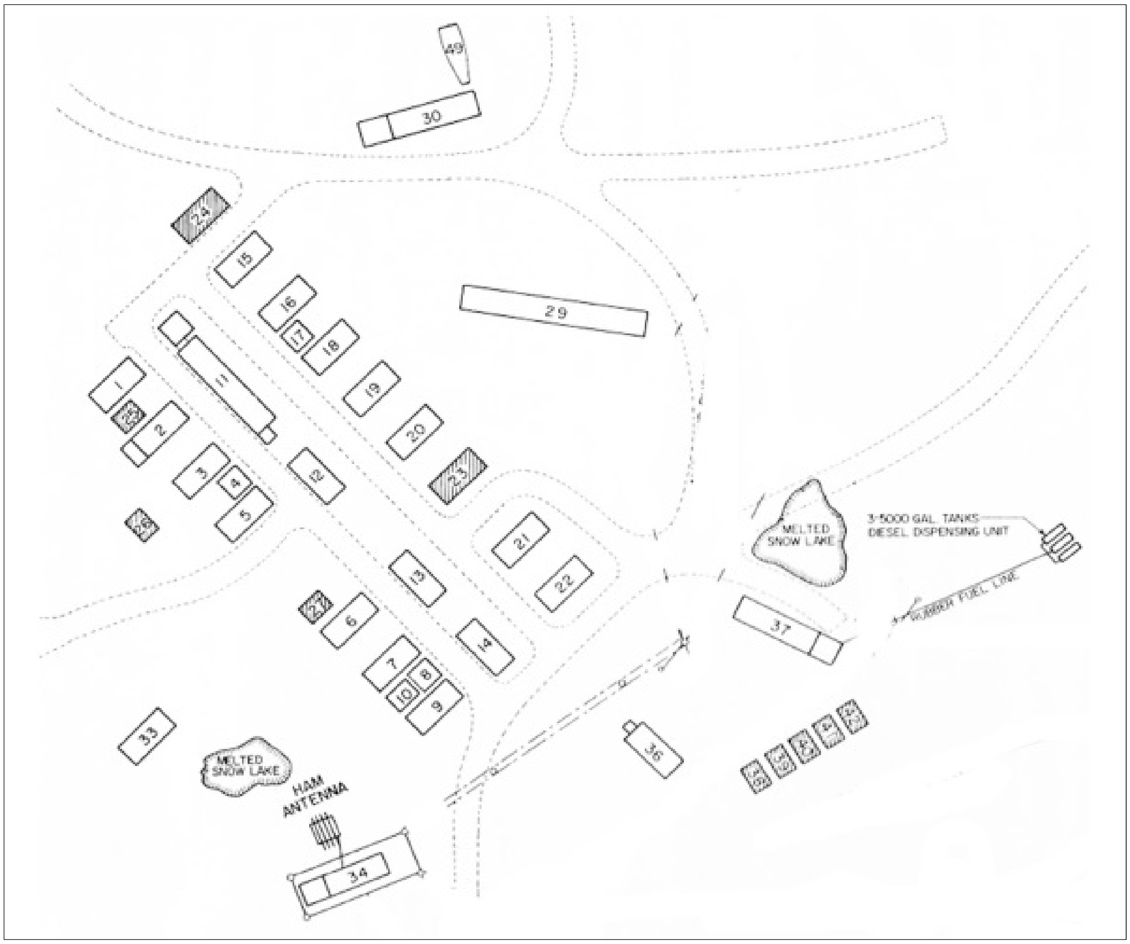


Figure 35: Layout of NAF McMurdo Sound. (NRC, 1957, Plate XI)

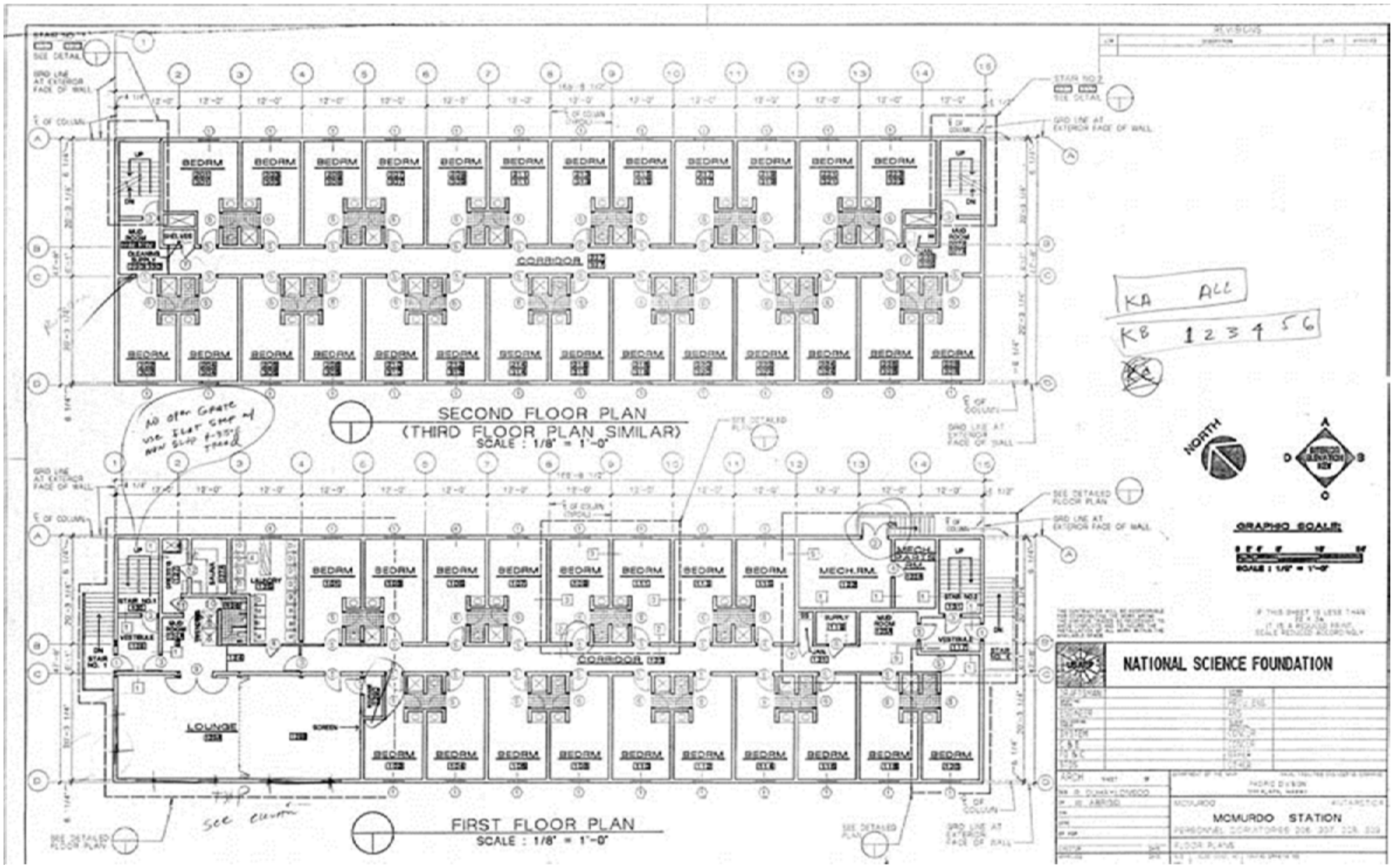


Figure 36: Floor plans for Buildings 206-209. Courtesy the U.S. National Archives, College Park,

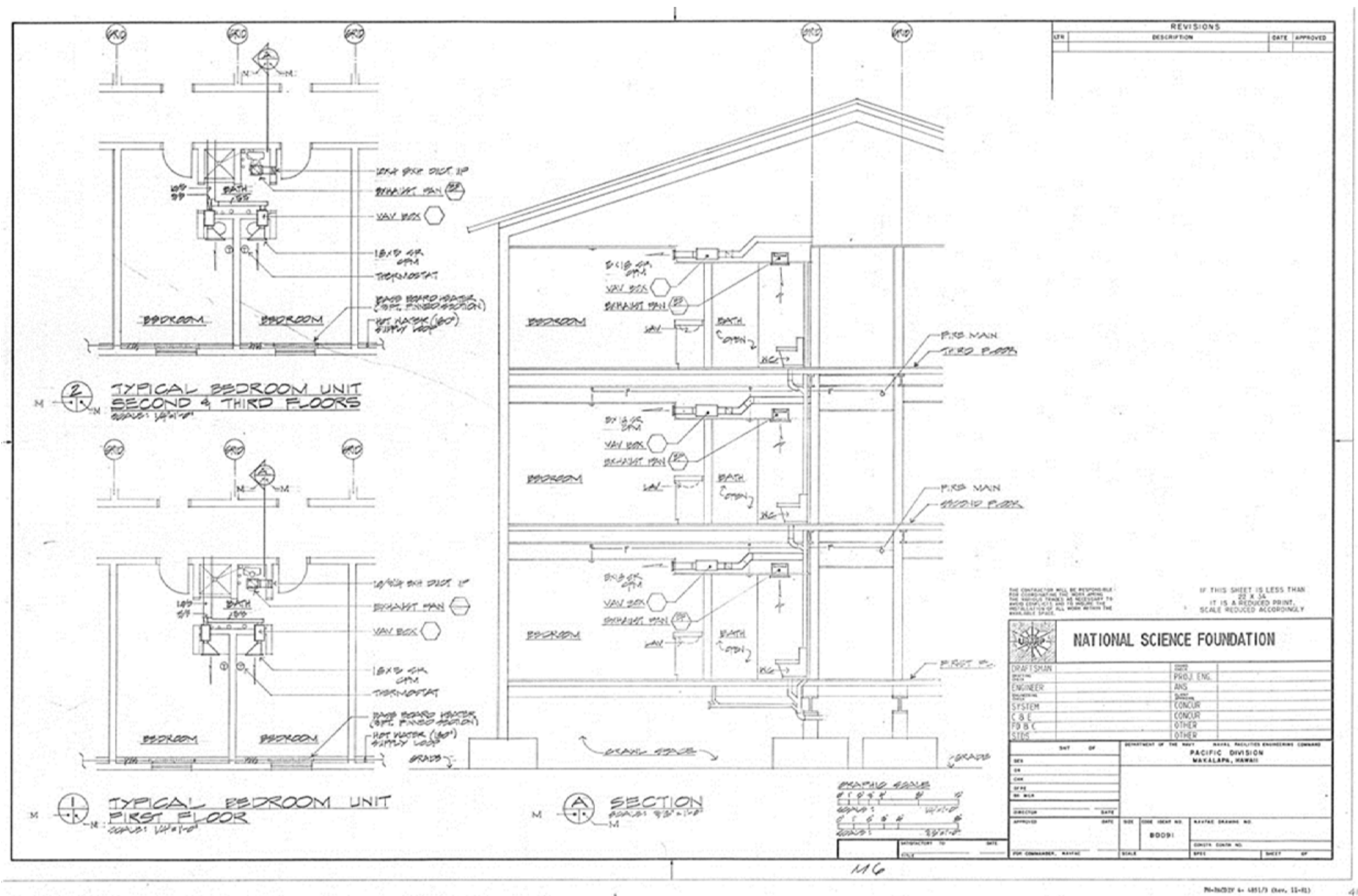


Figure 37: Building plans for Dorms 206-209 showing location of VAV boxes and exhaust fans in each room. Courtesy U.S. National Archives, College Park, MD.

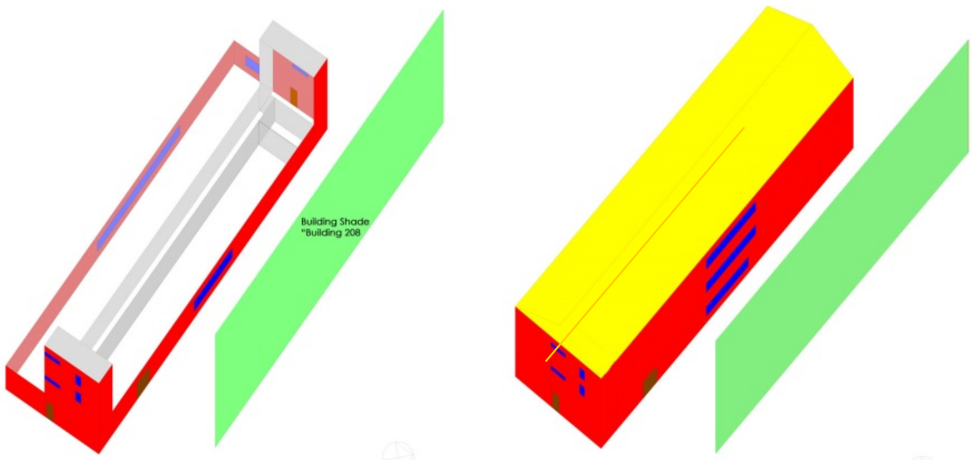


Figure 38: Building 209 as modeled in DOE-2.1E, visualized in Draw BDL. The left image shows the building with only the first floor and three story staircases. On the right shows the complete building.

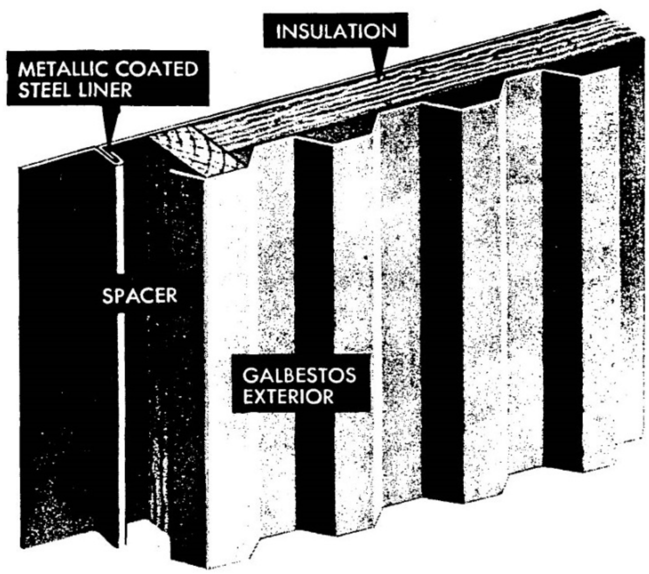


Figure 39: A section of a wall that the NCEL described as a "[t]ypical panel in permanent structures at McMurdo Station. Note the use of galbestos. (USN, p 36)

Figure 40: room in the new 203 dorm, c. 1980. Courtesy U.S. National Archives, College Park, MD.

Figure 41: A room in the 203 dorm, still vacant the end of the Winter season 2010. The last occupants used on of the large closets as a visual barrier. Photo by author, 2010.

Figure 42: Lounge in the newly built 203 series dorm, c. 1980. Photo courtesy U.S. National Archives, College Park, MD.

Figure 43: Lounge in the 203 series dorms. It is still mostly dark outside and quite cold, so the blue blinds are still attached to the window frames with Velcro. Photo by author, 2010.

Figure 44: McMurdo Coffee House/Wine Bar early in the season, when there are fewer people.

Figure 45: Coffee House interior during Winfly. Note the low ceiling, wood panel finish, and low wattage task lighting. There are also a few fake plants. Photo by author, 2009.

Figure 47: Dorm 203 with its low foundation (left) and a view of the underside of the building, showing its cladding, piping, and low clearance.

Figure 46: The wall and ground floor connection showing some ice problems.

APPENDIX S

APPENDIX FIGURES

Figure A- 1: Naval Air Facility and Observation Hill, McMurdo Sound, December 1956. Official U.S. Navy Photo. (NRC, 1957)

Figure A- 2: The original "Chapel of the Snows" at McMurdo Station, Antarctica, 1965. Quonset hut with vestibule entrance. Official U.S. Navy photograph, National Archives collection.

Figure A- 3: Two men stand on top of the Geodetic Satellite Tracking Building, McMurdo Station Antarctica, 1973. Courtesy U.S. National Archives, College Park, MD. Accessed March, 2012.

Figure A- 4: The McMurdo Station “Gerbil Gym,” a T-5 hut from. Photo by author, 2009.

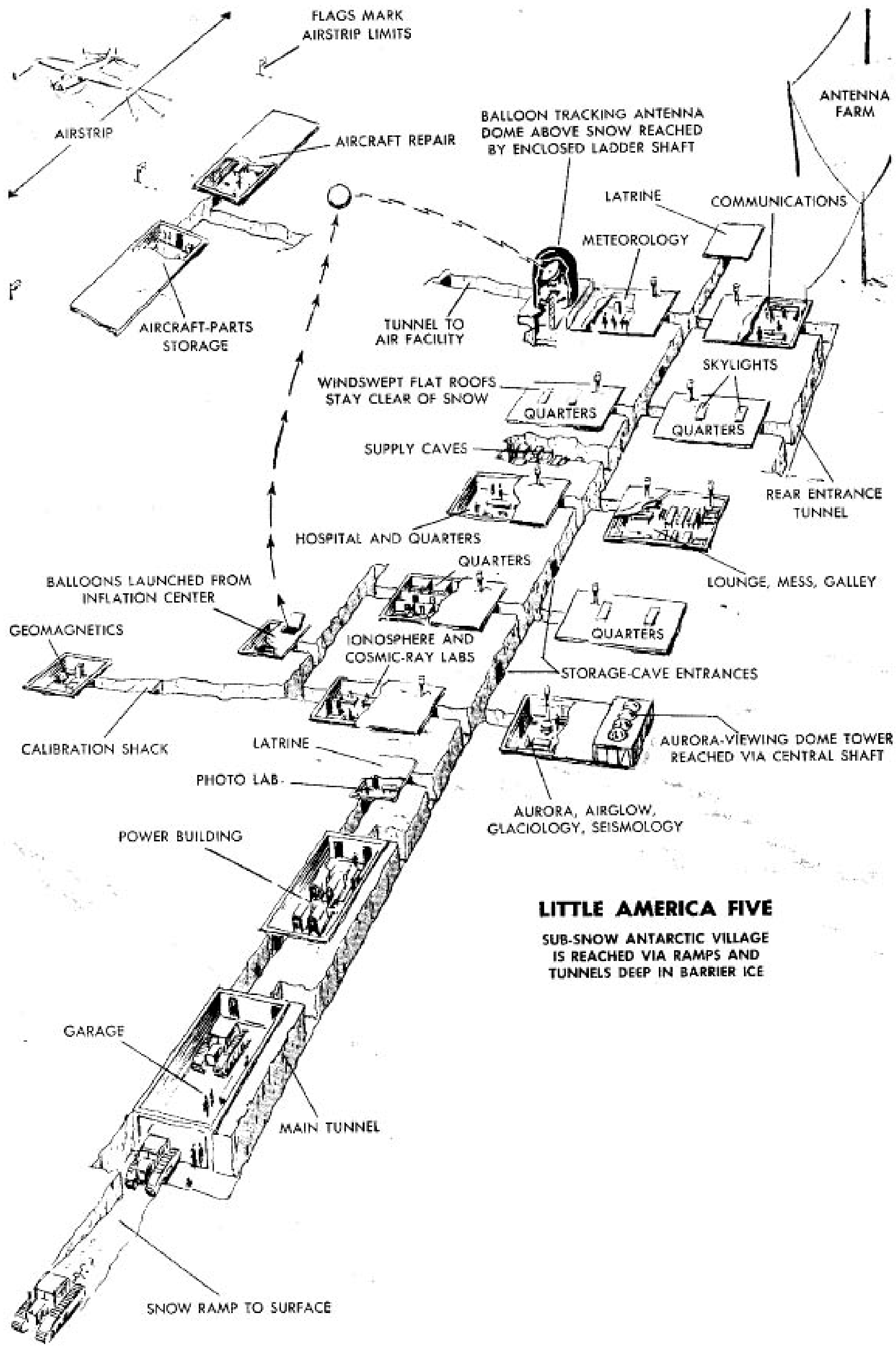


Figure A- 5: Little America V. Dempewolff, 1956, p. 90.

Figure A- 6: Little America Station, January, 1957. Official U.S. Navy Photo. NRC, 1957.

Figure A- 7: "Sky View McMurdo Sound Naval Air Facility." 1957.

