A COMPREHENSIVE EVALUATION OF THE IMPACT OF CONTINUOUS COMMISSIONING®

A Dissertation

by

ALAINA JONES RUFFIN

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Chair of Committee,	David Claridge
Committee Members,	Juan-Carlos Baltazar
	Charles Culp
	Michael Pate
Head of Department,	Andreas Polycarpou

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ABSTRACT

The primary goal of this study was to quantify the impact of Continuous Commissioning®[1] (CC®) since the inception of the process in the early 1990s using a comprehensive evaluation of the impact of CC® projects implemented primarily by the Texas A&M Engineering Experiment Station's Energy Systems Laboratory. Several quantitative analysis and comparison tasks were completed to accomplish the research objectives. The overall impact of Continuous Commissioning was analyzed including the energy cost savings as well as identification of non-energy impacts. The evaluation of the impact of CC by building type included education buildings, health care facilities, laboratory facilities, and office buildings. ASHRAE Standard 169-2006 was employed for the analysis of the impact of CC by climate zone. The project objectives were compared to the project results using the predicted and actual energy cost savings. The CC energy cost savings were compared based on the level of project completeness as determined by the proposed and implemented CC measures. The impact of CC was presented for several case study projects.

The 340 CC projects that were compiled and reviewed include 920 buildings (895 buildings with available information represent over 98 million ft^2 of building area). The impact of CC according to four building types considered 159 CC projects: 76 educational, 46 healthcare, 13 laboratory, and 24 offices with average annual savings of

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[1] The terms Continuous Commissioning® and CC® are registered trademarks of the Energy Systems Laboratory, Texas A&M Engineering Experiment Station, Texas A&M University System.

$0.48/ft^2, $0.64/ft^2, $1.51/ft^2, and $0.49/ft^2, respectively. The impact of 196 CC projects grouped by climate zone designations revealed that the majority of the total annual cost savings, about 90%, is from three zones. The average annual energy cost savings was $0.68/ft^2 for climate zone 2a hot and humid, $0.55/ft^2 for climate zone 3a warm and humid, and $0.58/ft^2 for climate zone 4a mixed and humid.

Comfort issues, including thermal comfort, indoor air quality, and noise, were identified in 59 CC projects with resolutions for at least 34 projects. The annual energy cost savings, as of December 2016, exceeded $29.7 million (2017 $), for 198 CC projects (over 600 buildings with more than 60 million ft^2 of area). The cumulative cost savings up to December 2017 are $390 million (2017 $).

DEDICATION

I would like to dedicate this work to my husband and my parents for their unconditional love, unending patience, and unwavering support.

ACKNOWLEDGEMENTS

I would like to extend my deepest appreciation to my committee chair, Dr. Claridge, for his encouragement, direction, and support throughout the course of this research. I would also like to extend my gratitude to my committee members, Dr. Baltazar, Dr. Culp, and Dr. Pate for their invaluable contributions.

Many thanks to my friends and colleagues at the Energy Systems Laboratory. I appreciate everyone with whom I have had the pleasure to work. I would also like to thank my friends and colleagues throughout Texas A&M University who have offered helpful advice, practical suggestions, accountability, or simply a listening ear.

I am forever indebted to my parents who have made it possible for me to pursue my dreams and who first believed in me. Most importantly, I wish to thank my loving, patient, and compassionate husband, Jamal, who is my source of unparalleled inspiration.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Professors David Claridge [advisor] and Michael Pate of the Department of Mechanical Engineering and Professors Juan-Carlos Baltazar and Charles Culp of the Department of Architecture.

All work for the dissertation was completed by the student, under the advisement of Dr. Claridge of the Department of Mechanical Engineering.

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CHAPTER I

INTRODUCTION

1.1 Background

The total United States energy use has increased from 31.98 quadrillion Btu (Quads) in 1949 to 97.74 Quads in 2017, according to the U.S. Energy Information Administration (EIA, 2018). The commercial building sector consumed 18% of the total U.S. energy use in 2017, based on the April 2018 EIA Monthly Energy Review. (EIA, 2018) From 1979 to 2012, the U.S. commercial building stock has increased by 1.8 million buildings and 36 billion square feet. (EIA, 2016) With the growing commercial building stock, there are numerous opportunities to reduce the energy consumption.

The building industry has made significant technological advances improving building comfort and decreasing building energy consumption since the energy crisis of the early 1970s. In the midst of the improvements in technology, building commissioning became the preferred method of ensuring that building systems were installed and operated to provide the performance envisioned by the designer. (Liu, et al., 2003) The building commissioning industry has been growing and thriving for the past few decades. ASHRAE (formerly the American Society of Heating Refrigerating and Air-Conditioning Engineers) has developed several guidelines and standards related to building commissioning. According to ASHRAE Standard 202-2013, commissioning is a quality focused process to enhance the delivery of a project in new construction and to attain the current facility requirements of existing facilities. Continuous

Commissioning®[2] (CC®) is a form of existing building commissioning that was developed by the Texas A&M Engineering Experiment Station's[3] Energy Systems Laboratory in the early 1990s. Continuous Commissioning® is an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities. (Liu, et al., 2002) The Continuous Commissioning process follows the basic steps outlined in ASHRAE Guideline 1.2-2019 Technical Requirements for the Commissioning Process for Existing HVAC&R Systems and Assemblies. The impact of individual CC projects is documented and there have been several studies detailing the impact of multiple projects. However there has not been a comprehensive evaluation of all CC projects. Therefore, this research will quantify the impact of Continuous Commissioning® since the inception of the process.

1.2 Purpose and Objectives

The purpose of the study is to quantify the impact of Continuous Commissioning® since the inception of the process. The objectives of the research are:

(1) to quantify the energy savings impact of CC®,

(2) to identify the non-energy impacts of CC®,

(3) to determine and compare the achieved results with defined project objectives.

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[2] The terms Continuous Commissioning® and CC® are registered trademarks of the Energy Systems Laboratory, Texas A&M Engineering Experiment Station, Texas A&M University System. To enhance readability, these marks will not be used in some sections of this dissertation.
[3] At the time the Texas A&M Engineering Experiment Station was known as the Texas Engineering Experiment Station, however the TEES acronym has not changed.

1.3 Significance and Limitations

The intent of this research is to quantify the impact of Continuous Commissioning since the inception of the process. With a growing emphasis on existing building commissioning it is imperative to have a comprehensive study that specifically focuses on the value added by the CC process. The major meta-analysis prepared by Mills, et al. (2004) includes some CC projects; however the results of CC projects are combined with other existing building commissioning projects. A comprehensive evaluation of all CC projects should prove useful in many ways including justification of future projects and training for CC professionals, technicians, and others involved including CC licensees.

There are some limitations associated with this study. The compilation of CC projects is limited to the information available electronically or in print as of December 2016. Non-energy impacts are not always included in the project documentation. In comparing the impact of CC by building type, only education buildings, medical facilities, laboratory facilities, and office buildings are evaluated.

CHAPTER II

LITERATURE REVIEW

The literature reviewed for the development of this study covered three main categories. First, the history of building commissioning is addressed. The next section covers types of building commissioning and respective definitions. Lastly, the scope and impact of Continuous Commissioning® is addressed.

2.1 History of Building Commissioning

The building industry did not develop the practice of commissioning but rather borrowed the term from the process a new naval ship underwent to ensure it was ready for service. Keeping with naval practices, building commissioning began as a process for new construction. In 1977, Public Works Canada (now Public Works and Government Services Canada [PWGSC]) established a Building Commissioning Section and is considered the first organization to start using building commissioning. (National Commissioning Committee, 2006; Fischer & Hawkins, 2012; Akin, et al., 2004) Although aware of the need for building commissioning there was a shortage of practical experience and apparent opposition to change within the design community. In 1981, Disney became one of the first corporations to include commissioning in the design, construction, and start-up of the Epcot theme park. (Akin, et al., 2004)

In 1984 ASHRAE (known at the time as the American Society of Heating Refrigerating and Air-Conditioning Engineers) formed a Commissioning Guideline

Committee. According to Akin, et al. (2004), “The task of the committee was to define a process which guarantees that fully functioning buildings were turned over to the building owners. The motivation for the ASHRAE Commissioning Committee was the growing number of complaints about unmanageable HVAC systems, increasing operation expenses, decreasing comfort levels, and uneducated operations and maintenance staff who did not understand how to maintain or operate new buildings.” Five years later the original ASHRAE commissioning guideline was published. The same year (1989), the Bonneville Power Administration (BPA) published a commissioning guideline prepared by Portland Energy Conservation, Inc. (PECI). (Fischer & Hawkins, 2012)

In the mid to late 1980s, universities were getting involved with building commissioning. The University of Wisconsin, Madison offered a commissioning course and the University of Michigan established a facilities evaluation and commissioning group. (Akin, et al., 2004) State and local government was getting more involved with commissioning in the late 1980s. In 1989, Maryland’s Montgomery County began a commissioning program. (Fischer & Hawkins, 2012)

Several activities were transpiring within the building commissioning industry in the 1990s. In the early 1990s, electric utilities began to require commissioning on the installation of energy efficient equipment. In 1992, the Texas A&M Engineering Experiment Station’s Energy Systems Laboratory (ESL) at Texas A&M University began commissioning of existing buildings as part of the Texas LoanSTAR program and by 1995 began the Continuous Commissioning® of the buildings at Texas A&M

University. In 1993, the University of Washington began requiring commissioning and developing commissioning specifications. In 1994, Sacramento Municipal Utility District (SMUD) was one of the first to offer incentives to owners who developed commissioning plans. The state of Washington in 1995 and Tennessee a year later were some of the first states to require commissioning of state buildings. (Fischer & Hawkins, 2012)