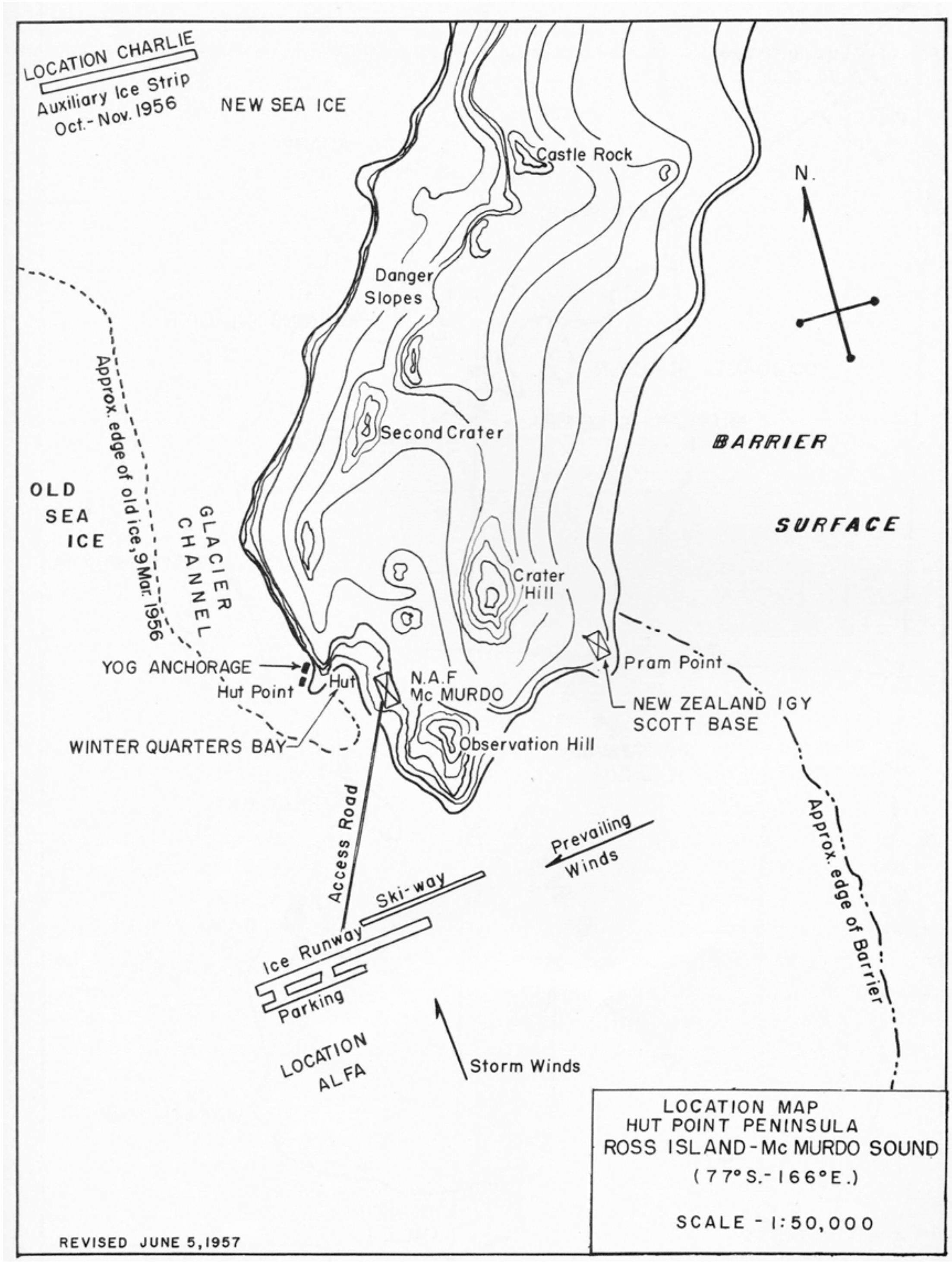


Figure A- 8: Tip of the Hut Point Peninsula, showing McMurdo, it’s airfields, and the noted storm and prevailing wind directions. NRC, 1957, Plate II.

Figure A- 10: Building 155 nearly completed in December 1967. USN, 1968, p. 36.

Figure A- 9: Building 155 completed. Photo from 1968. Naval Photographic Center. Washington, D.C. Subject: 53169 & 25030. Date: 11-9-68. Official Navy Photograph: K-62562. Photographer: PHCS H.T. Faulkner. Courtesy the U.S. National Archives Branch in College Park, MD.

Figure A- 11: Building 155 halfway built, c. 1967.   Pope, 1967, p. 139

Figure A- 12: Building 155, now painted blue, after a wind event, August 2010. East side with entrance (left) and south side (right). Photo by author, 2010.

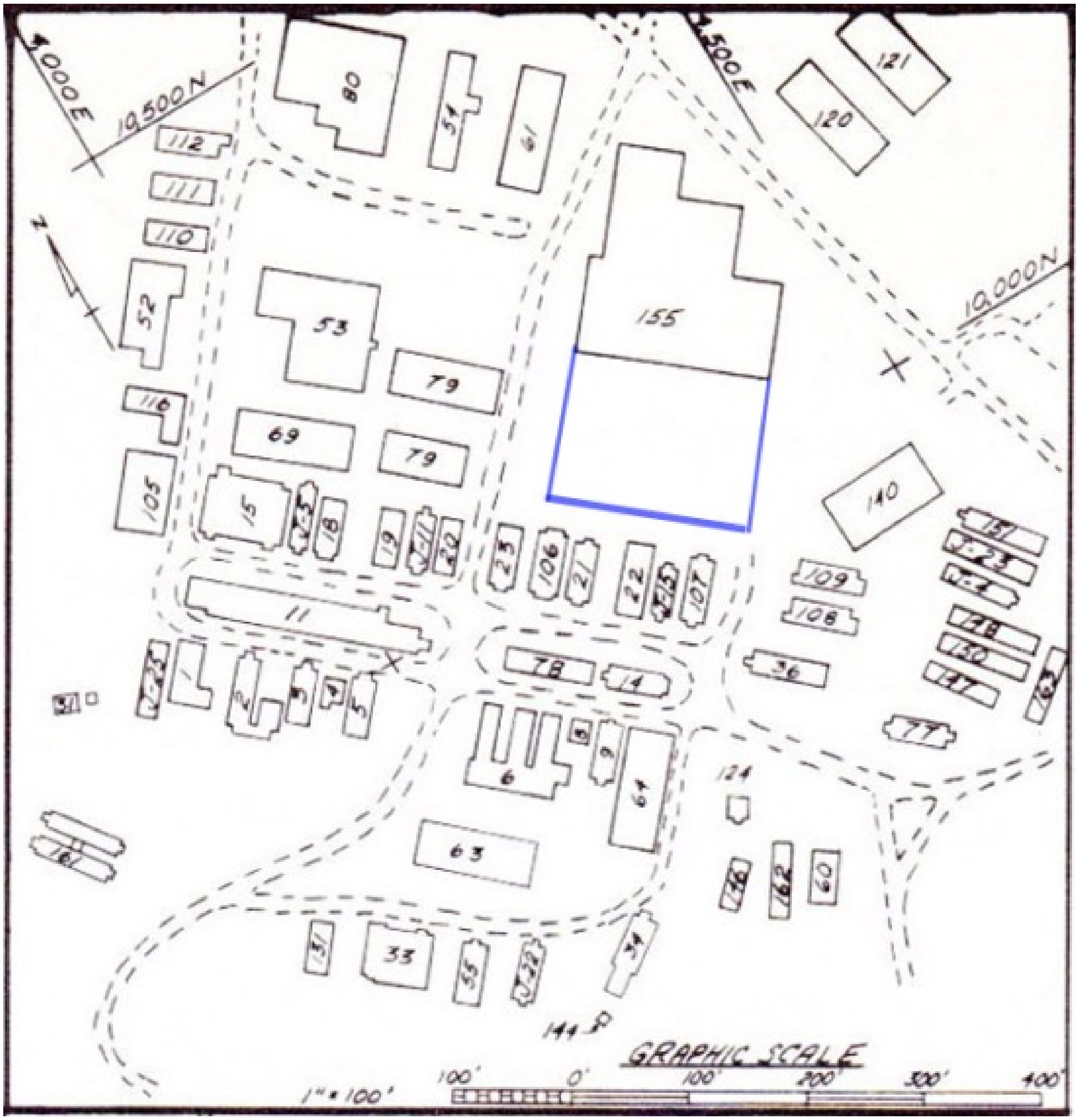


Figure A- 13: Layout of station c. 1968 showing a half-built 155 (blue lines, added by author, show final extent). USN, 1968, p. 24.

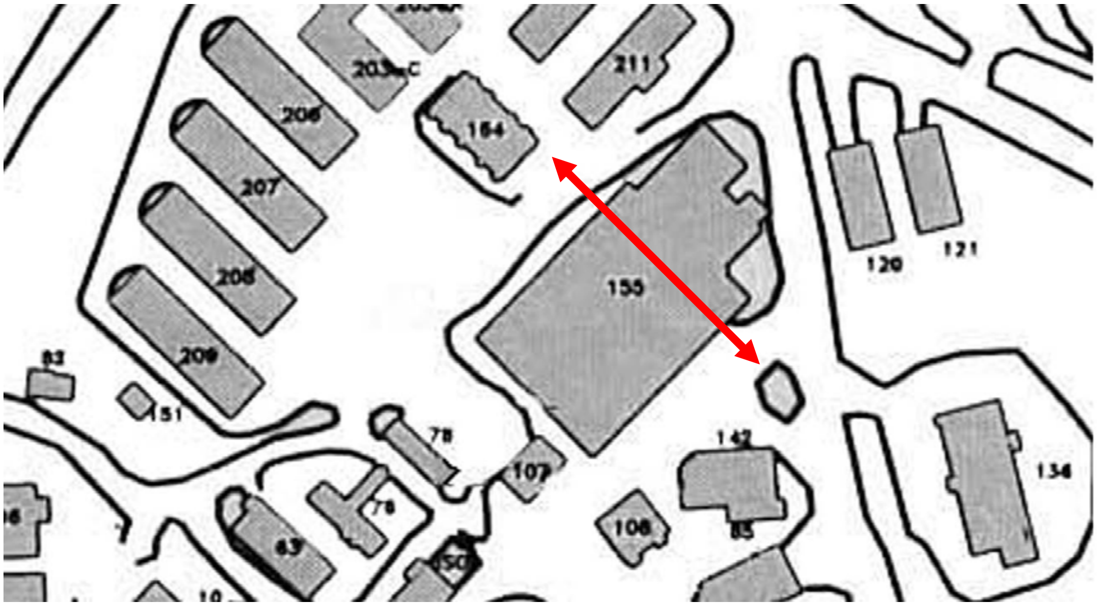


Figure A- 14: People sometimes take advantage of the shelter provided by Building 155 and pass through it to get to the other side of the station.


Figure A- 15: McMurdo Station, 1972, aerial view.

Figure A- 17: The Galley before Building 155 was in a T-5 hut. This photo, from February 1968, shows the enlisted messing facilities. U.S. Navy Photo K-44981. Courtesy U.S. National Archives, College Park, MD. Accessed March 2012.

Figure A- 16: A Lockheed LC-130 transports people and supplies to the sea ice runway in McMurdo Station, Mainbody 2001. Photo by R.W. Davis. Used with permission.

Figure A- 18: McMurdo Station changes 1960-1999. Aerial views from USGS.

Figure A- 19: Science Support Center. Photo by author, 2009.

Figure A- 20: A Quonset hut in McMurdo Station with a vestibule entrance addition. Photo by author, 2009.

Figure A- 21: Byrd Surface Camp, Antarctica. Jamesway tent under construction during the Deep Freeze 1980 season. (Note the flooring.) Photographer: Jeff Hilton. Date: Nov. 6, 1979. Naval Photographic Center, Naval District, Washington, D.C. Official U.S. Navy Photograph.

Figure A- 22: Cargo handler battalion One CHB-1 Barrack. Floor space is 16 ft. x 52 ft. with twenty bunks. McMurdo Station, Operation Deep Freeze '64. Photographer: PH2 D.C. Armstrong. Courtesy U.S. National Archives, College Park, MD. Accessed March, 2012.

Figure A- 23: Barrack J-24 Floor space 16 ft. x 28 ft. with 10 bunks in Barrack and 8 men Assigned. McMurdo Station, Antarctica. Deep Freeze '64. Photographer: PH2 D.C. Armstrong. Courtesy U.S. National Archives, College Park, MD. Accessed March, 2012.

Figure A- 24: A Jamesway still in use today (2009) in a field camp outside of McMurdo Station. Note the vestibule entrance. Photo by author, 2009.

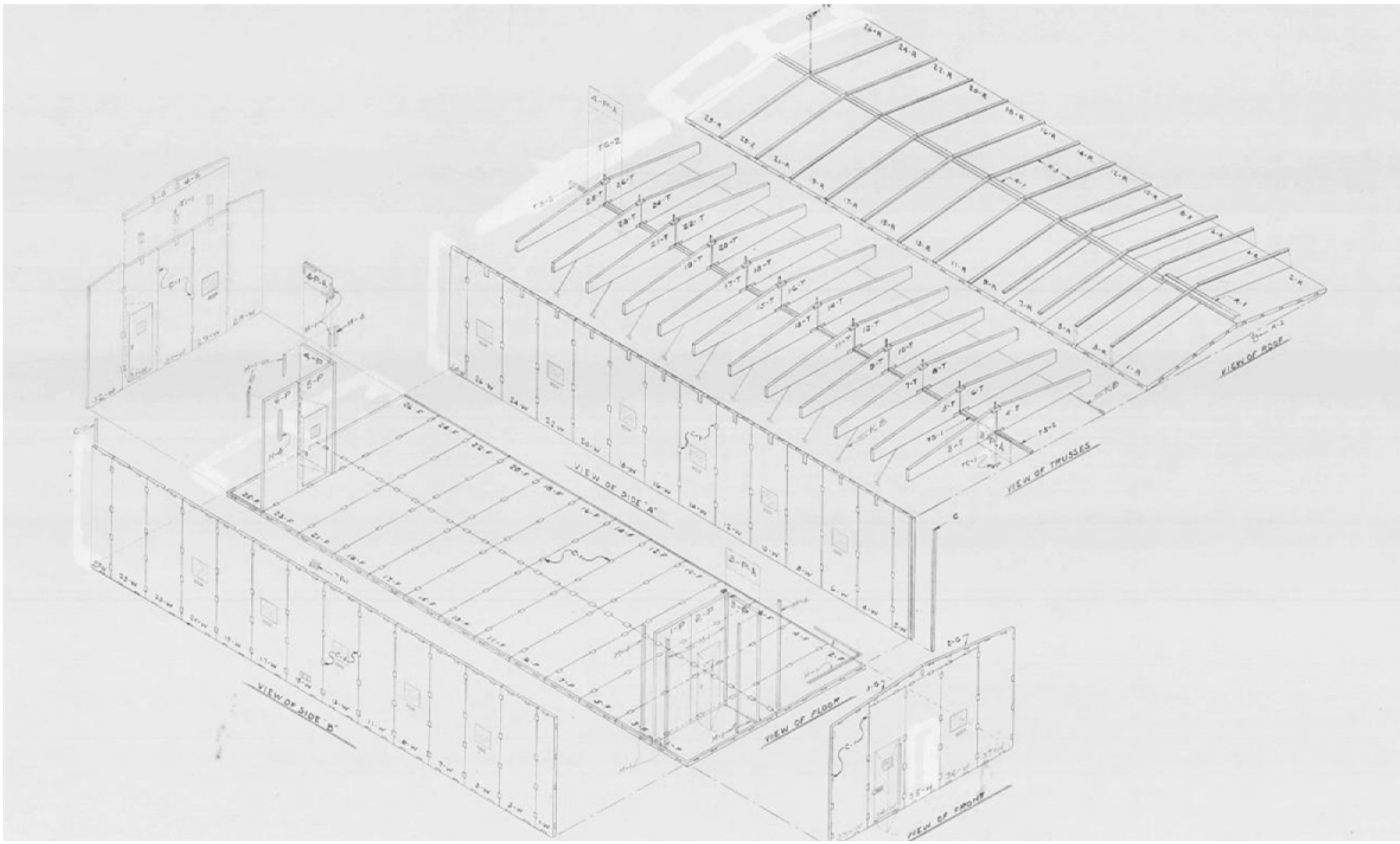


Figure A- 25: Building, Prefabricated, Panelized, Wood Arctic. McMurdo Sound Air Facilities. 20’x48’x12’ Assembly Diagram. From National Archives in College Park, MD.

Figure A- 26: The McMurdo Station "Gerbil Gym," a T-5 hut from 1960. Currently it is stocked with gym equipment and sometimes doubles as a band practice room. Photo by author, 2009.

Figure A- 27: Detail of the exterior wall of the "Gerbil Gym" showing four clip fasteners and a window. Photo by author, 2009.

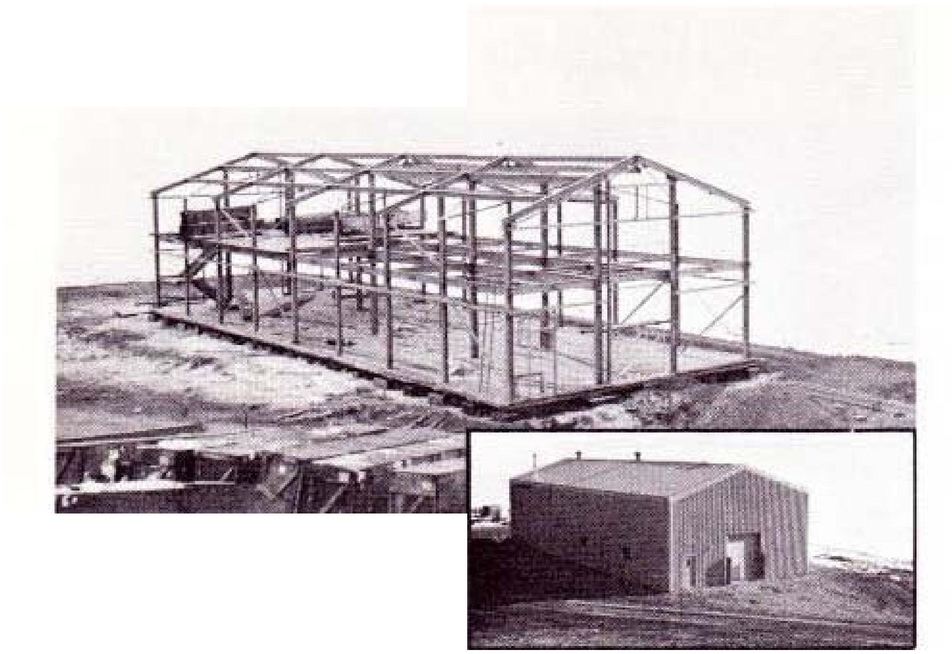


Figure A- 28: The frame of a Robertson building around 1968. Like the T-5 before it, these were easy to transport and build, but offered greater flexibility in the interior design. USN, 1968, p. 36.

Figure A- 29: The Medical dispensary around 1968. This is one example of a Robsertson building. The front door has changed some, but this building has stood since 1961. USN, 1968, p. 36.

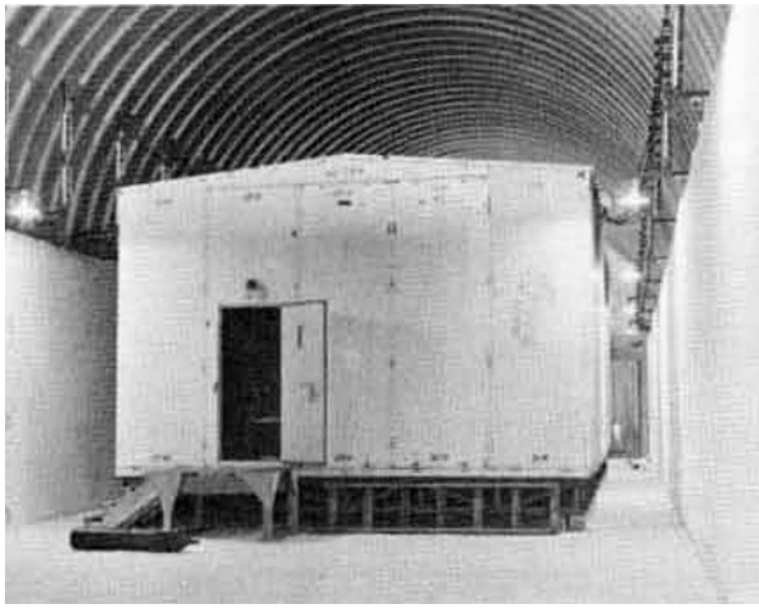


Figure A- 31: A T-5 building within the protection of a snow trench beneath a large "Wonder Arch." USN, 1968.