Building commissioning was on the rise in the 1990s with many organizations starting commissioning practices, issuing regulations, and publishing guidelines and standards. BPA published the second edition of its building commissioning guidelines in 1992. The first National Conference on Building Commissioning (NCBC) was held in 1993. Also in 1993, The National Environmental Balancing Bureau (NEBB) published Procedural Standards for Building Systems Commissioning. NEBB, established in 1971, is an internal certification association. In 1994 President Clinton issued Executive Order 12902 regarding energy efficiency and water conservation at Federal facilities requiring commissioning programs for Federal buildings. That same year the Army Corps of Engineers developed HVAC commissioning procedures. Public Works Canada also published a project commissioning manual. The following year the United States General Services Administration published a building commissioning guide and initiated their commissioning program. Also in 1995, the Energy Star Building Partnership Program began to include commissioning. (Fischer & Hawkins, 2012) In 1996 an updated version of the ASHRAE commissioning guideline (Guideline 1-1996) was published detailing the HVAC commissioning process that would ensure HVAC systems performed according to the design intent. The guideline included commissioning procedures for the program (pre-design), design, construction, acceptance and post-acceptance phases of new construction as well as a commissioning program for existing buildings. The International Measurement and Verification Protocols began to recommend commissioning in all projects starting in 1996. The following year, the Model Commissioning Plan and Guide Specifications was published and had been developed by PECI and US DOE (FEMP). Commissioning was added to the US Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) criteria in 1998. Concurrently, MasterSpec began to integrate commissioning into specifications. Also in 1998, Seattle began to incorporate commissioning for HVAC and lighting controls into the city's energy code. (Fischer & Hawkins, 2012) In 1999 there seemed to be an increased interest in existing building commissioning. Portland Energy Conservation, Inc. and Oak Ridge National Laboratory prepared a practical guide for commissioning existing buildings for the U.S. Department of Energy (DOE). SMUD began to offer an existing building commissioning program. Commonwealth Edison Company (ComEd) launched the Maintenance Operations and Repairs Program which included existing building commissioning. ComEd also began to offer commissioning as one of its advisory services. The Association of State Energy Research and Technology Transfer Institutions offered commissioning training curriculum which was used in seven state workshops. Tennessee began a New Construction Commissioning Initiative. The Building Commissioning Association (BCA) had been considered at early NCBC meetings and was finally established. (Fischer & Hawkins, 2012) Some highlighted events from the 1990s are shown in Figure 1.

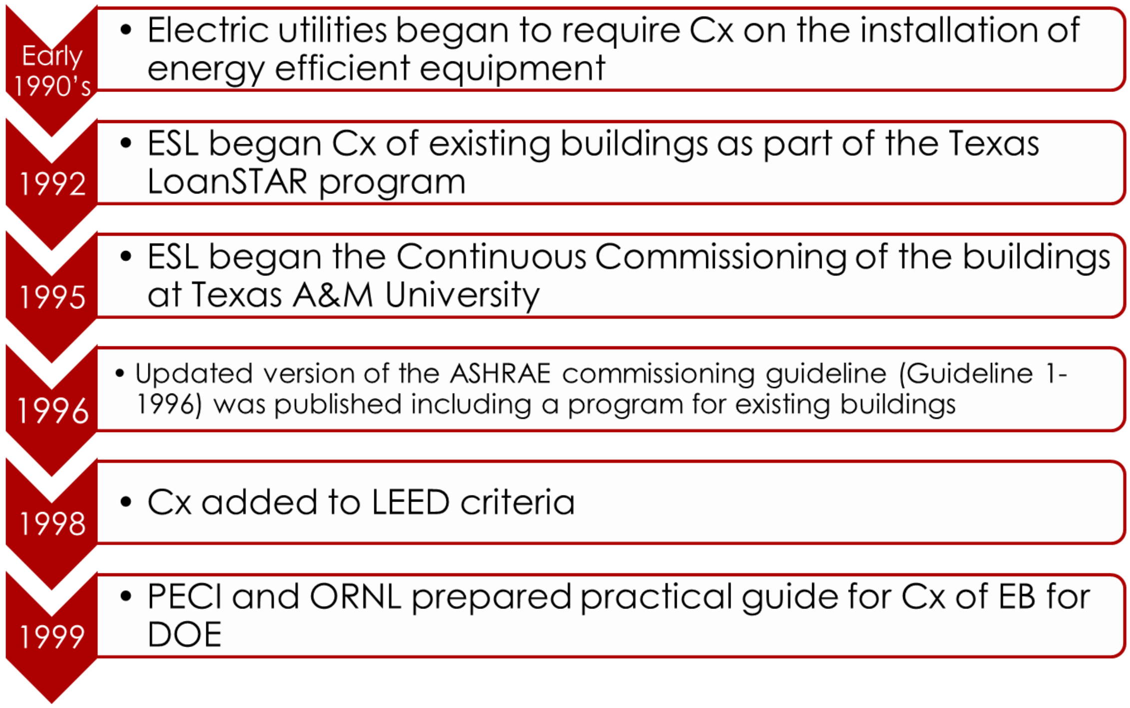

Figure 1. Highlighted building commissioning industry events from the 1990s

More states were getting involved beginning in the early 2000s from the west coast with the formation of the California Commissioning Collaborative (CCC) to the east coast with the New York State Energy Research and Development Authority (NYSERDA) implementing commissioning in their programs. Hawaii and Massachusetts added some commissioning components to the state building codes. More utility companies like Pacific Gas and Electric (PG&E), San Diego Gas and Electric, and Xcel Energy were beginning to include commissioning in their offered services.