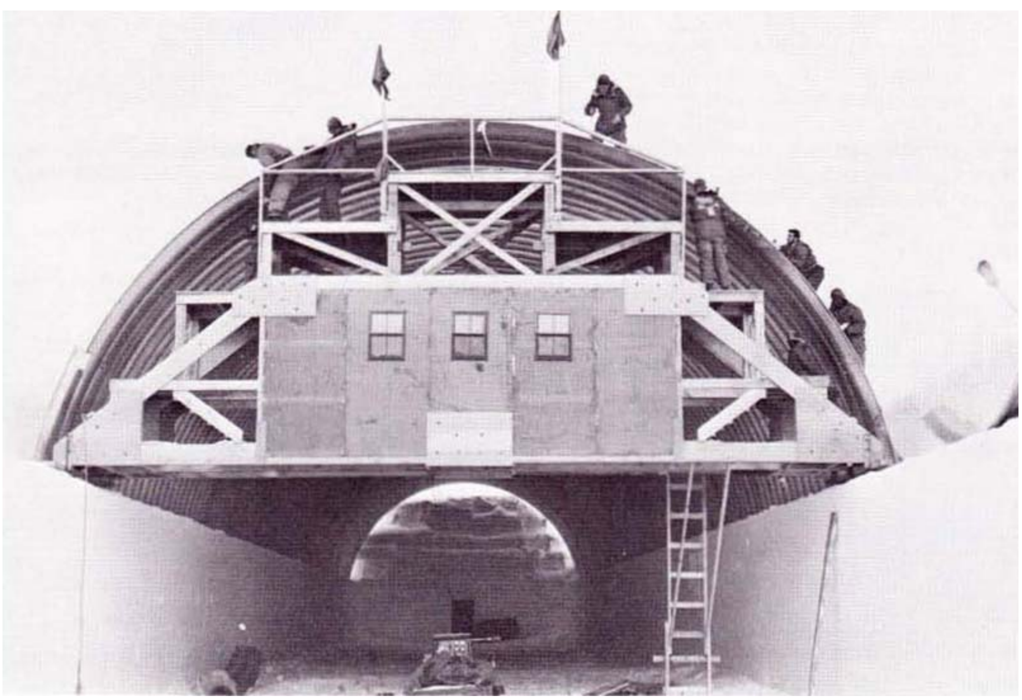


Figure A- 30: Men installing Wonder-arches at South Pole Station use a movable scaffold above a plowed trench. USN, 1968 (34).

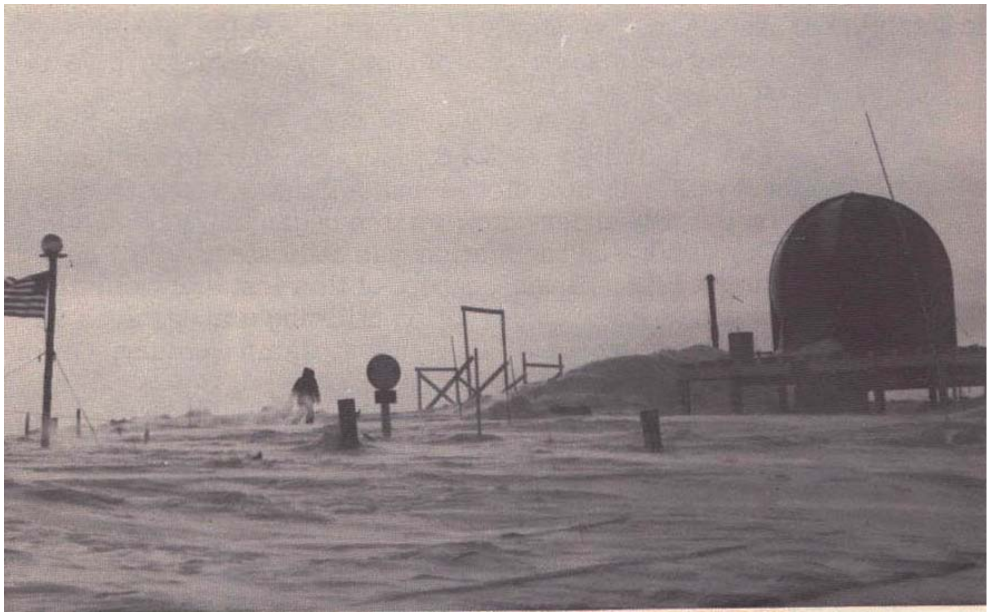


Figure A- 32: South Pole Station, 1964. USN, 1964, p. 3.

Figure A- 33: Men removing snow from the entrance to South Pole Station, Antarctica, to ease the strain on the supporting timbers to that they may be rebuilt. Operation Deep Freeze ’65. Photo by PH3 Jerry W. Lakso. Courtesy U.S. National Archives, College Park, MD.

Figure A- 34: The NSF Chalet. 11-16-1072. Photographed by PH2 David M Dyer.
Courtesy U.S. National Archives, College Park, MD.

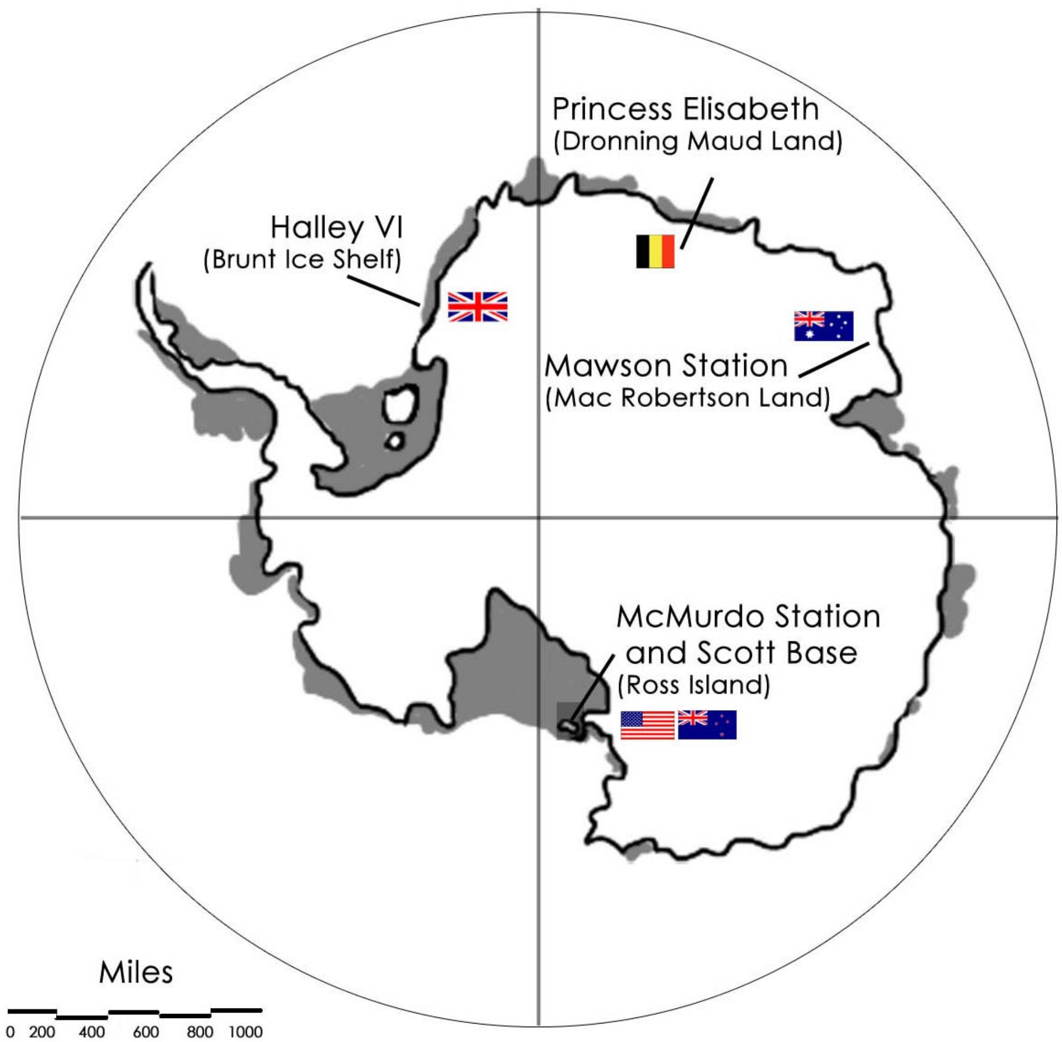


Figure A- 35: Map showing different international research stations

Figure A- 37: Halley VI, designed by Hough Broughton Architects. Antony Dubber, British Antarctic Survey.

Figure A- 36: Module A being towed to Halley VI site. Karl Tuplin, British Antarctic Survey.

Figure A- 38: A typical bunk/bed room used by two people during the summer and by one person during the long winter at the Halley VI Research Station on the Brunt Ice Shelf Antarctica. Antony Dubber, British Antarctic Survey.

Figure A- 39: Module C connected to Module E1. Halley VI site. Karl Tuplin, British Antarctic Survey.

Figure A- 40: Casey Station, Antarctica. A view of the tubular shield and buildings on silts, which protect the buildings from an accumulation of snow on the Australian base. 2-27-74. Photo by PH2 Michael C. Wright, Official U.S. Navy Photograph. Courtesy U.S. national Archives, College Park, MD.

Figure A- 41: Princess Elisabeth Station. Project © International Polar Foundation. Engineering and Technical Design for the Structure and the Shell © Philippe SAMYN and PARTNERS.

Figure A- 42: View of Princess Elisabeth station. Project © International Polar Foundation. Engineering and Technical Design for the Structure and the Shell © Philippe SAMYN and PARTNERS.

Figure A- 43: a bunk room in the Princess Elisabeth station. ©International Polar Foundation / René Robert. Used with permission.

Figure A- 44: Common area at Princess Elisabeth station. ©International Polar Foundation / René Robert. Used with permission.

Figure A- 45: Office area at Princess Elisabeth station. ©International Polar Foundation / René Robert. Used with permission.

Figure A- 46: The thick layers in the walls reportedly allow the station to be completely passively heated Project © International Polar Foundation. Engineering and Technical Design for the Structure and the Shell © Philippe SAMYN and PARTNERS.

Figure A- 47: Aerial photo of Mawson station (Photo by D. McVeigh). Australian Antarctic Division.

Figure A- 48: A view of Scott Base from one of its buildings. Photo by author, 2009.

Figure A- 49: Scott Base building foundation. Photo by author, 2009.

Figure A- 51: Scott Base lounge (large windows look out into the darkness of a September night). Photo by author, 2009.

Figure A- 50: A hallway connection between two buildings at Scott Base. Photo by author, 2009.

Figure A- 52: Photographer's mate First Class Robert L. Zeisler, left background, and Photographer's mate Third Class Alan T. Brown, right, film activity as a lineman repairs a utility pole. Naval Photographic Center, Naval District, Washington, D.C. Official Nvy photograph. November 13, 1987. Photographer: Charles J. Williamson. Courtesy U.S. National Archives, College Park, MD.

Figure A- 53: Pipes and a pedestrian bridge in front of Building 165, Mac Ops (Communications Building). Photo by author, September, 2009.

Figure A- 54: Observation Hill, on the southwest side of the station. Photo by author, 2010.

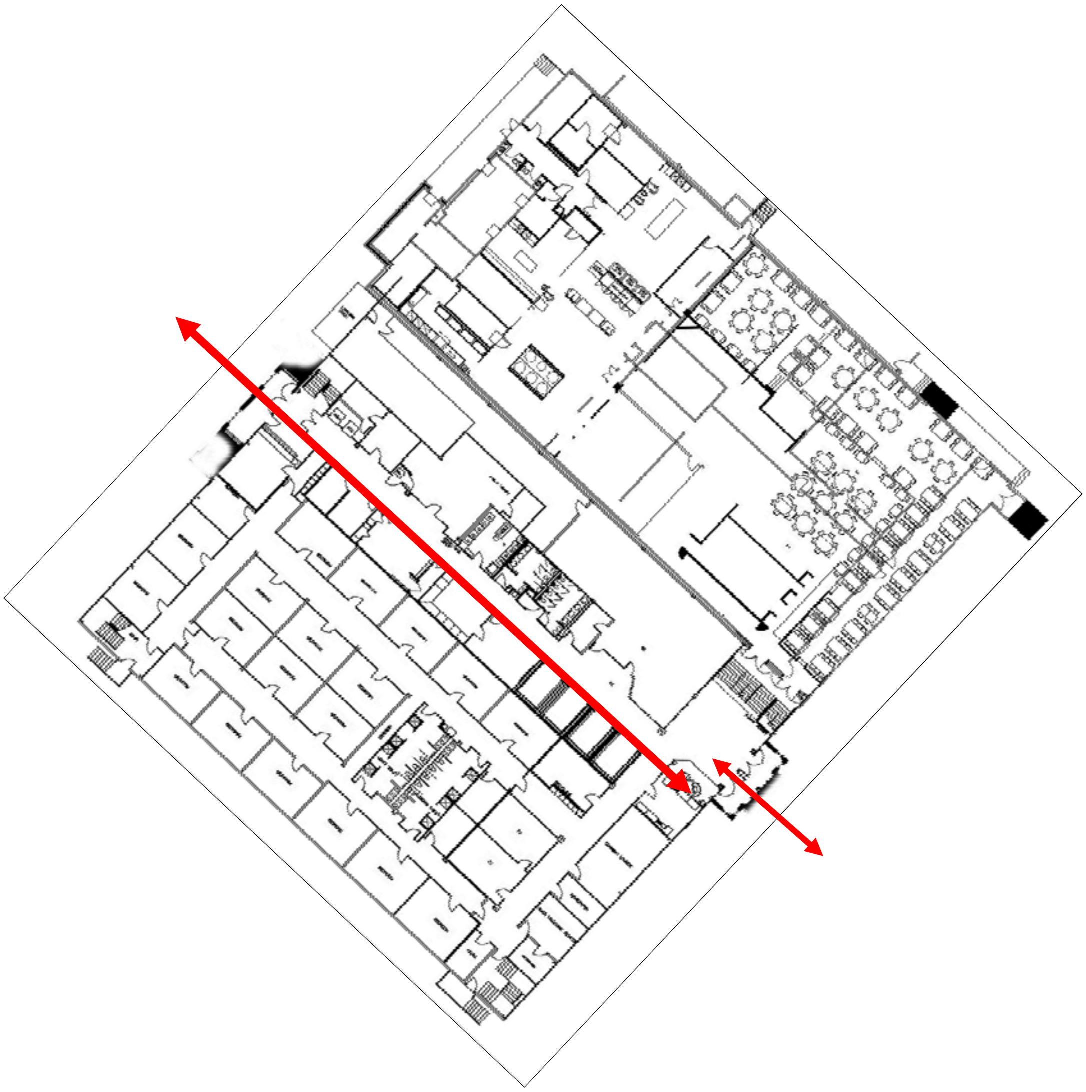
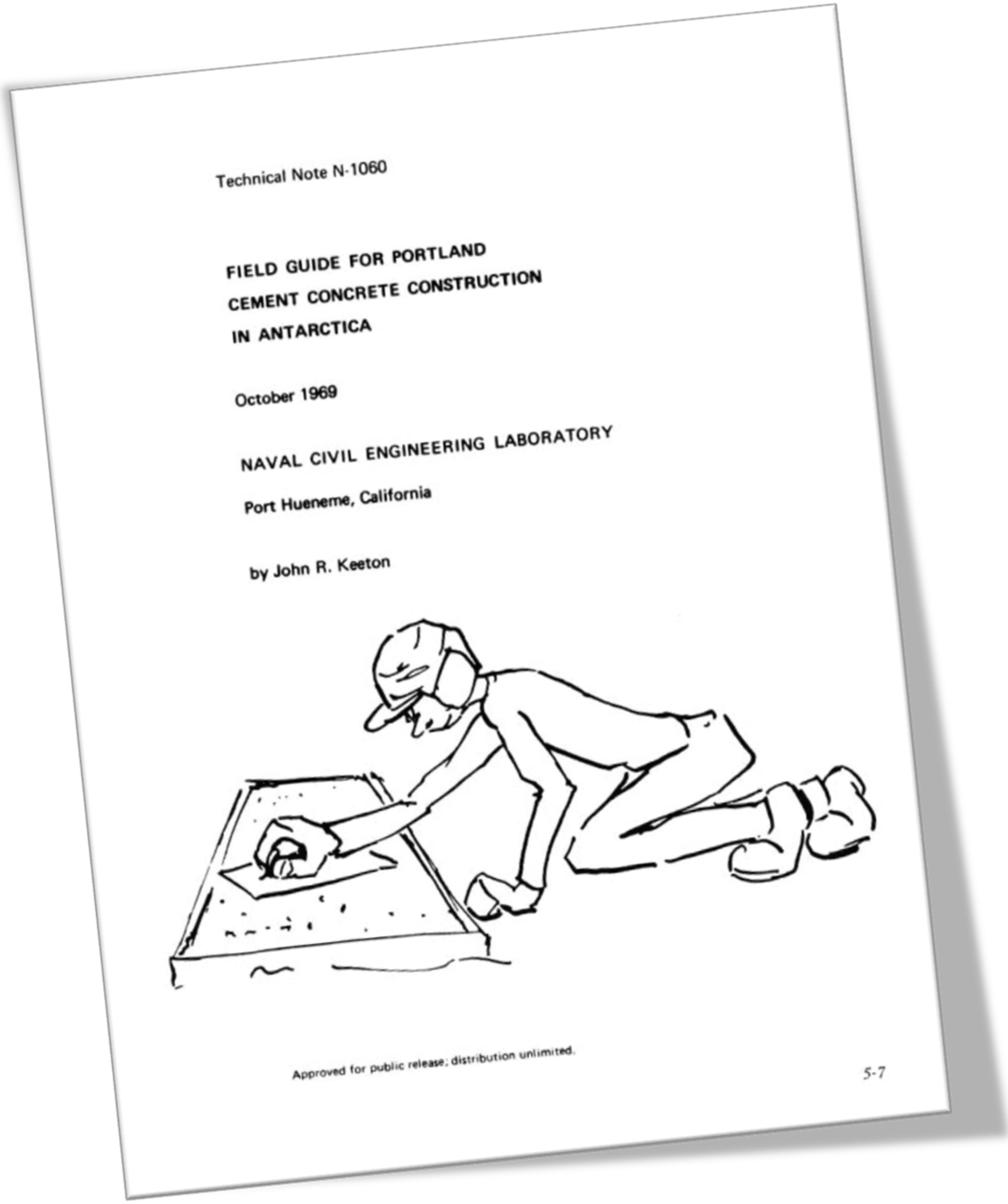


Figure A- 55: Floor plan of the ground floor of Building 155, showing the nearly straight-light corridor ("Highway 1") that connects one side of the building to the other

Figure A- 56: A long hallway with juxtaposed stairs and a ramp connects all three phases of the Crary lab as they descend the terrain of the coastline. Photo by author, 2010.


Technical Note N-1060

FIELD GUIDE FOR PORTLAND
CEMENT CONCRETE CONSTRUCTION
IN ANTARCTICA

October 1969

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

by John R. Keeton

Approved for public release; distribution unlimited.

5-7

Figure A- 57: Cover of section regarding cement concrete in the NCEL 1974 report. (Hoffman,1974, p. 5-7)

Figure A- 58: Example of a concrete footing in McMurdo Station. Photo by author, 2009.

Figure A- 59: Example of a concrete footing in McMurdo Station. Photo by author, 2009.

Figure A- 60: Example of a concrete footing in McMurdo Station. Photo by author, 2009

Figure A- 61: Window with curtain, showing moisture, spindrift, and icing problems. Photo by author, 2010.

Figure A- 62: McMurdo Station, Antarctica. Coast Guard and civilian inhabitants of Hut 9 assist the firemen in fighting a fire in their hut. February, 1979. Photographer PH3 Howard M. Weigner. Photo courtesy of the U.S. National Archives, College Park, MD.

Figure A- 63: McMurdo Station, Antarctica: Chief Aviation Boatswain's mate James Sizemore examines the fire in the United States Antarctic Research Program Camping Issue Building. December 15, 1976. Photo Courtesy the U.S. National Archives, College Park, MD.

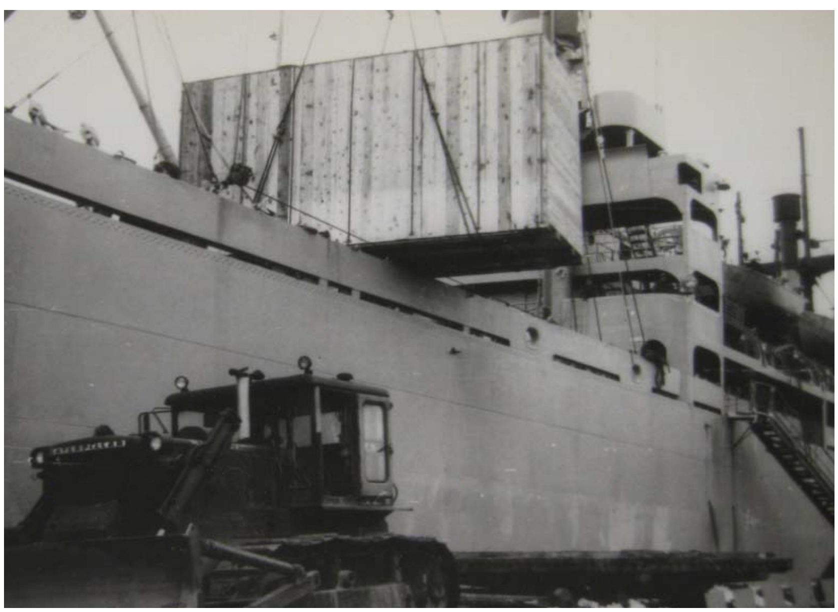


Figure A- 64: A 25 ton diesel generator to be installed in the diesel power plant being off loaded from the USNS PVT. J.R. Towle (T-AK-240) at McMurdo Station, Antarctica. December 20, 1964. Deep Freeze '65.