Building commissioning research activities continued. The Air-Conditioning and Refrigeration Technology Institute (ARTI) began to research the automation of commissioning. The California Energy Commission examined the persistence of commissioning measures through the Public Interest Energy Research (PIER) Electric program. Several online compilations of resources were made available. Energy Design Resources (EDR) published online energy design tools and resources. EDR is administered by a conglomerate of utility companies and is funded by California utility customers. The CCC developed an online library including commissioning related research, articles, brochures and white papers. PG&E published a commissioning test protocol library. More commissioning guidelines were published by various entities including NYSERDA and AABC (Associated Air Balance Council). The International Society for Pharmaceutical Engineering (ISPE) published ISPE Baseline Guide, Volume 5: Commissioning and Qualification in 2001. (Fischer & Hawkins, 2012) The Continuous Commissioning Guidebook for Federal Energy Managers was published in 2002 by the FEMP US DOE prepared by the Energy Systems Laboratories of the Texas A&M University System and the University of Nebraska. In 2004, USGBC introduced LEED-EB for existing buildings which was later restructured to LEED-EBOM for existing building operation and maintenance in 2008. Also in 2004, The University of California, California State University, and Investor Owned Utility (UC/CSU/IOU) Partnership launched a Monitoring Based Commissioning (MBCx) Program. NECA 90-2004 Recommended Practice for Commissioning Building Electrical Systems was published in 2004 by the National Electrical Contractors Association (NECA) developed with Enviro-Management & Research, Inc. In 2005, the BCA and the University of Wisconsin formed a training partnership offering courses through the College of Engineering Department of Engineering Professional Development. (Fischer & Hawkins, 2012)

As the building commissioning industry continued to progress, ASHRAE remained in the forefront of developing and publishing guidelines and standards. ASHRAE in conjunction with the National Institute of Building Sciences (NIBS) published The Commissioning Process (Guideline 0-2005) in 2005 which differs from Guideline 1-1996 in that it focuses on the Owner's Project Requirements instead of the Design Intent Document and the whole building rather than just HVAC systems. Guideline 1-1996 was superseded by ASHRAE Guideline 1.1-2007: HVAC&R Technical Requirements for the Commissioning Process which was published in 2007. In 2013, ANSI/ASHRAE/IES published Standard 202-2013: Commissioning Process for Buildings and Systems in order to identify the minimum acceptable process derived from Guideline 0-2005. To complement the ASHRAE Guideline 0-2005, the NIBS Total Building Commissioning Guideline series intends to publish discipline specific guidelines prepared by the appropriate professional societies. (Grondzik, 2009) In 2006, the first guideline of the series, NIBS Guideline 3, was published which covered the commissioning of building enclosures. In 2011, The Commissioning Process Applied to Lighting and Control Systems (IES DG-29-11), developed by the Illuminating Engineering Society in association with the Lighting Controls Association, was published. ASHRAE Guideline 0.2-2015: Commissioning Process for Existing Systems and Assemblies was published in 2015. ASHRAE recently released Guideline 1.2-2019 Technical Requirements for the Commissioning Process for Existing HVAC&R Systems and Assemblies and is developing Guideline 1.3 Building Operation and Maintenance Training for the HVAC&R Commissioning Process.

Fischer and Hawkins presented the history of commissioning at the 2012 National Conference of Building Commissioning including NCBC highlights as well as BCA development. The NCBC highlights shed light on some of the building commissioning industry discussions and development through the years. At the first NCBC in 1993, the attendees were focused on defining commissioning and understanding the stakeholders of the process. During the next year's conference the discussion addressed the utility concerns with the performance of funded energy efficiency measures. The whole building approach to commissioning was also discussed. At the third conference in 1995, the barriers to making commissioning a more common practice were identified. The "Great Debate Session" at the 1996 conference regarded certification programs for the Commissioning Authority, the leader of the building commissioning team. The DOE/FEMP National Strategy for Building Commissioning was presented at the sixth NCBC. Commissioning and benchmarking was also discussed during that conference. The topics of the eighth NCBC in 2000 included commissioning guidelines and standards, utility programs, diagnostic tools, training for Commissioning Authorities and building operators, and commissioning for green buildings. Commissioning in mission critical buildings was discussed at the next NCBC. At the 10th NCBC in 2002 there were discussions about LEED commissioning and emerging tools for building commissioning. The attendees at the next conference had the opportunity to participate in an on-site existing building commissioning demonstration. At the 14th NCBC in 2006, there were technical sessions on the use of DDC systems as commissioning tools, the use of data loggers, underfloor air distribution, and commissioning lighting systems. Some of the discussion at the NCBC in 2009 included metering and performance metrics and Smart Grid use in conjunction with commissioning. (Fischer & Hawkins, 2012)

2.2 Types of Building Commissioning

Building commissioning can occur during any phase of a building's life and can be applied to most building systems. The types of systems that can be commissioned include mechanical systems (e.g. HVAC, chilled water, hot water, steam, piping, and plumbing), electrical systems (e.g. generators, switchgear, transformers, grounding, lighting, photovoltaic, and electric metering), fire and life safety systems such as fire alarms, integrated systems for instance building automation or direct digital controls, specialty systems, and building envelope (e.g. windows, walls, doors, and roof construction). Some examples of specialty systems are security systems, voice/data systems, wastewater treatment, renewable energy, transport systems, automated manufacturing, and combined heat and power (CHP).

The following definitions are from ASHRAE Standard 202-2013:

“The Commissioning Process is a quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements.”

“The Existing Building Commissioning Process is a quality-focused process for attaining the Current Facility Requirements of an existing facility and its systems and assemblies being commissioned. The process focuses on planning, investigating, implementing, verifying, and documenting that the facility and/or its systems and assemblies are operated and maintained to meet the Current Facility Requirements, with a program to maintain the enhancements for the remaining life of the facility.” Standard 202-2013 further defines two forms of existing building commissioning: Re-Commissioning applies to a previously commissioned building and Retro-Commissioning applies to an existing facility that was not previously commissioned.

“The On-Going Commissioning Process is a continuation of the Commissioning Process well into Occupancy and Operations to continually improve the operation and performance of a facility to meet current and evolving Current Facility Requirements or Owner’s Project Requirements. On-Going Commissioning Process activities occur throughout the life of the facility; some of these will be close to continuous in implementation, and others will be either scheduled or un-scheduled as needed.”

There are other forms of existing building commissioning that are not specifically defined in ASHRAE Standard 202-2013 including Monitoring-Based Commissioning and Continuous Commissioning.

“Monitoring-Based Commissioning (MBCx) employs remote energy system metering with trend log capability to identify previously unrecognized inefficiencies in energy system operations, facilitate the application of diagnostic protocols, document energy savings from operational improvements, and ensure persistence of savings through ongoing recommissioning.” (Brown & Anderson, 2006)

The focus of this research is the Continuous Commissioning process which is a form of existing building commissioning. Continuous Commissioning is an ongoing process to resolve operating problems, improve comfort, optimize energy use, and identify retrofits for existing commercial and institutional buildings and central plant facilities. (Liu, et al., 2002)

2.3 Continuous Commissioning

There are several entities that govern and/or execute existing building commissioning. However, the Continuous Commissioning process was developed by the Texas A&M Engineering Experiment Station’s Energy Systems Laboratory. Only trained ESL engineers and technicians and trained licensees are qualified to provide CC services. The Continuous Commissioning process development began in 1992 as

Operation and Maintenance (O&M) measures were implemented in buildings following retrofits as part of the Texas LoanSTAR program. In 1998 at the National Conference on Building Commissioning the definition of Continuous Commissioning was introduced. (Turner, et. al. 1998) The process was formally documented in 1999 in the Energy Research Journal (Liu, et al. 2005). In 2002, the Continuous Commissioning^{SM} Guidebook: Maximizing Building Energy Efficiency and Comfort (here after referred to as CC guidebook) was published. At the time of the CC guidebook publishing, Continuous Commissioning was service marked and has since been trademarked.

2.3.1 Scope of Continuous Commissioning

There are two main phases of the CC process: project development and CC implementation and verification, as shown in Figure 2. During the first phase, buildings and facilities to be included in the project will be identified. A CC assessment will be performed, the project scope will be developed, and a CC contract signed. There are six steps involved in the second phase:

1. Develop the CC plan and form the CC team
2. Develop performance baselines
3. Conduct system measurements and develop CC measures
4. Implement CC measures
5. Document comfort improvements and energy savings
6. Keep the commissioning continuous