Figure A- 65: Rear Admiral Wright shakes the hand of Specialist David Gough of the U.S. Army … in front of the Nuclear Power Plant. December 5.

Figure A- 66: Power Plant—Nuclear PM-3A. McMurdo Station, Antarctica. Operation Deep Freeze ‘65.

Figure A- 68: Equipment operator First Class Lester Strawbridge, left, and Senior Chief Construction Electrician Bill Asher work in the control room of the PM-3A nuclear power plant. McMurdo Station, Antarctica, January 4, 1973.

Figure A- 67: A view of a shield replacement at the nuclear power plant. McMurdo Station, Antarctica. November 19, 1974.

Figure A- 69: Wind batters a Jamesway structure in a field camp outside McMurdo Station (Mt Erebus in the background) in 2001.

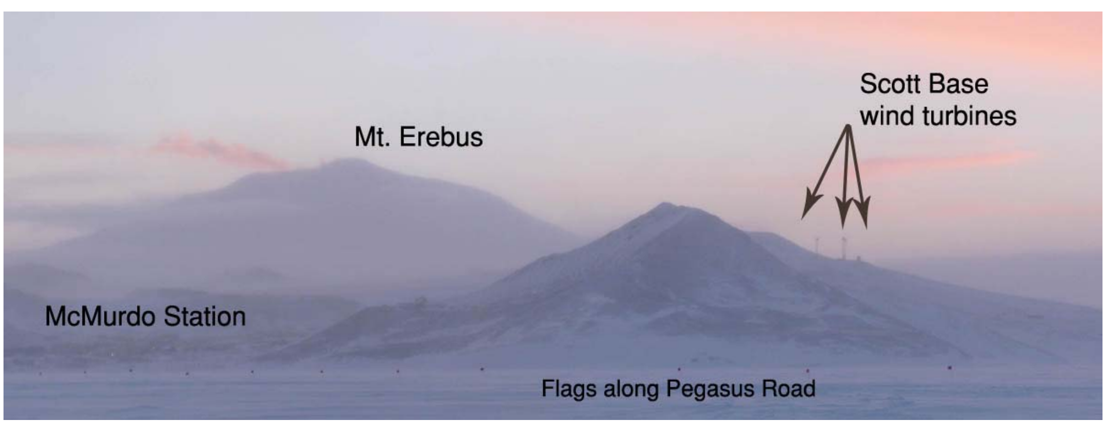


Figure A- 70: View from the ice looking towards the station (left), Mt. Erebus, Observation Hill, and the Scott Base wind turbines. August 2010.

Figure A- 72: Just some of the equipment used in the RO process in McMurdo's water treatment facility.

Figure A- 71: Section cut-out of an RO filter showing its many layers.

Figure A- 74: McMurdo Waste Water Treatment Facility, which sits at the edge of the coastline.

Figure A- 73: Inside McMurdo's wastewater treatment facility

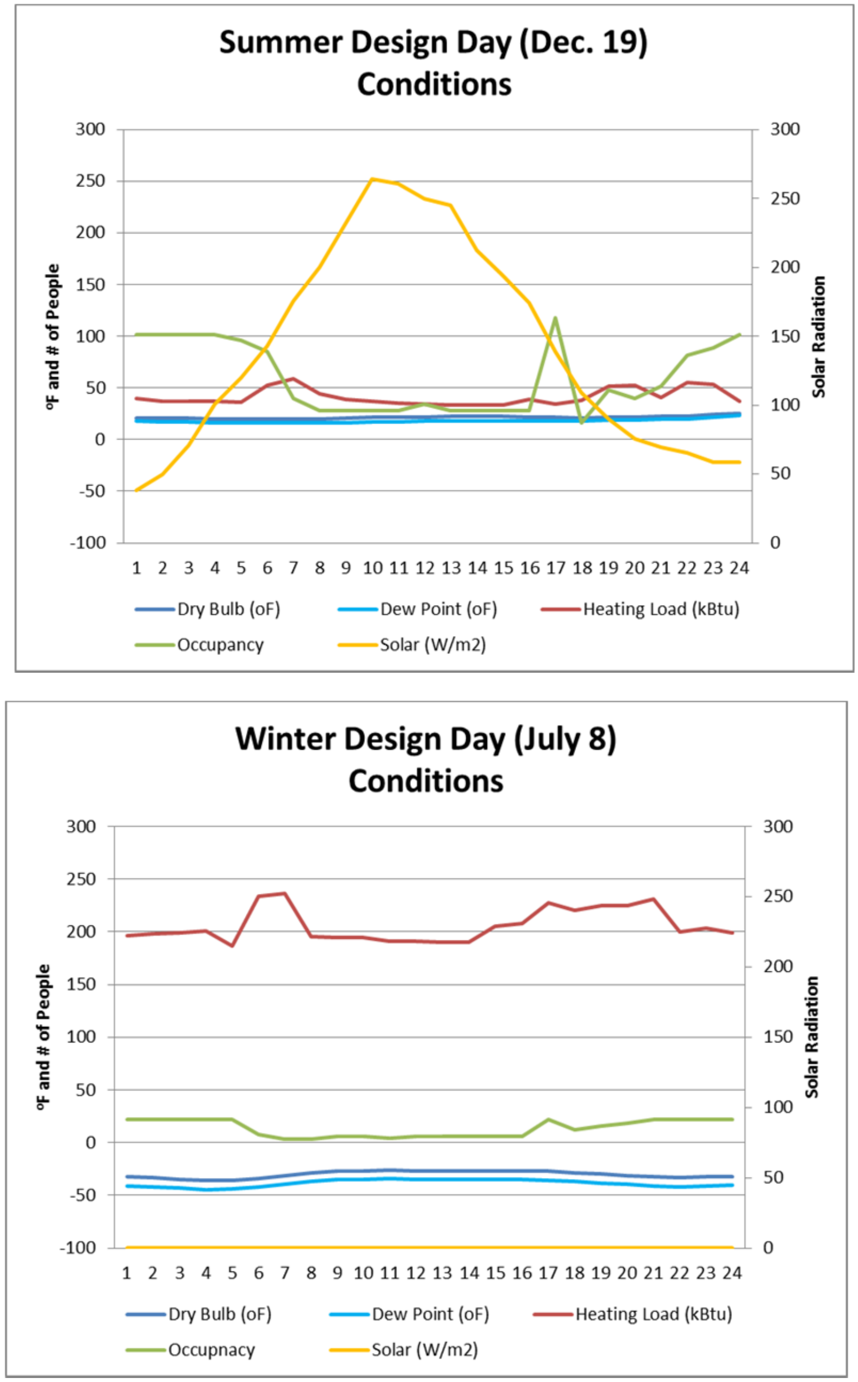


Figure A- 75: Weather conditions for the two design days, along with the base case heating load.

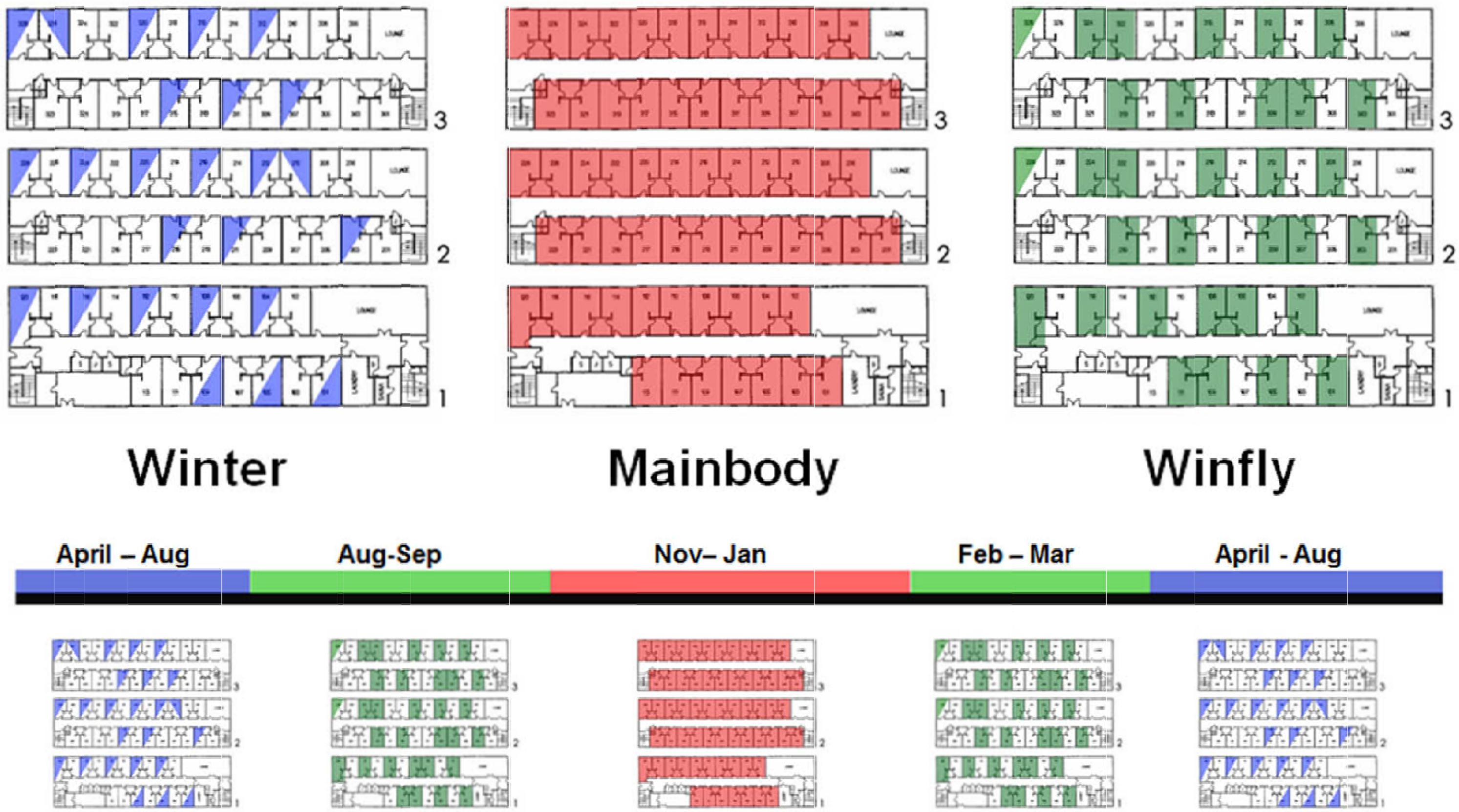


Figure A- 76: Graphic representation of population changes across three seasons and on the three floors of the dormitories. Fully colored rooms indicate double occupancy, while half-shaded rooms indicate single occupancy.

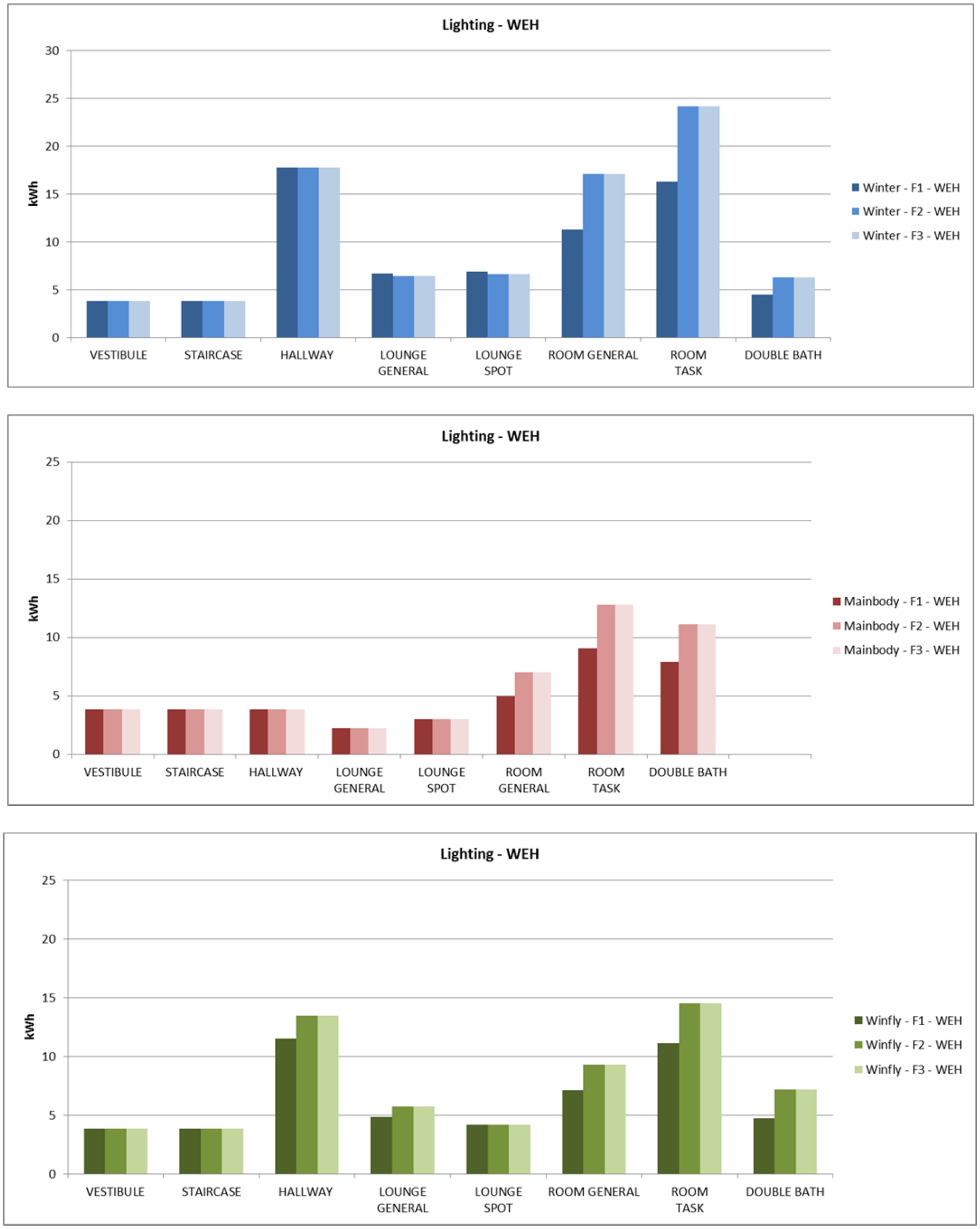


Figure A- 77: Base case weekend lighting loads for Winter, Mainbody, and Winfly seasons.

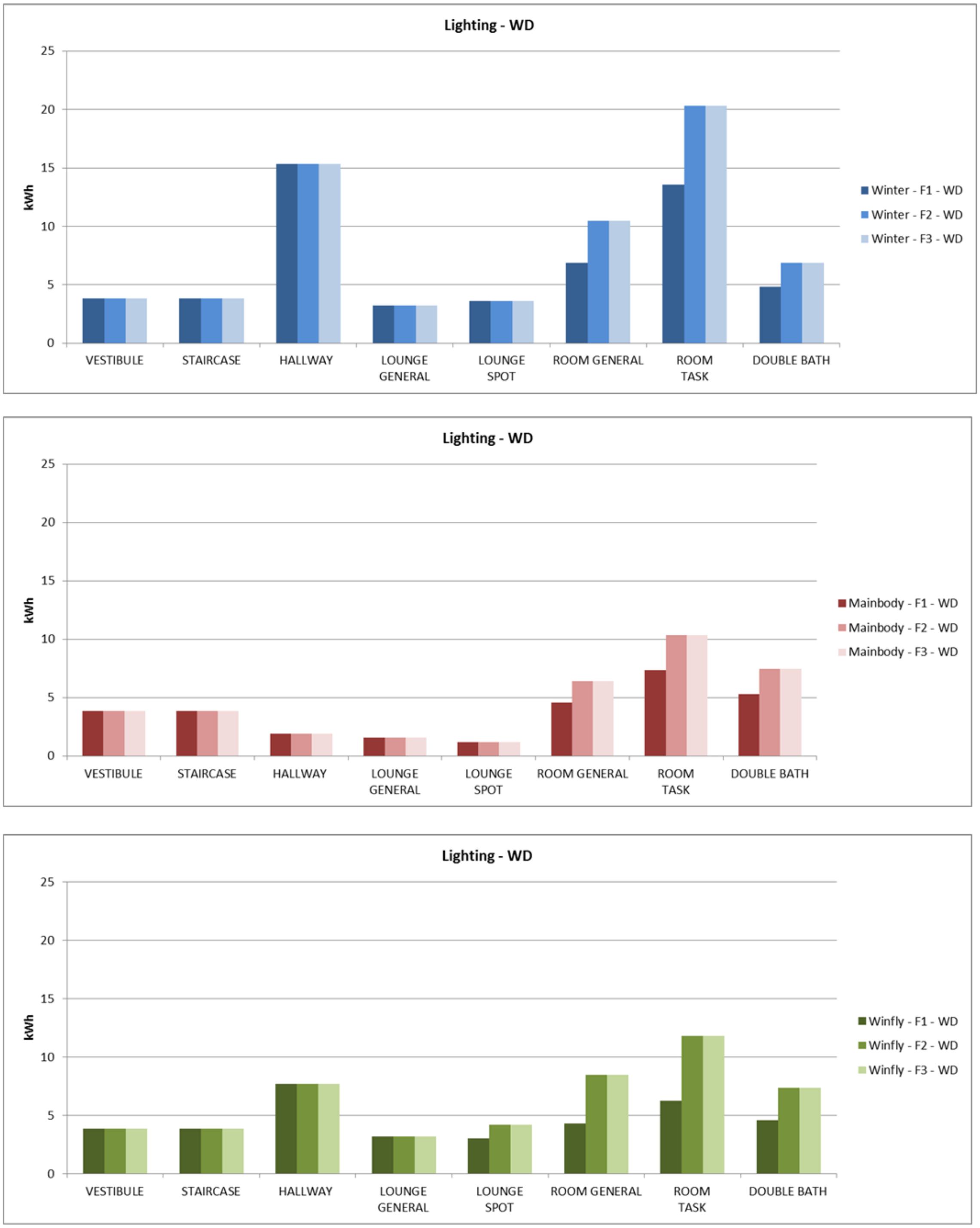


Figure A- 78: Base case weekday lighting load for Winter, Mainbody, and Winfly seasons.

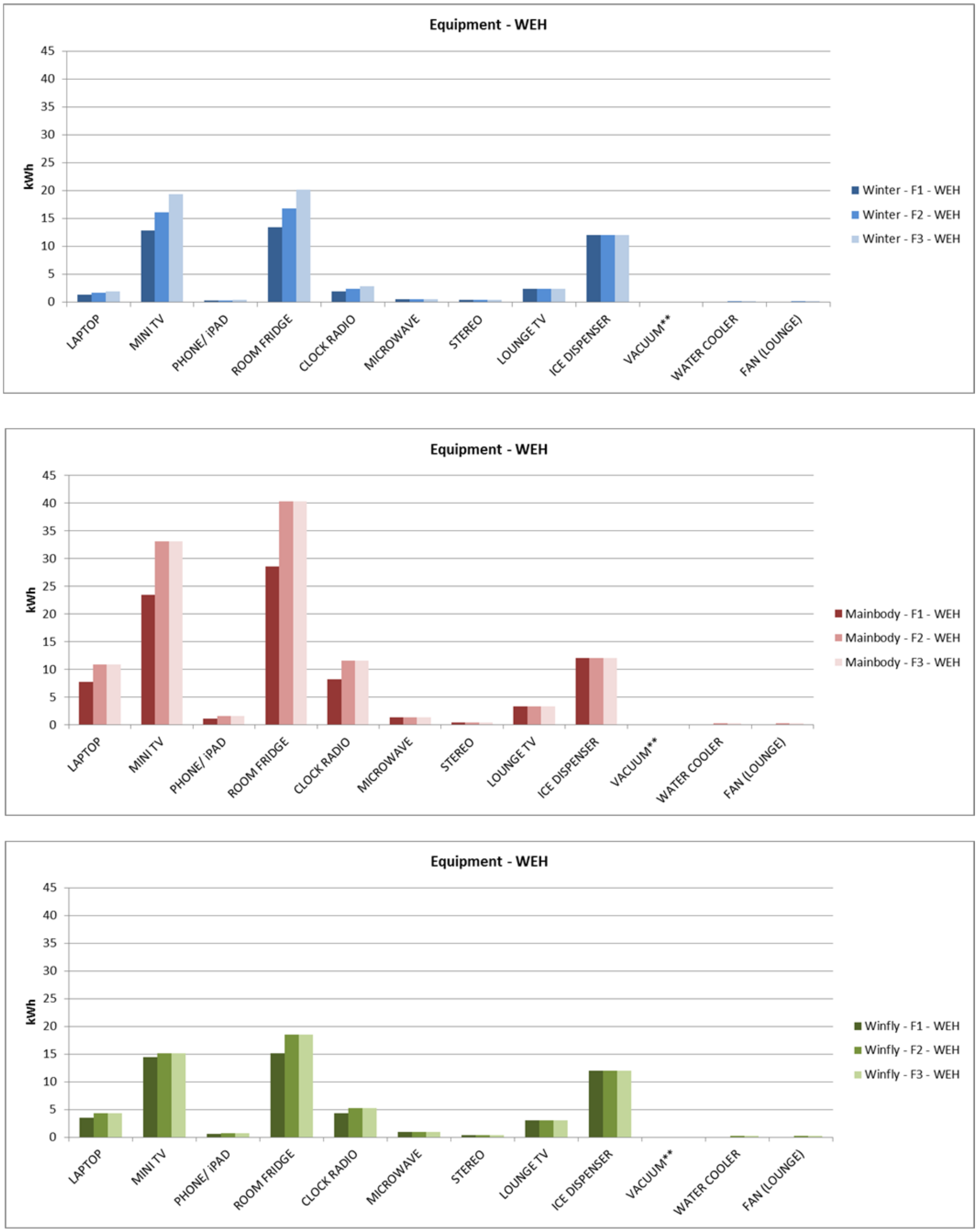


Figure A- 79: Base case weekend equipment loads for Winter, Mainbody, and Winfly seasons.

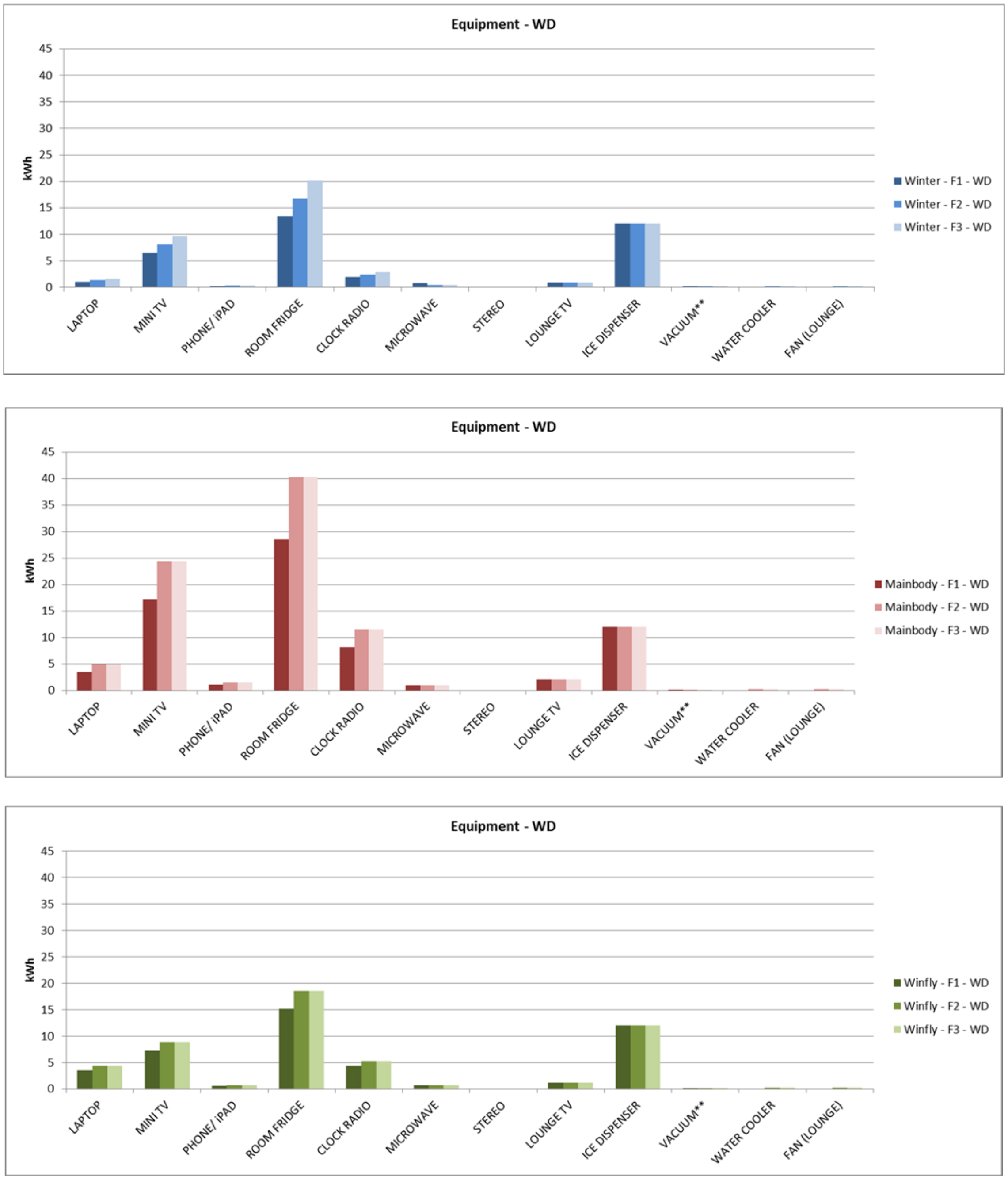


Figure A- 80: Base case weekday equipment load for Winter, Mainbody, and Winfly seasons.

Figure A- 81: Building 209 at the left, flanked by Buildings 208, 207, and 206. In the distance can be seen the Building 203 series (two-story, lighter brown). Photo by author, 2009.