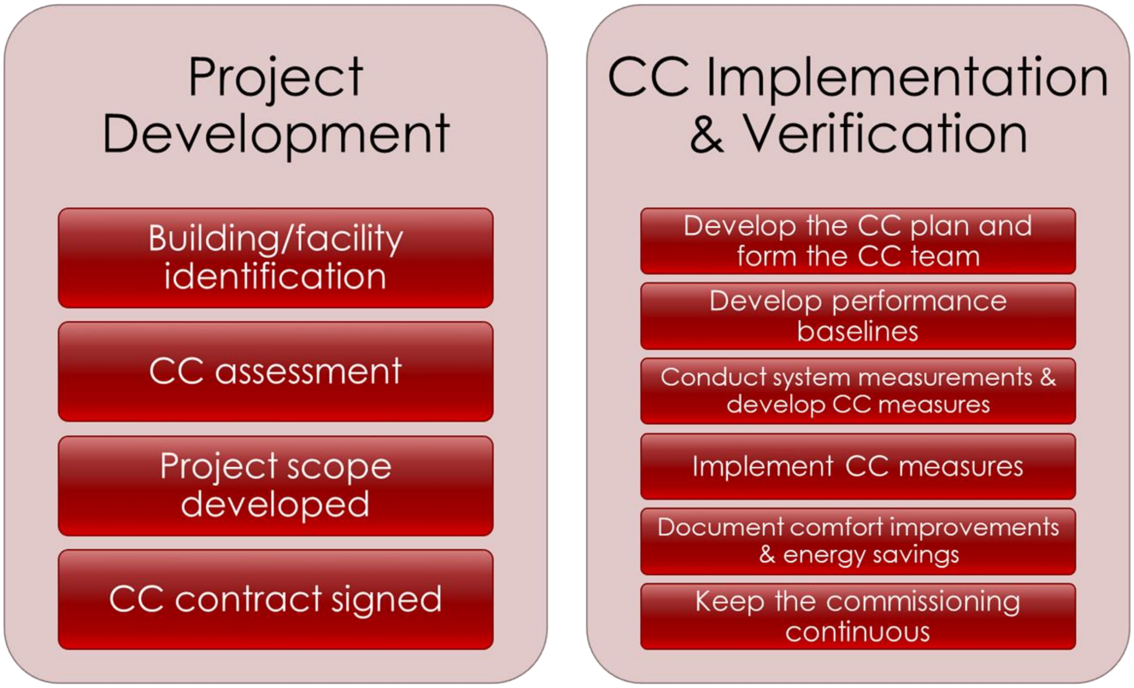

Figure 2. CC process phase 1 (project development) and phase 2 (CC implementation & verification)

The CC guidebook provides details on each phase as well as several examples that are useful in understanding the process. The ESL maintains a list of reports from the completed CC projects.

2.3.2 Impact of Continuous Commissioning

The main impacts of Continuous Commissioning are energy and cost savings, operational improvement, waste reduction and improvement in occupant comfort. Other benefits of the CC process include identifying potential energy retrofits and upgrading the technical level of in-house staff. (Liu, et al., 2003)

The energy and cost savings impact of various CC projects have been compiled in several studies. In 2003, based on the review of previous studies comprising 130 buildings, Liu, et al., concluded that the CC process resulted in an average energy reduction of over 20%. (Liu, et al., 2003) According to Wei, et al. (2006), at that time the CC process had been implemented in over 300 buildings and central plant facilities nationwide saving more than \$70 million since 1993 which represented 10-25% whole building energy cost reductions and typically simple paybacks of less than two years. A ten-year review of the CC process at Texas A&M University showed that while the campus area increased by 3 million ft^2 the energy use index decreased from 426 $kBtu/ft^2$ in 1996 to 276 $kBtu/ft^2$ in 2006. (Deng et al., 2006) In 2008, a study of the cost-effectiveness of CC over the previous ten years found an average energy cost savings of \$0.51/ft^2 for 60 buildings and sites. These savings represented an average annual energy cost savings of 14% with an average simple payback of 1.6 years. The total first year savings was \$5.284 million, where costs were normalized to 2006. (Bynum, et al., 2008) Also in 2008, a study of CC opportunities in hospitals and laboratories found an average energy cost savings of \$1.19/ft^2 (2006 \$) for 20 hospitals (48 buildings) representing an average annual energy cost savings of 26%. (Jones, et al., 2008) A more recent study of the implemented CC measures for school, hospital, and office buildings in the U.S. provided the achieved annual energy savings by building type; schools (43 buildings) \$0.25/ft^2, hospitals (68 buildings) \$0.27/ft^2, offices (4 buildings) \$0.77/ft^2, and other (11 buildings) \$0.42/ft^2. Examples of the building type "other" included a courthouse, research center, and cultural centers. The total first year savings was $2,740,563 (cost as per project year). (Oh, et al., 2014)

Non-energy savings impacts of Continuous Commissioning are not as often analyzed or documented. There are presently no large scale compilations of non-energy savings impacts of CC.

2.4 Summary of Literature Review

The literature review delved into the history of building commissioning, types of building commissioning, and the Continuous Commissioning process including the scope and impact. The history highlights the progression of the building commissioning industry including the development and refining of guidelines, protocols, procedures, and standards. The types of building commissioning and definitions help set the stage for the focus on Continuous Commissioning. The scope of CC is helpful in understanding the impact of CC. The impact of CC as highlighted by the reviewed literature has historically been focused on energy cost savings.

CHAPTER III

METHODOLOGY

This research includes a comprehensive evaluation of the impact of Continuous Commissioning projects implemented primarily by the Texas A&M Engineering Experiment Station's Energy Systems Laboratory. In order to accomplish the research objectives the following methodology was used. The first task was to compile and review all CC projects. The next few tasks included a quantitative analysis of the impact of CC overall, by building type, and by climate zone. The last couple of tasks included a comparison of project objectives to project results and a comparison of CC savings based on project completeness.