APPENDIX T

THE INPUT FILE

```
INPUT LOADS  ..

TITLE
LINE-1 *McMurdo Station 209 Dorm *
LINE-2 *FINAL base case no infil; DHW removed*
LINE-3 *DESIGN DAY ONLY*
LINE-4 *Georgina Davis NOV 2014* ..


RUN-PERIOD        DEC 19 2004 THRU DEC 19 2004  ..
ABORT             ERRORS  ..
DIAGNOSTIC        ERRORS  ..

LOADS-REPORT      SUMMARY = (ALL-SUMMARY)
                          VERIFICATION=(ALL-VERIFICATION) ..
BUILDING-LOCATION   LATITUDE= -65.5          $ Lat. Must be above Ant. Circle
                              LONGITUDE= -166.7   $ or weather file will not run.
                              ALTITUDE =80             $ Station just above sea level.

                              TIME-ZONE =-11                     $ NZ time.
                              AZIMUTH=45                         $ Upper-case dorms.
                              DAYLIGHT-SAVINGS = YES
                              HOLIDAY= NO ..

$-----HOURLY REPORTS-----$

$BUILDING DESCRIPTION

$STRUCTURE   THE BUILDING REPRESENTS BLDG 209
$BASELINE    BASELINE DESCRIPTIONS FROM MCMURDO INTRANET FILES

$ CONSTRUCTION


ACOUSTIC-TILE  = MATERIAL                    $(AC01: MAT LIB)
          THICKNESS    = 0.0313        $(FT)
          CONDUCTIVITY = 0.033         $(BTU.FT/HR.FT^2.F)
          DENSITY      = 18            $(LB/FT^3)
          SPECIFIC-HEAT = 0.32 ..      $(BTU/LB.F)

CARPET-WITH-RUBBER-PAD      = MATERIAL        $(CP02: MAT LIB)
          THICKNESS    = 0.0313        $(FT)
          CONDUCTIVITY = 0.034         $(BTU.FT/HR.FT^2.F)
```

```
            DENSITY      = 18            $(LB/FT^3)
            RESISTANCE   = 1.23   ..     $(HR.FT^2.F/BTU))

GYPSUM-BOARD   = MATERIAL                $(GP01: MAT LIB)
            THICKNESS    = 0.0417        $(FT)
            CONDUCTIVITY = 0.0926        $(BTU.FT/HR.FT^2.F)
            DENSITY      = 50            $(LB/FT^3)
            SPECIFIC-HEAT = 0.20 ..      $(BTU/LB.F)

PLYWOOD-HALF   = MATERIAL                $(PW03: MAT LIB)
            THICKNESS    = 0.0417        $(FT)
            CONDUCTIVITY = 0.0667        $(BTU.FT/HR.FT^2.F)
            DENSITY      = 34            $(LB/FT^3)
            SPECIFIC-HEAT = 0.29 ..      $(BTU/LB.F)

PLYWOOD-ONE          = MATERIAL                $(PW06: MAT LIB)
            THICKNESS    = 0.0833        $(FT)
            CONDUCTIVITY = 0.0667        $(BTU.FT/HR.FT^2.F)
            DENSITY      = 34            $(LB/FT^3)
            SPECIFIC-HEAT = 0.29 ..      $(BTU/LB.F)

BATT-11              = MATERIAL                      $(IN01: MAT LIB)
            THICKNESS    = 0.1882        $(FT)
            CONDUCTIVITY = 0.0250        $(BTU.FT/HR.FT^2.F)
            DENSITY      = 0.60          $(LB/FT^3)
            RESISTANCE   = 11.83 ..            $(HR.FT^2.F/BTU)

BATT-07              = MATERIAL                      $(IN02: MAT LIB)
            THICKNESS    = 0.2957        $(FT) 3.5"
            CONDUCTIVITY = 0.0250        $(BTU.FT/HR.FT^2.F)
            DENSITY      = 0.60          $(LB/FT^3)
            RESISTANCE   = 7.53 ..             $(HR.FT^2.F/BTU)

POLYEURETHANE-1  = MATERIAL              $(IN45: MAT LIB)
             THICKNESS    = 0.1667      $(FT) 2-inches
             CONDUCTIVITY = 0.0133      $(BTU.FT/HR.FT^2.F)
             DENSITY      = 1.50        $(LB/FT^3)
             SPECIFIC-HEAT = 0.38 ..    $(BTU/LB.F)

POLYEURETHANE-2 =MATERIAL                $(IN41: MAT LIB)
            THICKNESS    = 0.0417        $(FT) half inch
            CONDUCTIVITY = 0.0133        $(BTU.FT/HR.FT^2.F)
            DENSITY      = 1.50          $(LB/FT^3)
            SPECIFIC-HEAT = 0.38 ..      $(BTU/LB.F)

AIR-LAYER-4      = MATERIAL                    $(AL33:MAT LIB)
            THICKNESS    = 6                $(FT)
            RESISTANCE   = 0.92   ..     $(HR.FT^2.F/BTU)


WA1=LAYERS  MATERIAL = (IN45, IN41, IN01, GP01) ..  $ Ext. Vertical Walls
```

```
                $ Polyurethane, batt, gypsum
               $ "Robertson Versawall panels."
WA2=LAYERS  MATERIAL = (PW06, PW03, IN02, CP02) ..$ Ext. Horizontal Walls (i.e., Floor) are

                    $ two layers of plywood, insul., carpet.
RF1=LAYERS  MATERIAL = (IN45, IN41, IN01) ..           $ Roof, same as walls.
CE3=LAYERS  MATERIAL = (IN02, PW03, AC01, CP02) .. $ Ceiling
                                                       $ Insul., plywood, tiles, carpet
DR1=LAYERS  MATERIAL = (GP01, GP01, IN01) ..           $ Interior Walls are two layers of
                                                       $ gyp on studs, with insulation.
DOO1=LAYERS MATERIAL = (GP01, GP01, IN41) ..           $ Door construction

S-WALL    = CONSTRUCTION  LAYERS=WA1  ..
ROOF-C    = CONSTRUCTION  LAYERS=RF1  ..
FOUND     = CONSTRUCTION  LAYERS=WA2 ..
CEIL_C    = CONSTRUCTION  LAYERS=CE3 ..
DRY-1     = CONSTRUCTION  LAYERS=DR1 ..
DOOR-C              = CONSTRUCTION  LAYERS=DOO1 ..


SET-DEFAULT FOR EXTERIOR-WALL  HEIGHT=48  $ ft.
CONSTRUCTION=S-WALL  ..

GLASS1    = GLASS-TYPE
PANES = 3
GLASS-TYPE-CODE= 1
GLASS-CONDUCTANCE = 0.12
$INSIDE-EMISS = 0.84         DEFAULT(0 TO 1)
$FRAME-CONDUCTANCE = 1.254    DEFAULT(BTU/HR.FT^2.F)
FRAME-ABS = 0.7   ..       $ DEFAULT(0 TO 1)solar absorptance

$  OCCUPANCY
$  Winter  .....  In winter there are fewer people, and
$                                    everyone has his or her own room.
$                           Occupancy schedules were simplified from two days per
$                           floor for each season.  The fractions were found to
$                           nearly equal the fraction of the total building population
$                           (34, 48, 48 vs 130).  Therefore, the total building population
$                           fractions are used here.
   OC-1-1          =DAY-SCHEDULE                    $WEEKDAY
                                    HOURS = (1,8)
                           VALUES = (0.17, 0.17, 0.17, 0.17,
                                                      0.17, 0.05, 0.02, 0.02)
                           HOURS = (9,17)
                           VALUES = (0.05, 0.05, 0.05, 0.05, 0.05,
                                                      0.05, 0.05, 0.05, 0.17)
                           HOURS = (18,24)
                           VALUES = (0.09, 0.12, 0.14, 0.17,
                                                      0.17, 0.17, 0.17)  ..

   OC-2-1          =DAY-SCHEDULE                    $WEEKEND
                                    HOURS = (1,8)
```

```
                    VALUES = (0.22, 0.22, 0.22, 0.22,
                                          0.22, 0.22, 0.22, 0.22)
                    HOURS = (9,17)
                          VALUES = (0.22, 0.17, 0.02, 0.02, 0.02,
                                          0.19, 0.19, 0.19, 0.17)
                    HOURS = (18,24)
                    VALUES = (0.02, 0.02, 0.08, 0.08,
                                          0.17, 0.22, 0.22)  ..

OC-WEEK1     =WEEK-SCHEDULE    (MON, SAT)  OC-1-1
                                                   (SUN, HOL) OC-2-1  ..

$Main            Mainbody is the high season.  The dorms are maxed out
$                      and often overcrowded.  Some lounges turn into bunk rooms
$                      and some double rooms house 3-5.  This is not depicted here
$                      at this time.
      OC-3-1           =DAY-SCHEDULE
                                  HOURS = (1,8)           $WEEKDAY

                            VALUES = (0.78, 0.78, 0.78, 0.78,
                                            0.74, 0.66, 0.30, 0.22)
                            HOURS = (9,17)
                            VALUES = (0.22, 0.22, 0.22, 0.26, 0.22,
                                            0.22, 0.22, 0.22, 0.91)
                            HOURS = (18,24)
                            VALUES = (0.12, 0.37, 0.31, 0.40,
                                            0.63, 0.69, 0.78)  ..
      OC-4-1           =DAY-SCHEDULE    $WEEKEND
                                  HOURS = (1,8)

                            VALUES = (0.89, 0.89, 0.89, 0.89, 0.89,
                                            0.89, 0.89, 0.85)
                            HOURS = (9,17)
                                  VALUES = (0.85, 0.34, 0.21, 0.17, 0.26, 0.28,
                                            0.28, 0.28, 0.48)
                            HOURS = (18,24)
                            VALUES = (0.20, 0.28, 0.32 0.46,
                                            0.54, 0.86, 0.89)  ..

OC-WEEK2     =WEEK-SCHEDULE    (MON,SAT)  OC-3-1
                                                   (SUN, HOL) OC-4-1  ..

$WinF   This transitional season finds most people sharing rooms
$                but not all rooms are occupied, especially at the beginning.

      OC-5-1           =DAY-SCHEDULE    $WEEKDAY
                                  HOURS = (1,8)

                            VALUES = (0.38, 0.38, 0.38, 0.38,
                                            0.38, 0.38, 0.05, 0.07)
                            HOURS = (9,17)
                            VALUES = (0.11, 0.10, 0.09, 0.14, 0.09,
                                            0.09, 0.10, 0.09, 0.25)
```

```
                                HOURS = (18,24)
                                VALUES = (0.09, 0.22, 0.26, 0.26,
                                               0.34, 0.38, 0.38)  ..
        OC-6-1   =DAY-SCHEDULE    $WEEKEND
                                     HOURS = (1,8)

                                VALUES = (0.40, 0.40, 0.40, 0.40, 0.38,
                                               0.38, 0.34, 0.38)
                                HOURS = (9,17)
                                     VALUES = (0.38, 0.29, 0.05, 0.05, 0.12,
                                               0.13, 0.14, 0.14, 0.20)
                                HOURS = (18,24)
                                VALUES = (0.06, 0.06, 0.21, 0.42,
                                               0.35, 0.40, 0.40)  ..

OC-WEEK3      =WEEK-SCHEDULE    (MON,SAT)  OC-5-1
                                                 (SUN, HOL) OC-6-1  ..
OCCUPY-1      =SCHEDULE     THRU JAN 31  OC-WEEK2              $MAINBODY
                                THRU MAR 31  OC-WEEK3              $WINFLY
                                THRU AUG 15  OC-WEEK1              $WINTER
                                THRU OCT 31  OC-WEEK3              $WINFLY
                                THRU DEC 31  OC-WEEK2 ..      $MAINBODY



$Attic ... is unoccupied
        OC-AT            =DAY-SCHEDULE
                                     HOURS = (1,24)

                                VALUES = (0)  ..
OC-WEEK10      =WEEK-SCHEDULE    (ALL)  OC-AT ..
OCCUPY-4      =SCHEDULE   THRU JAN 31  OC-WEEK10               $MAINBODY
                        THRU MAR 31  OC-WEEK10            $WINFLY
                        THRU AUG 15  OC-WEEK10            $WINTER
                        THRU OCT 31  OC-WEEK10            $WINFLY
                        THRU DEC 31  OC-WEEK10 ..    $MAINBODY

$HALLWAYS ... are treated as unoccupied.
        OC-HL            =DAY-SCHEDULE
                                     HOURS = (1,24)

                                VALUES = (0)  ..
OC-WEEK11      =WEEK-SCHEDULE    (ALL)  OC-HL ..
OCCUPY-5H      =SCHEDULE   THRU JAN 31  OC-WEEK11              $MAINBODY
                                               THRU MAR 31  OC-WEEK11
        $WINFLY
                                               THRU AUG 15  OC-WEEK11
        $WINTER
                                               THRU OCT 31  OC-WEEK11
        $WINFLY
                                               THRU DEC 31  OC-WEEK11 ..
        $MAINBODY
```

```
$ LIGHTING SCHEDULE                    WEH and HOL find more people in the dorms, especially
$                                      in the middle of the day.  WD finds most rooms vacated
$                                              during the day, except for the night shift.


$ These values represent LIGHTING-KW, not LIGHTING-W/SQFT .
$ These values could not be combined like occupancy.  They are separate for each
$ floor; however, floors 2&3 are identical.
$ FLOOR 1       Each room has one over-head light with two fixtures.
$ Winter There is negligible natural light contribution for this period.

        $updated 9/3
LT-1-1      =DAY-SCHEDULE
                                              HOURS = (1,24)

                                       VALUES = (0.00, 0.00, 0.00, 0.00,
                                              0.06, 0.14, 0.03, 0.20, 0.25, 0.00,
                                              0.00, 0.00, 0.00, 0.00, 0.00, 0.00,    0.15,
                                              0.01, 0.42, 0.38, 0.34, 0.26, 0.28, 0.00)  ..

LT-2-1      =DAY-SCHEDULE
                                              HOURS = (1,24)

                                       VALUES = (0.26, 0.22, 0.00,
                                              0.00, 0.00, 0.00, 0.00, 0.04,
                                              0.34, 0.43, 0.00, 0.00, 0.00,
                                              0.27, 0.41, 0.43, 0.30, 0.02,
                                              0.02, 0.40, 0.26, 0.35, 0.18, 0.03)  ..

LT-WEEK1      =WEEK-SCHEDULE    (MON,SAT) LT-1-1
                                                             (SUN, HOL) LT-2-1  ..

$Mainbody       Maximum opportunity for daylight contribution, but since sun may
$                    be too bright, shades may still be drawn.
$                    Night time activities (e.g., movies, sleeping) will also prefer
$                    darkened conditions with supplemental artificial lighting.

LT-3-1      =DAY-SCHEDULE
                                              HOURS = (1,24)

                                       VALUES = (0.19, 0.00, 0.00,
                                              0.00, 0.00, 0.69, 0.24, 0.21,
                                              0.00, 0.00, 0.00, 0.00, 0.00,
                                              0.00, 0.00, 0.00, 0.35, 0.25,
                                              0.26, 0.12, 0.14, 0.39, 0.35, 0.13)  ..

LT-4-1      =DAY-SCHEDULE
                                              HOURS = (1,24)

                                       VALUES = (0.37, 0.18, 0.00,
                                              0.00, 0.00, 0.00, 0.00, 0.00,
                                              0.61, 0.49, 0.00, 0.00, 0.00,
```

```
                                        0.0086,  0.097, 0.14, 0.13, 0.11,
                                        0.050, 0.53, 0.39, 0.47, 0.62, 0.13)  ..

LT-WEEK2      =WEEK-SCHEDULE    (MON,SAT) LT-3-1
                                                        (SUN, HOL) LT-4-1  ..

$Winfly            Very little contribution from daylight, especially
$                           At the beginning of the season.  Most will opt for
$                           drawn shades and artificial lighting.

LT-5-1        =DAY-SCHEDULE
                                        HOURS = (1,24)

                                VALUES = (0.10, 0.00, 0.00,
                                        0.00, 0.00, 0.23, 0.00, 0.17,
                                        0.19, 0.00, 0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.00, 0.20, 0.25,
                                        0.25, 0.20, 0.20, 0.15, 0.18, 0.18)  ..

LT-6-1        =DAY-SCHEDULE
                                        HOURS = (1,24)

                                        VALUES = (0.28, 0.18, 0.00,
                                        0.00, 0.00, 0.00, 0.00, 0.00,
                                        0.46, 0.46, 0.00, 0.00, 0.00,
                                        0.00, 0.15, 0.15, 0.049, 0.18,
                                        0.24, 0.44, 0.44, 0.25, 0.25, 0.18)  ..

LT-WEEK3      =WEEK-SCHEDULE     (MON,SAT) LT-5-1
                                                        (SUN, HOL) LT-6-1  ..

LIGHTS-1      =SCHEDULE    THRU JAN 31 LT-WEEK2          $MAINBODY
                           THRU MAR 31 LT-WEEK3          $WINFLY
                           THRU AUG 15 LT-WEEK1          $WINTER
                           THRU OCT 31 LT-WEEK3          $WINFLY
                           THRU DEC 31 LT-WEEK2 ..       $MAINBODY

$ FLOOR 2 & 3
$Winter
LT-1-2        =DAY-SCHEDULE
                                        HOURS = (1,24)

                                VALUES = (0.00, 0.00, 0.00,
                                        0.00, 0.03, 0.10, 0.02, 0.16,
                                        0.17, 0.00, 0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.00, 0.18, 0.02,
                                        0.30, 0.27, 0.24, 0.18, 0.22, 0.00)  ..

LT-2-2        =DAY-SCHEDULE     $updated 8/27
                                        HOURS = (1,24)

                                VALUES = (0.21, 0.18, 0.00,
                                        0.00, 0.00, 0.00, 0.00, 0.04,
```

```
                                       0.30, 0.37, 0.00, 0.00, 0.00,
                                       0.22, 0.35, 0.37, 0.28, 0.02,
                                       0.02, 0.34, 0.21, 0.30, 0.15, 0.03)  ..

LT-WEEK4      =WEEK-SCHEDULE    (MON,SAT) LT-1-2
                                                        (SUN, HOL) LT-2-2  ..

$Mainbody

LT-3-2        =DAY-SCHEDULE
                                       HOURS = (1,24)

                                  VALUES = (0.21, 0.00, 0.00,
                                       0.00, 0.00, 0.73, 0.26, 0.19,
                                       0.00, 0.00, 0.00, 0.00, 0.00,
                                       0.00, 0.00, 0.00, 0.36, 0.26,
                                       0.26, 0.12, 0.13, 0.40, 0.37, 0.100)  ..

LT-4-2        =DAY-SCHEDULE     $updated 8/27
                                       HOURS = (1,24)

                                  VALUES = (0.34, 0.13, 0.00,
                                       0.00, 0.00, 0.00, 0.00, 0.00,
                                       0.64, 0.52, 0.00, 0.00, 0.00,
                                       0.0065, 0.10, 0.14, 0.13, 0.11,
                                       0.050, 0.51, 0.41, 0.50, 0.62, 0.100)  ..

LT-WEEK5      =WEEK-SCHEDULE    (MON,SAT) LT-3-2
                                                   (SUN, HOL) LT-4-2  ..

$Winfly

LT-5-2        =DAY-SCHEDULE
                                       HOURS = (1,24)

                                  VALUES = (0.23, 0.13, 0.00,
                                       0.00, 0.00, 0.00, 0.00, 0.00,
                                       0.41, 0.41, 0.00, 0.00, 0.00,
                                       0.00, 0.095, 0.18, 0.086, 0.17,
                                       0.17, 0.43, 0.31, 0.17, 0.18, 0.13)  ..

LT-6-2        =DAY-SCHEDULE
                                       HOURS = (1,24)

                                  VALUES = (0.10, 0.00, 0.00,
                                       0.00, 0.00, 0.40, 0.00, 0.14,
                                       0.16, 0.00, 0.00, 0.00, 0.00,
                                       0.00, 0.00, 0.00, 0.31, 0.24,
                                       0.24, 0.24, 0.20, 0.17, 0.19, 0.13)  ..

LT-WEEK6      =WEEK-SCHEDULE     (MON,SAT) LT-5-2
                                                        (SUN, HOL) LT-6-2  ..
```

```
LIGHTS-2     =SCHEDULE        THRU JAN 31 LT-WEEK5              $MAINBODY
                   THRU MAR 31 LT-WEEK6              $WINFLY
                   THRU AUG 15 LT-WEEK4              $WINTER
                   THRU OCT 31 LT-WEEK6              $WINFLY
                   THRU DEC 31 LT-WEEK5 ..           $MAINBODY


$ATTIC          There is some lighting in this space, but it is only
$                  used during maintenance, which here is done once weekly,
$                  lasting a few hours before and after lunch.

LT-AT1       =DAY-SCHEDULE
                                    HOURS = (1,24)

                              VALUES = (0)  ..

LT-AT2       =DAY-SCHEDULE
                                    HOURS = (1,24)

                              VALUES = (0.00,        0.00, 0.00,
                                    0.00, 0.00,       0.00, 0.00,       0.00,
                                    0.70, 0.70,       0.00, 0.00,       0.00,
                                    0.70, 0.70, 0.00, 0.00, 0.00,
                                    0.00, 0.00, 0.00, 0.00, 0.00, 0.00) ..

LT-WEEK10      =WEEK-SCHEDULE    (TUE,SUN) LT-AT1
                                              (HOL) LT-AT1
                                              (MON) LT-AT2   ..

LIGHTS-4     =SCHEDULE   THRU JAN 31 LT-WEEK10           $MAINBODY
                   THRU MAR 31 LT-WEEK10             $WINFLY
                   THRU AUG 15 LT-WEEK10             $WINTER
                   THRU OCT 31 LT-WEEK10             $WINFLY
                   THRU DEC 31 LT-WEEK10 ..      $MAINBODY

$ LIGHTING SCHEDULE HALLWAY
$ FLOOR 1
$ Winter        Lights are left on nearly all the time,
$                      even at night, when perhaps only half will
$                      be left on.
$updated 8/27
LT-1-1H       =DAY-SCHEDULE
                              HOURS = (1,24)

                         VALUES = (0.50, 0.50, 0.50,
                              0.50, 0.50, 0.50, 1.00, 1.00,
                              0.50, 0.50, 0.50, 0.50, 0.50,
                              0.50, 0.50, 0.50, 1.00, 1.00,
                              1.00, 1.00, 1.00, 1.00, 0.50, 0.50)  ..
```

```
LT-2-1H         =DAY-SCHEDULE
                                        HOURS = (1,24)

                                VALUES = (0.50, 0.50, 0.50,
                                        0.50, 0.50, 0.50, 0.50, 0.50,
                                        1.00, 1.00, 1.00, 1.00, 1.00,
                                        1.00, 1.00, 1.00, 1.00, 1.00,
                                        1.00, 1.00, 1.00, 0.50, 0.50, 0.50)  ..
LT-WEEK1H       =WEEK-SCHEDULE    (MON,SAT) LT-1-1H
                                                        (SUN, HOL) LT-2-1H  ..

$Mainbody                   Lights are needed less frequently, especially
$                                   in the hallways.

LT-3-1H         =DAY-SCHEDULE
                                                HOURS = (1,24)

                                        VALUES = (0.25, 0.00, 0.00,
                                                0.00, 0.00, 0.50, 1.0010, 0.50,
                                                0.50, 0.00, 0.00, 0.00, 0.00, 0.00,
                                                0.00, 0.00, 0.25, 0.25, 0.75,
1.0010,
                                                0.50, 0.00, 0.00, 0.00)  ..

LT-4-1H         =DAY-SCHEDULE
                                                HOURS = (1,24)

                                        VALUES = (0.00, 0.00, 0.00,
                                                0.00, 0.00, 0.00, 0.00, 0.00,
                                                0.50, 0.50, 0.00, 0.00, 0.00,
                                                0.00, 0.00, 0.00, 0.00, 0.50,
                                                0.50, 0.50, 0.00, 0.00, 0.00, 0.00)
..

LT-WEEK2H       =WEEK-SCHEDULE    (MON,SAT) LT-3-1H
                                                        (SUN, HOL) LT-4-1H  ..

$Winfly             Lights are used only sometimes, with many places
$                           still affecting a low-power, after-hours mode.
$                           Half-lights are often employed.

LT-5-1H         =DAY-SCHEDULE
                                                HOURS = (1,24)

                                        VALUES = (0.50, 0.50, 0.50,
                                                0.50, 1.00          1.00, 1.00, 1.00,
                                                0.50, 0.50, 0.50, 0.50, 0.50,
                                                0.50, 0.50, 0.50, 1.00, 1.50,
                                                1.50, 1.50, 1.00, 1.00, 0.50, 0.50)
..

LT-6-1H         =DAY-SCHEDULE
                                                HOURS = (1,24)
```

```
                                        VALUES = (0.50, 0.50, 0.00,
                                        0.00, 0.00, 0.00, 0.00, 0.50,
                                        1.00, 1.00, 0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.50, 0.50, 0.50,
                                        0.50, 0.50, 0.50, 0.00, 0.00, 0.00)
..

LT-WEEK3H    =WEEK-SCHEDULE   (MON,SAT) LT-5-1H
                                                  (SUN, HOL)
LT-6-1H  ..

LIGHTS-1H    =SCHEDULE    THRU JAN 31 LT-WEEK2H          $MAINBODY
                          THRU MAR 31 LT-WEEK3H          $WINFLY
                          THRU AUG 15 LT-WEEK1H          $WINTER
                          THRU OCT 31 LT-WEEK3H          $WINFLY
                          THRU DEC 31 LT-WEEK2H ..   $MAINBODY

$ FLOORS 2 & 3  updated 8/27
$Winter
LT-1-2H      =DAY-SCHEDULE
                                  HOURS = (1,24)

                              VALUES = (0.50, 0.50, 0.50,
                                  0.50, 0.50, 0.50, 1.00, 1.00,
                                  0.50, 0.50, 0.50, 0.50, 0.50,
                                  0.50, 0.50, 0.50, 1.00, 1.00,
                                  1.00, 1.00, 1.00, 1.00, 0.50, 0.50)  ..

LT-2-2H      =DAY-SCHEDULE
                                  HOURS = (1,24)

                              VALUES = (0.50, 0.50, 0.50,
                                  0.50, 0.50, 0.50, 0.50, 0.50,
                                  1.00, 1.00, 1.00, 1.00, 1.00,
                                  1.00, 1.00, 1.00, 1.00, 1.00,
                                  1.00, 1.00, 1.00, 0.50, 0.50, 0.50)  ..

LT-WEEK4H    =WEEK-SCHEDULE  (MON,SAT) LT-1-2H
                                              (SUN, HOL) LT-2-2H  ..

$Mainbody

LT-3-2H      =DAY-SCHEDULE
                                  HOURS = (1,24)

                              VALUES = (0.00, 0.00, 0.00,
                                  0.00, 0.00, 0.50, 0.50, 0.00,
                                  0.00, 0.00, 0.00, 0.00, 0.00,
                                  0.00, 0.00, 0.00, 0.00, 0.00,
                                  0.50, 0.50, 0.00, 0.00, 0.00, 0.00)  ..

LT-4-2H      =DAY-SCHEDULE
```

```
                                        HOURS = (1,24)

                                   VALUES = (0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.00, 0.00, 0.00,
                                        0.50, 0.50, 0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.00, 0.00, 0.50,
                                        0.50, 0.50, 0.00, 0.00, 0.00, 0.00)  ..

LT-WEEK5H     =WEEK-SCHEDULE    (MON,SAT) LT-3-2H
                                                      (SUN, HOL) LT-4-2H  ..

$Winfly

LT-5-2H       =DAY-SCHEDULE
                                        HOURS = (1,24)

                                   VALUES = (0.50, 0.50, 0.00,
                                        0.00, 0.00, 0.00, 0.00, 0.50,
                                        1.00, 1.00, 0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.50, 0.50, 0.50,
                                        0.50, 0.50, 0.50, 0.00, 0.00, 0.00)  ..

LT-6-2H       =DAY-SCHEDULE
                                        HOURS = (1,24)

                                   VALUES = (0.00, 0.00, 0.00,
                                        0.00, 0.50, 0.50, 0.50, 0.50,
                                        0.00, 0.00, 0.00, 0.00, 0.00,
                                        0.00, 0.00, 0.00, 0.50, 1.00,
                                        1.00, 1.00, 0.50, 0.50, 0.00, 0.00)  ..

LT-WEEK6H     =WEEK-SCHEDULE     (MON,SAT) LT-5-2H
                                                      (SUN, HOL) LT-6-2H  ..

LIGHTS-2H     =SCHEDULE   THRU JAN 31 LT-WEEK5H               $MAINBODY
                    THRU MAR 31 LT-WEEK6H               $WINFLY
                    THRU AUG 15 LT-WEEK4H               $WINTER
                    THRU OCT 31 LT-WEEK6H               $WINFLY
                    THRU DEC 31 LT-WEEK5H ..      $MAINBODY
$STAIRS         LIGHTS WINTER

ST-1-1S       =DAY-SCHEDULE
                                        HOURS = (1,24)

                                   VALUES = (0.25, 0.25, 0.25,
                                        0.25, 0.50, 0.50, 0.50, 0.50,
                                        0.50, 0.25, 0.25, 0.25, 0.25,
                                        0.25, 0.25, 0.25, 0.50, 0.50,
                                        0.50, 0.50, 0.50, 0.50, 0.25, 0.25)  ..

ST-1-2S       =DAY-SCHEDULE
                                        HOURS = (1,24)
```

```
                                  VALUES = (0.25, 0.25, 0.00,
                                            0.00, 0.00, 0.00, 0.00, 0.25,
                                            0.50, 0.50, 0.00, 0.00, 0.00,
                                            0.50, 0.50, 0.50, 0.50, 0.25,
                                            0.25, 0.50, 0.50, 0.50, 0.25, 0.25)  ..

ST-WEEK1S    =WEEK-SCHEDULE       (MON,SAT) ST-1-1S
                                                  (SUN, HOL) ST-1-2S   ..

$STAIRS        LIGHTS MAINBODY

ST-1-3S      =DAY-SCHEDULE
                                            HOURS = (1,24)

                                  VALUES = (0.50, 0.00, 0.00,
                                            0.00, 0.00, 0.00, 1.00, 1.00,
                                            1.00, 0.00, 0.00, 0.00, 0.00,
                                            0.00, 0.00, 0.00, 0.50, 0.50,
                                            0.50, 1.00, 1.00, 0.00, 0.00, 0.00)  ..

ST-1-4S      =DAY-SCHEDULE
                                            HOURS = (1,24)

                                  VALUES = (1.0, 1.0, 0.0,
                                            0.0, 0.0, 0.0, 0.0, 0.0,
                                            1.0, 1.0, 0.0, 0.0, 0.0,
                                            0.0, 1.0, 1.0, 1.0, 1.0,
                                            1.0, 1.0, 1.0, 0.0, 0.0, 0.0)  ..

ST-WEEK2S    =WEEK-SCHEDULE       (MON,SAT) ST-1-3S
                                                  (SUN, HOL) ST-1-4S   ..


$STAIRS        LIGHTS WINFLY

ST-1-5S      =DAY-SCHEDULE
                                            HOURS = (1,24)

                                  VALUES = (1.0, 0.5, 0.5,
                                            0.5, 0.5, 1.0, 1.0, 1.0, 1.0,
                                            1.0, 0.5, 0.5, 0.5, 0.5, 0.5,
                                            0.5, 1.0, 1.0, 1.0, 1.0, 1.0,
                                            0.5, 0.5, 0.5)  ..

ST-1-6S      =DAY-SCHEDULE
                                            HOURS = (1,24)

                                  VALUES = (0.50, 0.50, 0.00,
                                            0.00, 0.00, 0.00, 0.00, 0.00,
                                            1.00, 1.00, 0.00, 0.00, 0.00,
                                            0.00, 0.00, 1.00, 1.00, 1.00,
                                            1.00, 1.00, 1.00, 0.00, 0.00, 0.00)  ..
```

```
ST-WEEK3S       =WEEK-SCHEDULE     (MON,SAT) ST-1-5S
                                                        (SUN, HOL) ST-1-6S   ..

STAIRS-1S      =SCHEDULE   THRU JAN 31 ST-WEEK2S             $MAINBODY
                           THRU MAR 31 ST-WEEK3S             $WINFLY
                           THRU AUG 15 ST-WEEK1S          $WINTER
                           THRU OCT 31 ST-WEEK3S             $WINFLY
                           THRU DEC 31 ST-WEEK2S ..      $MAINBODY

$ EQUIPMENT SCHEDULE  UPDATED 8/27
$ Floor 1
$                     Assumptions include: 66% of occupants on each floor have
$                     laptops; every occupied room has 1 mini TV/VCR; 80% of occupants
$                     have one electronic device that must be charged daily
$                     (i.e., overnight); every occupied room has one mini fridge;
$                     every occupant has a clock radio; each lounge has 1
$                     microwave, 1 stereo, and one large TV.
$ These values represent EQUIPMENT-KW, not EQUIPMENT-W/SQFT.
$ These values could not be combined like occupancy.  They are separate for each
$ floor; however, floors 2&3 are identical.

$  Winter
     EQ-1-1     =DAY-SCHEDULE
                              HOURS = (1,24)

                         VALUES = (0.08, 0.08, 0.08,
                              0.08, 0.08, 0.31, 0.19, 0.08,
                              0.11, 0.08, 0.08, 0.08, 0.08,
                              0.08, 0.08, 0.08, 0.30, 0.12,
                              0.12, 0.16, 0.24, 0.23, 0.08, 0.08)  ..

     EQ-2-1          =DAY-SCHEDULE
                              HOURS = (1,24)

                         VALUES = (0.08, 0.08, 0.08,
                              0.08, 0.08, 0.08, 0.08, 0.12,
                              0.34, 0.37, 0.08, 0.08, 0.08,
                              0.30, 0.30, 0.34, 0.35, 0.12,
                              0.09, 0.17, 0.29, 0.25, 0.13, 0.08)  ..

EQ-WEEK1       =WEEK-SCHEDULE    (MON,SAT)  EQ-1-1
                                            (SUN, HOL) EQ-2-1  ..
$ Main
     EQ-3-1          =DAY-SCHEDULE
                              HOURS = (1,24)

                         VALUES = (0.21, 0.21, 0.21,
                              0.21, 0.21, 0.48, 0.43, 0.37,
                              0.37, 0.19, 0.19, 0.32, 0.19,
                              0.19, 0.19, 0.19, 0.67, 0.60,
                              0.28, 0.32, 0.56, 0.53, 0.24, 0.21)  ..
```

```
          EQ-4-1              =DAY-SCHEDULE
                                                    HOURS = (1,24)

                                          VALUES = (0.22, 0.21, 0.21,
                                                    0.21, 0.21, 0.21, 0.19, 0.23,
                                                    0.23, 0.84, 0.19, 0.19, 0.19,
                                                    0.19, 0.38, 0.39, 0.87, 0.67,
                                                    0.21, 0.88, 0.88, 0.74, 0.25, 0.22)  ..

EQ-WEEK2       =WEEK-SCHEDULE    (MON,SAT)  EQ-3-1
                                                          (SUN, HOL) EQ-4-1  ..
$ Winfly
          EQ-5-1              =DAY-SCHEDULE
                                                    HOURS = (1,24)

                                          VALUES = (0.11, 0.11, 0.11,
                                                    0.11, 0.11, 0.24, 0.10, 0.10,
                                                    0.10, 0.10, 0.10, 0.10, 0.10,
                                                    0.10, 0.10, 0.10, 0.45, 0.45,
                                                    0.19, 0.22, 0.22, 0.46, 0.15, 0.11)  ..

          EQ-6-1   =DAY-SCHEDULE
                                                    HOURS = (1,24)

                                          VALUES = (0.11, 0.11, 0.11,
                                                    0.11, 0.11, 0.11, 0.10, 0.14,
                                                    0.11, 0.46, 0.10, 0.10, 0.10,
                                                    0.10, 0.22, 0.23, 0.49, 0.35,
                                                    0.12, 0.49, 0.49, 0.42, 0.16, 0.11)  ..

EQ-WEEK3       =WEEK-SCHEDULE    (MON,SAT)  EQ-5-1
                                                          (SUN, HOL) EQ-6-1  ..

EQUIP-1      =SCHEDULE     THRU JAN 31  EQ-WEEK2              $MAINBODY
                           THRU MAR 31  EQ-WEEK3              $WINFLY
                           THRU AUG 15  EQ-WEEK1              $WINTER
                           THRU OCT 31  EQ-WEEK3              $WINFLY
                           THRU DEC 31  EQ-WEEK2 ..      $MAINBODY

$ Floors 2&3
$ Winter
          EQ-1-2     =DAY-SCHEDULE
                                                              HOURS = (1,24)

                                                    VALUES = (0.07, 0.07, 0.07,
                                                              0.07, 0.07, 0.27, 0.17, 0.07,
                                                              0.10, 0.07, 0.07, 0.07, 0.07,
                                                              0.07, 0.07, 0.07, 0.26, 0.10,
                                                              0.10, 0.13, 0.20, 0.19, 0.07, 0.07)  ..

          EQ-2-2              =DAY-SCHEDULE
                                                              HOURS = (1,24)
```

```
                                    VALUES = (0.07, 0.07, 0.07,
                                            0.07, 0.07, 0.07, 0.07, 0.09,
                                            0.29, 0.32, 0.07, 0.07,      0.07,
                                            0.26, 0.26, 0.29, 0.30, 0.09,
                                            0.08, 0.14, 0.24, 0.21, 0.11, 0.07)  ..

EQ-WEEK4     =WEEK-SCHEDULE   (MON,SAT)  EQ-1-2
                                              (SUN, HOL) EQ-2-2  ..
$ Main
    EQ-3-2          =DAY-SCHEDULE
                                            HOURS = (1,24)

                                    VALUES = (0.20, 0.20, 0.20,
                                            0.20, 0.20, 0.47, 0.42, 0.35,
                                            0.35, 0.18, 0.18, 0.30, 0.18,
                                            0.18, 0.18, 0.18, 0.64, 0.58,
                                            0.27, 0.29, 0.53, 0.51, 0.23, 0.20)  ..


    EQ-4-2          =DAY-SCHEDULE
                                            HOURS = (1,24)

                                    VALUES = (0.21, 0.20, 0.20,
                                            0.20, 0.20, 0.20, 0.18, 0.21,
                                            0.21, 0.81, 0.18, 0.18, 0.18,
                                            0.18, 0.35, 0.36, 0.83, 0.65,
                                            0.20, 0.84, 0.84, 0.70, 0.23, 0.21)  ..

EQ-WEEK5     =WEEK-SCHEDULE   (MON,SAT)  EQ-3-2
                                              (SUN, HOL) EQ-4-2  ..
$ Winfly
    EQ-5-2          =DAY-SCHEDULE
                                            HOURS = (1,24)

                                    VALUES = (0.09, 0.09, 0.09,
                                            0.09, 0.09, 0.09, 0.19, 0.08,
                                            0.08, 0.08, 0.08, 0.08, 0.08,
                                            0.08, 0.08, 0.08, 0.38, 0.38,
                                            0.15, 0.18, 0.18, 0.39, 0.12, 0.09)  ..

    EQ-6-2   =DAY-SCHEDULE
                                            HOURS = (1,24)

                                    VALUES = (0.09, 0.09, 0.09,
                                            0.09, 0.09, 0.09, 0.08, 0.11,
                                            0.32, 0.39, 0.08, 0.08, 0.08,
                                            0.08, 0.18, 0.19, 0.40, 0.30,
                                            0.10, 0.40, 0.40, 0.34, 0.13, 0.09)  ..

EQ-WEEK6     =WEEK-SCHEDULE   (MON,SAT)  EQ-5-2
                                              (SUN, HOL) EQ-6-2  ..

EQUIP-2     =SCHEDULE    THRU JAN 31  EQ-WEEK5            $MAINBODY
```

```
                  THRU MAR 31  EQ-WEEK6                 $WINFLY
                  THRU AUG 15  EQ-WEEK4                 $WINTER
                  THRU OCT 31  EQ-WEEK6                 $WINFLY
                  THRU DEC 31  EQ-WEEK5 ..      $MAINBODY


$ ATTIC                   Attic equipment includes the AHUs.  see samp2e

     EQ-AT    =DAY-SCHEDULE
                                                HOURS = (1,24)

                                           VALUES = (1)  ..


EQ-WEEK10      =WEEK-SCHEDULE    (ALL)  EQ-AT ..

EQUIP-4      =SCHEDULE    THRU JAN 31  EQ-WEEK10            $MAINBODY
                                                THRU MAR 31  EQ-WEEK10
     $WINFLY
                                                THRU AUG 15  EQ-WEEK10
     $WINTER
                                                THRU OCT 31  EQ-WEEK10
     $WINFLY
                                                THRU DEC 31  EQ-WEEK10 ..
     $MAINBODY

$HALLWAY     Equipment in the hallway includes 1 water fountain/floor,
$                         an ice machine per floor, and a vacuum.

     EQ-5H            =DAY-SCHEDULE
                                                HOURS = (1,24)

                                           VALUES = (0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.61, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44, 0.44)  ..


     EQ-6H            =DAY-SCHEDULE
                                                HOURS = (1,24)

                                           VALUES = (0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44,
                                                0.44, 0.44, 0.44, 0.44, 0.44, 0.44)  ..

EQ-WEEK-H      =WEEK-SCHEDULE    (MON,SAT)  EQ-5H
                                                          (SUN, HOL)  EQ-6H ..

EQUIP-H      =SCHEDULE    THRU JAN 31  EQ-WEEK-H            $MAINBODY
```

```
                                          THRU MAR 31  EQ-WEEK-H
    $WINFLY
                                          THRU AUG 15  EQ-WEEK-H
    $WINTER
                                          THRU OCT 31  EQ-WEEK-H
    $WINFLY
                                          THRU DEC 31  EQ-WEEK-H ..
    $MAINBODY


$ INFILTRATION SCHEDULE

$INFIL-SCH     =SCHEDULE     THRU JAN 31  (ALL) (1,24) (0) WAS(0.16)  GKSR 1642
$                       THRU MAR 31  (ALL) (1,24) (0) WAS(0.17)
$                       THRU AUG 15  (ALL) (1,24) (0) WAS(0.20)
$                      THRU OCT 31  (ALL) (1,24) (0) WAS(0.17)
$                     THRU DEC 31  (ALL) (1,24) (0) .. WAS(0.16)
$

$ SET DEFAULT VALUES

SET-DEFAULT FOR SPACE FLOOR-WEIGHT=0 ..
SET-DEFAULT FOR EXTERIOR-WALL CONSTRUCTION = S-WALL ..
SET-DEFAULT FOR INTERIOR-WALL CONSTRUCTION = DRY-1 ..
SET-DEFAULT FOR DOOR CONSTRUCTION = DOOR-C ..
SET-DEFAULT FOR WINDOW HEIGHT = 3.0
                           GLASS-TYPE  = GLASS1 ..
$ GENERAL SPACE DEFINITION

DORM-F1-LIVING                        =SPACE-CONDITIONS
                           PEOPLE-SCHEDULE     =OCCUPY-1
    PEOPLE-HEAT-GAIN    =450                   $Lec 621 p 27/40
    LIGHTING-SCHEDULE    =LIGHTS-1
    LIGHTING-TYPE       =SUS-FLUOR             $SUSPENDED FLUORESCENT
    LIGHT-TO-SPACE      =1.0

    LIGHTING-W/SQFT     =1.01           $ max
    EQUIP-SCHEDULE      =EQUIP-1
    EQUIPMENT-W/SQFT    =1.18           $ max
                              $INF-METHOD                = CRACK
                              $INF-SCHEDULE       =INFIL-SCH
                           ZONE-TYPE                    =CONDITIONED  ..

DORM-F1-HALL                          =SPACE-CONDITIONS
                           PEOPLE-SCHEDULE     =OCCUPY-5H
    LIGHTING-SCHEDULE    =LIGHTS-1H
    LIGHTING-TYPE       =SUS-FLUOR             $SUSPENDED FLUORESCENT
    LIGHT-TO-SPACE      =1.0
    LIGHTING-W/SQFT     =0.83                  $ max
                           EQUIP-SCHEDULE      =EQUIP-H
    EQUIPMENT-W/SQFT    =1.01
                              $INF-METHOD                = CRACK
                              $INF-SCHEDULE       =INFIL-SCH
```

```
                    ZONE-TYPE              =CONDITIONED ..


DORM-F2-LIVING     =SPACE-CONDITIONS
                    PEOPLE-SCHEDULE    =OCCUPY-1
     PEOPLE-HEAT-GAIN    =450
     LIGHTING-SCHEDULE   =LIGHTS-2
     LIGHTING-TYPE       =SUS-FLUOR
     LIGHT-TO-SPACE      =1.0
     LIGHTING-W/SQFT     =1.33
     EQUIP-SCHEDULE      =EQUIP-1
     EQUIPMENT-W/SQFT    =1.70
                         $INF-METHOD            = CRACK
                         $INF-SCHEDULE     =INFIL-SCH
                    ZONE-TYPE              =CONDITIONED ..


DORM-F2-HALL        =SPACE-CONDITIONS
                    PEOPLE-SCHEDULE    =OCCUPY-5H
                    $PEOPLE-HEAT-GAIN   =350
     LIGHTING-SCHEDULE   =LIGHTS-2H
     LIGHTING-TYPE       =SUS-FLUOR
     LIGHT-TO-SPACE      =1.0
     LIGHTING-W/SQFT     =0.83
     EQUIP-SCHEDULE      =EQUIP-H
     EQUIPMENT-W/SQFT    =1.01
                         $INF-METHOD            = CRACK
                         $INF-SCHEDULE     =INFIL-SCH
                    ZONE-TYPE              =CONDITIONED ..


DORM-F3-LIVING     =SPACE-CONDITIONS
                    PEOPLE-SCHEDULE    =OCCUPY-1
     PEOPLE-HEAT-GAIN    =450
     LIGHTING-SCHEDULE   =LIGHTS-2
     LIGHTING-TYPE       =SUS-FLUOR
     LIGHT-TO-SPACE      =1.0
     LIGHTING-W/SQFT     =1.33
     EQUIP-SCHEDULE      =EQUIP-1
     EQUIPMENT-W/SQFT    =1.70
                         $INF-METHOD            = CRACK
                         $INF-SCHEDULE     =INFIL-SCH
                    ZONE-TYPE              =CONDITIONED ..

DORM-F3-HALL        =SPACE-CONDITIONS
                    PEOPLE-SCHEDULE    =OCCUPY-5H
     LIGHTING-SCHEDULE   =LIGHTS-2H
     LIGHTING-TYPE       =SUS-FLUOR
     LIGHT-TO-SPACE      =1.0
     LIGHTING-W/SQFT     =0.83
     EQUIP-SCHEDULE      =EQUIP-H
     EQUIPMENT-W/SQFT    =1.01
                         $INF-METHOD   = CRACK
```

```
                         $INF-SCHEDULE       =INFIL-SCH
                    ZONE-TYPE                      =CONDITIONED  ..

DORM-AT        =SPACE-CONDITIONS
                    PEOPLE-SCHEDULE     =OCCUPY-4
      PEOPLE-HEAT-GAIN    =350
      LIGHTING-SCHEDULE   =LIGHTS-4
      LIGHTING-TYPE       =SUS-FLUOR        $SUSPENDED FLUORESCENT
      LIGHT-TO-SPACE      =1.0
      LIGHTING-W/SQFT     =0.50

      $INF-METHOD                    = CRACK
                    $INF-SCHEDULE       =INFIL-SCH
                    ZONE-TYPE                      =UNCONDITIONED  ..


STAIRSX3       =SPACE-CONDITIONS
                    PEOPLE-SCHEDULE     =OCCUPY-4
      LIGHTING-SCHEDULE   =STAIRS-1S
      LIGHTING-TYPE       =SUS-FLUOR
      LIGHT-TO-SPACE      =1.0
      LIGHTING-W/SQFT     =0.71
                         $INF-METHOD   = CRACK
                         $INF-SCHEDULE      =INFIL-SCH
                    ZONE-TYPE                      =CONDITIONED  ..



$ SPECIFIC SPACE DETAILS
$FRONT = SOUTH         "FACES WATER"          "180
$BACK = NORTH          "FACES 208"            "0"
$LEFT = WEST  "FACES WINTER"                  "270"
$RIGHT = EAST          "MAIN"                 "90"

STAIRCASE      =SPACE
                    SPACE-CONDITIONS = STAIRSX3
                    AREA = 672  VOLUME = 20160
                    Z=6         NUMBER-OF-PEOPLE = 0 ..

     STAIR-1-BL  =EXTERIOR-WALL  HEIGHT = 30   WIDTH = 12
           X= 12  Y=48  AZIMUTH = 0   ..
     STAIR-1-L   =EXTERIOR-WALL  HEIGHT = 30   WIDTH = 28
           X= 0  Y=48  AZIMUTH = 270   ..
                         DR-3  = DOOR   $BACK DOOR "LEFT"
                              WIDTH = 3.5      HEIGHT = 7         $(FT)
                              X = 15.5          Y = 0 ..
                         WIN8 = WINDOW
                           GLASS-TYPE = GLASS1
                              CONDUCT-SCHEDULE =CD-SCHED
                              WIDTH = 2.75   HEIGHT = 4
                              X= 3  Y = 13   ..
                         WIN9 = WINDOW
                              GLASS-TYPE = GLASS1
```

```
                                        CONDUCT-SCHEDULE =CD-SCHED
                                        WIDTH = 8         HEIGHT = 1.5
                                        X = 10 Y= 16 ..
                                WIN14 = WINDOW
                                  GLASS-TYPE = GLASS1
                                        CONDUCT-SCHEDULE =CD-SCHED
                                        WIDTH = 2.75   HEIGHT = 4
                                        X = 3  Y = 23  ..
                                WIN15 = WINDOW
                                        GLASS-TYPE = GLASS1
                                        CONDUCT-SCHEDULE =CD-SCHED
                                        WIDTH = 8   HEIGHT = 1.5
                                        X = 10  Y=23   ..
STAIR-1-FL  =INTERIOR-WALL  NEXT-TO LEVEL-1-LIVING
                                                HEIGHT = 30   WIDTH = 12
          X= 0  Y=20  AZIMUTH = 180   ..
C4-SL       =INTERIOR-WALL    NEXT-TO LEVEL-4         $ceiling for left stair
                                X=12   Y=20   Z=30
                                HEIGHT=28 WIDTH=12
                                TILT=180           AZIMUTH = 0
                                CONSTRUCTION = CEIL_C   ..
FLOOR-SL    =EXTERIOR-WALL          HEIGHT=28 WIDTH=10  $floor of left stair