3.1 Compilation and Review of CC Projects

CC projects including those completed solely by the ESL as well as 108 completed in conjunction with CC Licensees and seven projects completed solely by CC Licensees were compiled and reviewed. The CC projects included projects with completed CC work as well as CC assessments (or audits). A CC project is defined as any building or group of buildings that underwent part of the CC process. The CC reports were used as the main source of information for each project. Other available sources of information were also used as necessary. These other sources include conference presentations and proceedings, journal papers, technical papers, as well as data analysis reports and spreadsheets. A list of the sources of information can be found in the reference section. The preliminary information recorded for each project included the project name, building/site name, year of construction, building area, location, building type, CC assessment and implementation dates, and energy cost savings. The projects with non-energy CC impacts were recorded.

3.2 Characteristics of CC Projects

A total of 340 projects were compiled and reviewed. These projects include 920 buildings of which 895 (with available area information) have a total building area of 98,027,538 ft^2. The CC projects are primarily organized according to the location or the organization (school system, college or university, airport, etc.). Colleges and universities make up the largest group of projects. University projects include those at Texas A&M University in College Station, TX, Texas A&M University in Corpus Christi, TX, Prairie View A&M University in Prairie View, TX, Texas A&M International University in Laredo, TX, The Pennsylvania State University in State College, PA, Texas Tech University in Lubbock, TX, and The University of Texas at Austin, TX. Alamo Colleges District located in the greater San Antonio, TX area and Tarrant County College District located in and around Fort Worth, TX are two community colleges with CC projects. The K-12 education level includes projects at the Independent School Districts in Austin, College Station, Conroe, and Fort Worth, TX. Other CC projects in the academic realm include academic medical sites at The University of Texas Health Science Centers in San Antonio and Houston, TX, University of Colorado Health Science Center in Denver, CO, The University of Texas

Medical Branch in Galveston, TX, The University of Texas MD Anderson Cancer Center in Houston, TX, Texas A&M University Health Science Center in Houston, TX, and the University of Minnesota Fairview Medical Center in Minneapolis, MN. Over 45 military medical facilities have been commissioned for the U.S. Army Medical Command (MEDCOM) and the Veteran Health Administration of the U.S. Department of Veteran Affairs. There have been projects at 25 IBM sites across the US as well as in the United Kingdom and Canada. On the state level two Texas sites and five Utah sites are included. The city of Austin has several city operated sites and some buildings at the Texas Capitol Complex that have been commissioned. The CC projects at Dallas/Fort Worth International Airport and the Houston Airport System (HAS) are grouped individually. The projects completed by Smith Seckman Reid, Inc. Commissioning Group (SSRCx), a CC Licensee, are grouped. There are ten projects clustered under the heading Other Facilities.

The grouping of the CC projects is as follows: Alamo Colleges District, Austin Independent School District, City of Austin, College Station Independent School District, Conroe Independent School District, Dallas/Fort Worth International Airport, Fort Worth Independent School District, Academic Medical Centers, Houston Airport System, IBM facilities, U.S. Army Medical Command (MEDCOM), The Pennsylvania State University, Smith Seckman Reid, Inc. Commissioning Group (SSRCx), State of Texas, State of Utah, Tarrant County College District, Texas A&M University System, Texas A&M University, Texas Capitol Complex, Texas Tech University, University of Texas at Austin, Veteran's Affairs Hospitals, and Other facilities. Appendix A contains summary tables of each project group including a list of buildings with the year built and building area.

3.2.1 Building Year of Construction of CC Projects

The building year of construction is known for 257 projects. The earliest known year of construction was in the 1880s and the most recent building was built in 2011. The building year of construction was averaged for projects with multiple buildings. Figure 3 shows the number of projects grouped in 10 year increments from the 3 projects with buildings built before 1915 to the 20 projects with buildings built between 2005 and 2015. The majority of projects (around 80%) had buildings constructed after 1965. Within the 10 year increments, the least amount was 2 projects with averages between 1935 and 1945 and the greatest amount was 58 projects with averages between 1965 and 1975.

Figure 3. 10 year increments of average building year of construction for 257 projects

3.2.2 Number of Buildings per Project

The number of buildings per project are grouped in ranges from 1 to 5, 6 to 10, 11 to 15, 16 to 20, and greater than 20 buildings as shown in Figure 4. The vast majority of projects (308 projects, 91%) have 1 to 5 buildings. There are 12 projects with 6 to 10 buildings, 12 projects with 11 to 15 buildings, 2 projects with 16 to 20 buildings, and 6 projects with more than 20 buildings.