                                X=10   Y=20   Z=0
                                AZIMUTH = 0   TILT=180
                                CONSTRUCTION = FOUND   ..

STAIR-1-BR  =EXTERIOR-WALL  HEIGHT = 30   WIDTH = 12
          X= 168  Y=48  AZIMUTH = 0   ..
STAIR-1-R   =EXTERIOR-WALL  HEIGHT = 30   WIDTH = 28
          X= 168  Y=20  AZIMUTH = 90  ..
                                DR-2 = DOOR                $Front door "RIGHT"
                                        WIDTH = 3.5    HEIGHT = 7         $(FT)
                                        X = 1                   Y = 0   ..
                                WIN5 = WINDOW
                                  GLASS-TYPE = GLASS1
                                        CONDUCT-SCHEDULE =CD-SCHED
                                        WIDTH = 2.75  HEIGHT = 4
                                        X = 16  Y = 16 ..
                                WIN6 = WINDOW
                                        GLASS-TYPE = GLASS1
                                        CONDUCT-SCHEDULE =CD-SCHED
                                        WIDTH = 8         HEIGHT = 1.5
                                        X = 0 Y=16  ..
                                WIN11 = WINDOW
                                    GLASS-TYPE = GLASS1
                                          CONDUCT-SCHEDULE =CD-SCHED
                                                WIDTH = 2.75   HEIGHT = 4
                                                X = 16  Y = 23  ..
                                WIN12 = WINDOW
                                        GLASS-TYPE = GLASS1
                                        CONDUCT-SCHEDULE =CD-SCHED
                                        WIDTH = 8   HEIGHT = 1.5
```

```
                                          X = 0  Y = 26   ..

          STAIR-1-FR  =INTERIOR-WALL  NEXT-TO LEVEL-1-LIVING
                                                              HEIGHT = 30   WIDTH = 12
                X= 156  Y=20  AZIMUTH = 180  ..
          C4-SR      =INTERIOR-WALL    NEXT-TO LEVEL-4
                                      X=168   Y=20   Z=30
                                      HEIGHT=28 WIDTH=12
                                      TILT=180           AZIMUTH = 0
                                      CONSTRUCTION = CEIL_C   ..
          FLOOR-SR        =EXTERIOR-WALL       HEIGHT=28 WIDTH=10 $floor right stair
                                      X=168   Y=20   Z=0
                                      AZIMUTH = 0   TILT=180
                                      CONSTRUCTION = FOUND    ..

LEVEL-1-LIVING  =SPACE
                                 SPACE-CONDITIONS = DORM-F1-LIVING
          AREA = 6240  VOLUME = 62400
                                 Z=6              NUMBER-OF-PEOPLE = 34   ..

   RIGHT-1-B   =INTERIOR-WALL  NEXT-TO STAIRCASE
                                                              HEIGHT = 10   WIDTH = 20
                X= 156  Y=28  AZIMUTH = 90   .. $faces east
          BACK-1-B    =EXTERIOR-WALL  HEIGHT = 10   WIDTH = 144
                X= 156  Y=48  AZIMUTH = 0  ..
                                 WIN2 = WINDOW   WIDTH = 28
                                          GLASS-TYPE = GLASS1
                                            CONDUCT-SCHEDULE =CD-SCHED
                                                              HEIGHT = 4
                                                              X = 60 Y=3 ..
                     DR-1=   DOOR   WIDTH = 9        HEIGHT = 7   $mechanical "BACK"
                     X = 18              Y = 0 ..

          FRONT-1-F   =EXTERIOR-WALL  HEIGHT = 10   WIDTH = 168
                X= 0  Y=0     AZIMUTH = 180 ..
                                 WIN1 = WINDOW          GLASS-TYPE = GLASS1
                     CONDUCT-SCHEDULE =CD-SCHED
                     WIDTH = 60.5  HEIGHT = 4
                     X = 40 Y = 3  ..
          RIGHT-1-F   =EXTERIOR-WALL  HEIGHT = 10   WIDTH = 20
                X= 168  Y=0   AZIMUTH = 90   ..
          LEFT-1-F    =EXTERIOR-WALL  HEIGHT = 10   WIDTH = 20
                X= 0  Y=20    AZIMUTH = 270  ..
                                 WIN3 = WINDOW          GLASS-TYPE = GLASS1
                     CONDUCT-SCHEDULE =CD-SCHED
                     WIDTH = 8          HEIGHT = 4
                     X = 6 Y=3 ..
   FRONT-1-H   =INTERIOR-WALL  NEXT-TO LEVEL-1-HALL
               HEIGHT = 10   WIDTH = 144
                X= 10  Y=20    AZIMUTH = 180 ..
          BACK-1-H    =INTERIOR-WALL  NEXT-TO LEVEL-1-HALL
                     HEIGHT = 10   WIDTH = 144
                X= 156  Y=28  AZIMUTH = 0 ..
```

```
LEFT-1-B    =INTERIOR-WALL  NEXT-TO STAIRCASE
                  HEIGHT = 10    WIDTH = 20
                    X= 10  Y=48     AZIMUTH = 270  ..

      C1-F       =INTERIOR-WALL  NEXT-TO LEVEL-2-LIVING
                                          X=168   Y=0   Z=10  AZIMUTH = 0
                                          HEIGHT=20 WIDTH=168 TILT=180
                                          CONSTRUCTION = CEIL_C   ..
      C1-B      =INTERIOR-WALL   NEXT-TO LEVEL-2-LIVING
                                  X=156   Y=28   Z=10  AZIMUTH = 0
                                  HEIGHT=20 WIDTH=144  TILT=180
                                  CONSTRUCTION = CEIL_C   ..

      FLOORSURFACE-1-F    =EXTERIOR-WALL        HEIGHT=20 WIDTH=168
                                                  X=168   Y=0   Z=0
                                                  AZIMUTH = 0   TILT=180
                                                  CONSTRUCTION = FOUND   ..
      FLOORSURFACE-1-B    = EXTERIOR-WALL  HEIGHT=20 WIDTH=144
                                                  X=156   Y=28   Z=0
                                                  AZIMUTH = 0    TILT=180
                                                  CONSTRUCTION = FOUND   ..

LEVEL-1-HALL  =SPACE    SPACE-CONDITIONS = DORM-F1-HALL
                AREA = 1152  VOLUME = 11520
                  Z=6  NUMBER-OF-PEOPLE = 0 ..
      RIGHT-1-H   =INTERIOR-WALL    NEXT-TO LEVEL-1-LIVING
                          HEIGHT = 10   WIDTH = 8
                    X= 156  Y=20  AZIMUTH = 90   ..

      LEFT-1-H   =INTERIOR-WALL   NEXT-TO LEVEL-1-LIVING
                          HEIGHT = 10    WIDTH = 8
                    X= 10  Y=28     AZIMUTH = 270  ..

      C1-H       =INTERIOR-WALL   NEXT-TO LEVEL-2-HALL
                           X=156   Y=20   Z=10  AZIMUTH = 0
                           HEIGHT=8 WIDTH=144   TILT=180
                          CONSTRUCTION = CEIL_C   ..
      FLOORSURFACE-1-H    =  EXTERIOR-WALL  HEIGHT=8 WIDTH=144
                X=156   Y=20   Z=0
                  AZIMUTH = 0    TILT=180
                  CONSTRUCTION = FOUND   ..


LEVEL-2-LIVING  =SPACE      SPACE-CONDITIONS = DORM-F2-LIVING
                  AREA = 6240  VOLUME = 62400
                   Z=16   NUMBER-OF-PEOPLE = 48  ..
  RIGHT-2-B   =INTERIOR-WALL    NEXT-TO STAIRCASE
                          HEIGHT = 10    WIDTH = 20
                    X= 156  Y=28  AZIMUTH = 90   ..
      BACK-2-B    =EXTERIOR-WALL    HEIGHT = 10     WIDTH = 144
                     X= 156  Y=48    AZIMUTH = 0  ..
                          WIN7 = WINDOW
                          GLASS-TYPE = GLASS1
```

```
                              CONDUCT-SCHEDULE =CD-SCHED
                              WIDTH = 33   HEIGHT = 4
                                   X = 60  Y = 3 ..
          LEFT-2-B    =INTERIOR-WALL  NEXT-TO STAIRCASE
               HEIGHT = 10    WIDTH = 20
                X= 10  Y=48     AZIMUTH = 270  ..
   FRONT-2-F   =EXTERIOR-WALL  HEIGHT = 10     WIDTH = 168
                                   AZIMUTH = 180  X= 0  Y=0  ..
                                   WIN4 = WINDOW
                                   GLASS-TYPE = GLASS1
                                   CONDUCT-SCHEDULE =CD-SCHED
                                   WIDTH = 60.5   HEIGHT = 4
                                                            X = 40  Y = 3 ..
          RIGHT-2-F   =EXTERIOR-WALL  HEIGHT = 10  WIDTH = 20
                X= 168  Y=0  AZIMUTH = 90   ..
          LEFT-2-F    =EXTERIOR-WALL  HEIGHT = 10    WIDTH = 20
                X= 0  Y=20     AZIMUTH = 270  ..
          FRONT-2-H   =INTERIOR-WALL  NEXT-TO LEVEL-2-HALL
                                                       HEIGHT = 10     WIDTH = 144
                AZIMUTH = 180   X= 10  Y=20  ..
   BACK-2-H    =INTERIOR-WALL   NEXT-TO LEVEL-2-HALL
                                                       HEIGHT = 10     WIDTH = 144
                X= 156  Y=28    AZIMUTH = 0 ..
          C2-F      =INTERIOR-WALL   NEXT-TO LEVEL-3-LIVING
                                   X=168   Y=0   Z=10   AZIMUTH = 0
                                   HEIGHT=20 WIDTH=168 TILT=180
                                   CONSTRUCTION = CEIL_C   ..
   C2-B      =INTERIOR-WALL   NEXT-TO LEVEL-3-LIVING
                              X=156   Y=28   Z=10  AZIMUTH = 0
          HEIGHT=20 WIDTH=144  TILT=180
          CONSTRUCTION = CEIL_C   ..

LEVEL-2-HALL  =SPACE    SPACE-CONDITIONS = DORM-F2-HALL
            AREA = 11522  VOLUME = 115220
                                             Z=16  NUMBER-OF-PEOPLE = 0 ..
          RIGHT-2-H   =INTERIOR-WALL      NEXT-TO LEVEL-2-LIVING
                                             HEIGHT = 10  WIDTH = 8
                                             X= 156  Y=20  AZIMUTH = 90   ..

          LEFT-2-H    =INTERIOR-WALL   NEXT-TO LEVEL-2-LIVING
                                             HEIGHT = 10  WIDTH = 8
            X= 10  Y=28     AZIMUTH = 270  ..

          C2-H       =INTERIOR-WALL    NEXT-TO LEVEL-3-HALL
                                             X=156   Y=20   Z=10
                                             HEIGHT=8 WIDTH=144
                                             AZIMUTH = 0   TILT=180
                                             CONSTRUCTION = CEIL_C   ..


LEVEL-3-LIVING    =SPACE    SPACE-CONDITIONS = DORM-F3-LIVING
                AREA = 6240  VOLUME = 62400
                 Z=26    NUMBER-OF-PEOPLE = 48 ..
```

```
   RIGHT-3-B    =INTERIOR-WALL    NEXT-TO STAIRCASE
                     HEIGHT = 10   WIDTH = 20
                      X= 156  Y=28  AZIMUTH = 90   ..

          BACK-3-B    =EXTERIOR-WALL     HEIGHT = 10     WIDTH = 144
                        X= 156  Y=48    AZIMUTH = 0  ..
                                        WIN13 = WINDOW
                                               GLASS-TYPE = GLASS1
                                               CONDUCT-SCHEDULE =CD-SCHED
                                               WIDTH = 33   HEIGHT = 4
                                               X = 60  Y = 3 ..

          LEFT-3-B    =INTERIOR-WALL  NEXT-TO STAIRCASE
                              HEIGHT = 10    WIDTH = 20
                      X= 10  Y=48     AZIMUTH = 270  ..
   FRONT-3-F   =EXTERIOR-WALL    HEIGHT = 10     WIDTH = 168
                       AZIMUTH = 180   X= 0  Y=0  ..
                                        WIN10 = WINDOW
                                               GLASS-TYPE = GLASS1
                                               CONDUCT-SCHEDULE =CD-SCHED
                                               WIDTH = 60.5    HEIGHT = 4
                                               X = 40 Y = 3  ..

          RIGHT-3-F   =EXTERIOR-WALL    HEIGHT = 10  WIDTH = 20
                        X= 168  Y=0  AZIMUTH = 90   ..
          LEFT-3-F    =EXTERIOR-WALL    HEIGHT = 10    WIDTH = 20
                       X= 0  Y=20     AZIMUTH = 270  ..

          FRONT-3-H   =INTERIOR-WALL  NEXT-TO LEVEL-3-HALL
                              HEIGHT = 10     WIDTH = 144
                      AZIMUTH = 180   X= 10  Y=20  ..

          BACK-3-H    =INTERIOR-WALL  NEXT-TO LEVEL-3-HALL
                              HEIGHT = 10    WIDTH = 144
                      X= 156  Y=28   AZIMUTH = 0 ..

          C3-F       =INTERIOR-WALL   NEXT-TO LEVEL-4
                                        X=168   Y=0   Z=10
                                        HEIGHT=20 WIDTH=168
                                        TILT=180          AZIMUTH = 0
                                        CONSTRUCTION = CEIL_C   ..

          C3-B       =INTERIOR-WALL   NEXT-TO LEVEL-4
                                        X=156   Y=28   Z=10
                                        HEIGHT=20 WIDTH=144
                                        AZIMUTH = 0   TILT=180
                                        CONSTRUCTION = CEIL_C   ..

LEVEL-3-HALL  =SPACE    SPACE-CONDITIONS = DORM-F3-HALL
        AREA = 11522  VOLUME = 115220
                                 Z=26  NUMBER-OF-PEOPLE = 0 ..
```

```
        RIGHT-3-H   =INTERIOR-WALL  NEXT-TO LEVEL-3-LIVING
                    HEIGHT = 10   WIDTH = 8
                     X= 156  Y=20  AZIMUTH = 90   ..
        LEFT-3-H    =INTERIOR-WALL  NEXT-TO LEVEL-3-LIVING
                    HEIGHT = 10    WIDTH = 8
                      X= 10  Y=28     AZIMUTH = 270  ..

        C3-H        =INTERIOR-WALL    NEXT-TO LEVEL-4
                                          X=156   Y=20   Z=10
                                          HEIGHT=8 WIDTH=144
                                          TILT=180          AZIMUTH = 0
                                          CONSTRUCTION = CEIL_C   ..


LEVEL-4      =SPACE    SPACE-CONDITIONS = DORM-AT
              AREA = 8064  VOLUME = 32256
              Z = 26  NUMBER-OF-PEOPLE = 0  ..


ROOF1-POLY = POLYGON (0,0,10) (168,0,10) (168,25,18) (0,25,18) ..

        TOP-1      =ROOF    POLYGON = ROOF1-POLY
                                                  GND-REFLECTANCE=0
              CONSTRUCTION = ROOF-C   ..

ROOF2-POLY = POLYGON (0,25,18) (168,25,18) (168,48,10) (0,48,10) ..

   TOP-2      =ROOF    POLYGON = ROOF2-POLY
                                                  GND-REFLECTANCE=0
              CONSTRUCTION = ROOF-C   ..

SIDE1-POLY = POLYGON (0,0,10) (0,25,18) (0,48,10) ..

           SIDE-1  =ROOF   POLYGON = SIDE1-POLY
                                                  GND-REFLECTANCE=0
              CONSTRUCTION = S-WALL   ..

SIDE2-POLY = POLYGON (168,0,10) (168,48,10) (168,25,18) ..

                  SIDE-2  =ROOF   POLYGON = SIDE2-POLY
                                                  GND-REFLECTANCE=0
              CONSTRUCTION = S-WALL   ..

$CONDUCTION SCHEDULE (for aerogel)
CD-SCHED     =SCHEDULE           THRU DEC 31 (ALL) (1,24) (1)  ..

BLDG208 = BUILDING-SHADE   $Neighboring building, identical
HEIGHT = 48
WIDTH = 168
TRANSMITTANCE = 0.0
X = -35
Y = 83 z = 0
AZIMUTH = 180.0
```

```
TILT = 90.0 ..

END  ..
COMPUTE  LOADS   ..

INPUT SYSTEMS   ..

SYSTEMS-REPORT  SUMMARY=(ALL-SUMMARY)  ..
                    $ SYSTEM DESCRIPTION
                    $         "In 1999 the York Shipley oil-fired glycol boiler
                    $         was replaced with three 330,000 Btu/hr input, oil-fired,
                    $         cast iron, Hydrotherm glycol boilers. The boilers are controlled
                    $         in a staged manner so that only the number of boilers required
                    $         will activate. ... The system is configured to a primary-secondary
                    $         heating system with the distribution piping in a reverse return
                    $         configuration. The PRIMARY loop includes the boiler and a loop
                    $         to the heat exchanger for the potable hot water. The temperature
                    $         set point for the primary loop is 180F. The SECONDARY loop provides
                    $         heat to the baseboard radiators on six different zones and to
                    $         the two air handling units on one zone. The temperature
                    $         set point for the secondary zone varies with the outdoor temperature.
                    $         The range is approximately 100F to 180F. Heat is supplied from the
                    $         primary loop to the secondary loop by means of a diverting valve."

$ SYSTEMS SCHEDULES

FAN-1     =DAY-SCHEDULE   (1,24)(1)  ..
FAN-2     =DAY-SCHEDULE   (1,24) (1)   ..
FAN-SCHED  =SCHEDULE      THRU DEC 31 (MON, SAT) FAN-1
                                              (SUN, HOL) FAN-2  ..

HEAT-1    =DAY-SCHEDULE   (1,24)(65) ..
HEAT-2    =DAY-SCHEDULE   (1,24)(69)  ..
HEAT-WEEK   =WEEK-SCHEDULE   (MON,SAT)  HEAT-1  (SUN, HOL)  HEAT-2   ..
HEAT-SCHED  =SCHEDULE       THRU DEC 31   HEAT-WEEK   ..

COOLOFF    =SCHEDULE    THRU DEC 31 (ALL) (1,24) (1) .. $effectively disabled
HEATOFF    =SCHEDULE    THRU DEC 31 (ALL) (1,24) (1) .. $effectively disabled

COOL-1     =DAY-SCHEDULE    (1,24) (99)   ..
COOL-2     =DAY-SCHEDULE    (1,24) (99)   ..
COOL-WEEK   =WEEK-SCHEDULE   (MON,SAT)  COOL-1  (SUN, HOL)  COOL-2   ..
COOL-SCHED  =SCHEDULE       THRU DEC 31   COOL-WEEK   ..

LIVING-CONTROL  =ZONE-CONTROL
                                   DESIGN-HEAT-T=68  DESIGN-COOL-T=99
              HEAT-TEMP-SCH= HEAT-SCHED
              COOL-TEMP-SCH= COOL-SCHED
                      THROTTLING-RANGE = 4              $Ref.Man.2.1A sets min 4
                                                        $for VAV: stability
              THERMOSTAT-TYPE= REVERSE-ACTION
                                   BASEBOARD-CTRL=THERMOSTATIC ..
HALL-CONTROL    =ZONE-CONTROL
```

```
                              DESIGN-HEAT-T=65  DESIGN-COOL-T=99
          HEAT-TEMP-SCH= HEAT-SCHED
          COOL-TEMP-SCH= COOL-SCHED
          THROTTLING-RANGE = 4
          THERMOSTAT-TYPE= REVERSE-ACTION
                              BASEBOARD-CTRL=THERMOSTATIC ..

STAIR-CONTROL    =ZONE-CONTROL
                              DESIGN-HEAT-T=65  DESIGN-COOL-T=99
          HEAT-TEMP-SCH= HEAT-SCHED
          COOL-TEMP-SCH= COOL-SCHED
          THERMOSTAT-TYPE= REVERSE-ACTION
                              BASEBOARD-CTRL=THERMOSTATIC
                              THROTTLING-RANGE = 4 ..
ATTIC-AIR        =ZONE-CONTROL
                              DESIGN-HEAT-T=55  DESIGN-COOL-T=99 ..
          $HEAT-TEMP-SCH= HEAT-SCHED
          $COOL-TEMP-SCH= COOL-SCHED
          $THERMOSTAT-TYPE= REVERSE-ACTION ..
LEVEL-1-LIVING  =ZONE   $ZONE-AIR=ZAIR-LIVING
                              SIZING-OPTION=ADJUST-LOADS
            ZONE-TYPE=CONDITIONED
                               ZONE-CONTROL=LIVING-CONTROL
                               BASEBOARD-RATING =-350000
                               OUTSIDE-AIR-CFM = 510 .. $17 rooms @ 30 cfm
LEVEL-2-LIVING  =ZONE   LIKE LEVEL-1-LIVING
                              OUTSIDE-AIR-CFM = 720 .. $ 24 rooms @ 30 cfm
LEVEL-3-LIVING  =ZONE   LIKE LEVEL-1-LIVING   ..

LEVEL-1-HALL    =ZONE   $ZONE-AIR=ZAIR-HALL
                                  SIZING-OPTION=ADJUST-LOADS
            ZONE-TYPE=CONDITIONED
                              ZONE-CONTROL=HALL-CONTROL
                              BASEBOARD-RATING= -350000
                              OUTSIDE-AIR-CFM = 58 .. $ 1152 ft @ 0.5 cfm/ft2
LEVEL-2-HALL    =ZONE   LIKE LEVEL-1-HALL   ..
LEVEL-3-HALL    =ZONE   LIKE LEVEL-1-HALL   ..

LEVEL-4         =ZONE   $ZONE-AIR=ZAIR-ATTIC
                              SIZING-OPTION=ADJUST-LOADS
            ZONE-CONTROL=ATTIC-AIR
                              ZONE-TYPE = UNCONDITIONED ..

STAIRCASE  =ZONE              $ZONE-AIR=ZAIR-STAIR
                              SIZING-OPTION=ADJUST-LOADS
            ZONE-TYPE=CONDITIONED
                              ZONE-CONTROL=STAIR-CONTROL
                              BASEBOARD-RATING = -250000
                              OUTSIDE-AIR-CFM = 34 ..        $672 ft2 @ 0.6 cfm/ft2


S-CONT  =SYSTEM-CONTROL COOLING-SCHEDULE= COOLOFF
                                  HEATING-SCHEDULE= HEATOFF
```

```
                HEAT-SET-T=65              $CHECK THIS LATER
                $COOL-CONTROL=RESET
                $COOL-RESET-SCH=RESET-SCHED
                HEAT-CONTROL=CONSTANT
                                             $HEAT-RESET-SCH=RESET-SCHED
                                                    $MIN-HUMIDITY=
                                        MIN-SUPPLY-T=60 ..

S-FAN-L   =SYSTEM-FANS   FAN-SCHEDULE=FAN-SCHED
                                      FAN-CONTROL=CONSTANT-VOLUME
           SUPPLY-STATIC=2.0  SUPPLY-EFF=0.55 ..

S-FAN-A = SYSTEM-FANS   FAN-SCHEDULE=FAN-SCHED
                                      FAN-CONTROL=SPEED  $Variable speed motor
           SUPPLY-STATIC=5.5  SUPPLY-EFF=0.55  $see samp2e
                                      RETURN-STATIC=2.0  RETURN-EFF=0.53 ..

S-TERM  =SYSTEM-TERMINAL $REHEAT-DELTA-T=60
           MIN-CFM-RATIO=0.10 ..  $MIN CFM 10%
$                                            Min. allowable air supply flow rate,
$                                            expressed as decimal frac. of design flow rate.
$                                            For VAV systems, the supply air flow rate is set at
$                                            a constant volume when in heating mode (usually
$                                            this equals the MIN-CFM-RATIO.

SYST-1  =SYSTEM    SYSTEM-TYPE=VAVS
           SYSTEM-CONTROL= S-CONT
                                      SYSTEM-FANS= S-FAN-A
           SYSTEM-TERMINAL= S-TERM
           $ECONO-LIMIT-T=65
           PREHEAT-T = 55
                                      HEAT-SOURCE = HOT-WATER
                                      ZONE-HEAT-SOURCE = HOT-WATER
                                      PREHEAT-SOURCE = HOT-WATER
                                      BASEBOARD-SOURCE=HOT-WATER
                                      RETURN-AIR-PATH=DIRECT
           ZONE-NAMES=(LEVEL-1-LIVING, LEVEL-1-HALL,
                                        LEVEL-2-LIVING, LEVEL-2-HALL, LEVEL-3-LIVING,
                                             LEVEL-3-HALL, LEVEL-4, STAIRCASE)   ..

SYST-1-AIR = SYSTEM-AIR
$        SUPPLY-CFM= 6000  this is usually omitted (p. 248)
$        MIN-OUTSIDE-AIR = 0.63  constant flow rate of fresh air, expressed
                                $as decimal fraction of max air supply flow rate.
                                $1123/1773 see SAMPS
$        RETURN-CFM = no data --> program assumes
                                $RA flow = (supply-airflow - zone-exhaust)
         OA-CONTROL = FIXED  .. $Outside air flow rate is controlled at a fixed
                                $user-specified volume
$        MAX-OA-FRACTION = 0.7 ..  upper limit on OA quantity allowed when temp-
                         $controlled economizer is operating.  Use
                          $only
```

```
                              $when outside dampers do not allow
                               $100% OA.

END   ..
COMPUTE SYSTEMS   ..

INPUT PLANT   ..
$ PLANT1 = PLANT-ASSIGNMENT  ..
 PLANT-REPORT  SUMMARY=(ALL-SUMMARY)  ..

$ EQUIPMENT DESCRIPTION
$ HOT-WATER MODULAR BOILER

SBOIL1  = PLANT-EQUIPMENT              $mod. boiler for 209
      TYPE = HW-BOILER
      SIZE= -999
                    FUEL-METER = M2
      MAX-NUMBER-AVAIL = 3
                    INSTALLED-NUMBER = 3  ..

$CHIL1   =PLANT-EQUIPMENT
                              $TYPE=HERM-REC-CHLR  SIZE=-999  ..

$DHW   = PLANT-EQUIPMENT
$                   TYPE =DHW-HEATER
$                   SIZE = -999
$                   FUEL-METER = M2 ..

PLANT-PARAMETERS
          HERM-REC-COND-TYPE=AIR
          BOILER-CONTROL = STANDBY
          HW-BOILER-HIR = 1.33  ..  $ratio of fuel input(Btu)
                                                $to heat energy output @ full load.
                                                $Range: 0+ - 3.0
                                                $1/1.33 = 75% efficiency


$PLANT-COSTS     PROJECT-LIFE=25  DISCOUNT-RATE=5 ..
ENERGY-RESOURCE  RESOURCE ELECTRICITY
                                    FUEL-METERS = (M1)  ..
ENERGY-RESOURCE  RESOURCE = OTHER-FUEL
                                    OTHER-FUEL-NAME = JP-5
                                    SOURCE-SITE-EFF = 1.0
                                    ENERGY/UNIT = 125270    $NAVY:  125,270 Btu/gal
                                    UNIT-NAME = GAL
                                    DEM-UNIT-NAME = GAL/HR
                                    FUEL-METERS = (M2)  ..

END  ..
COMPUTE PLANT   ..

STOP ..
```