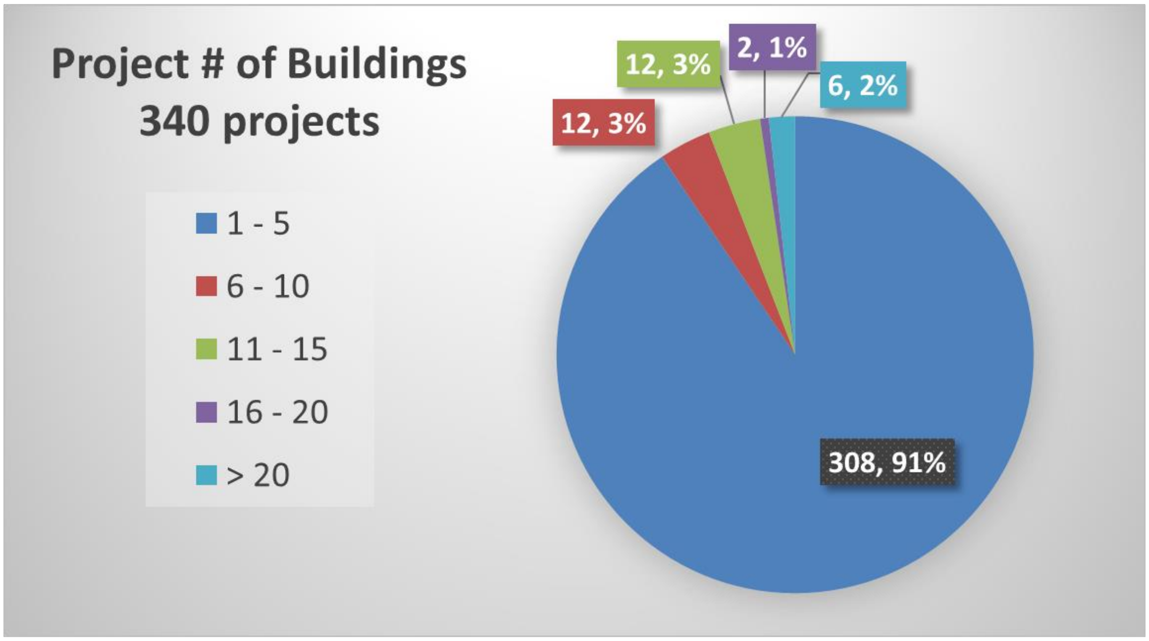

Figure 4. Ranges of number of buildings per project

3.2.3 CC Projects Building Area

The building area is known for 317 projects (98,027,538 ft²) and is gathered in the following ranges as shown in Figure 5: less than 50,000 ft² (50 projects), 50,000 to 100,000 ft² (71 projects), 100,000 to 500,000 ft² (140 projects), 500,000 to 1,000,000 ft² (37 projects), and greater than 1,000,000 ft² (19 projects).

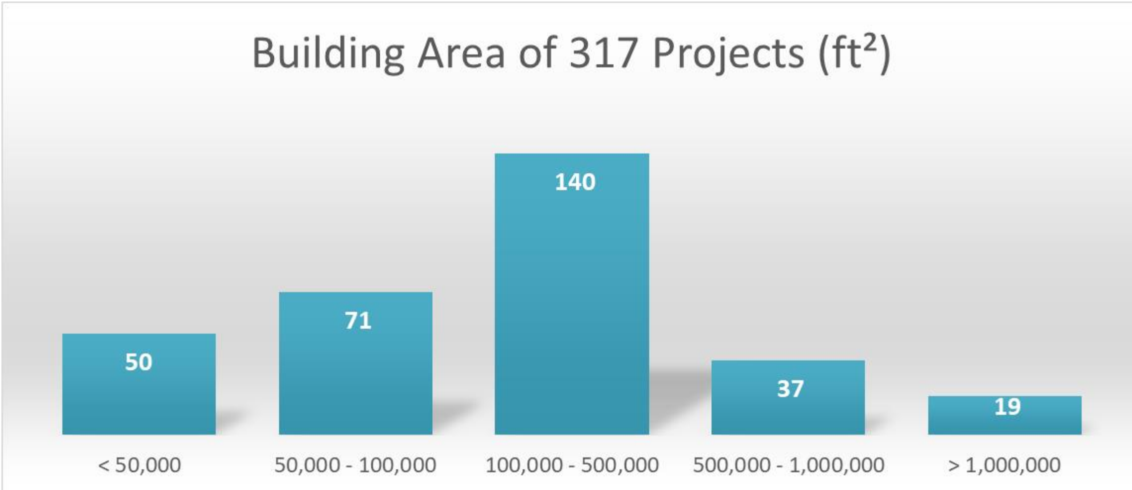

Figure 5. Building area ranges (ft^2) of 317 projects

3.2.4 Project Locations

The majority of the projects (257, 76%) are located in Texas (TX). Figure 6 presents the number of projects in different cities/towns throughout TX. There were 94 projects in College Station, 73 in Austin, 40 in the Dallas/Fort Worth area, 15 in San Antonio and less than 10 projects in the other cities/towns.

There are 73 projects located in states other than TX as displayed in Figure 7. There were five projects in Louisiana (LA), Minnesota (MN), New York (NY), and Utah (UT). There were four projects in Alabama (AL) and Georgia (GA). There were three projects in Arkansas (AR), California (CA), Colorado (CO), Kentucky (KY), Maryland (MD), Oklahoma (OK), Pennsylvania (PA), and Tennessee (TN). There were two projects in Arizona (AZ), Kansas (KS), Missouri (MO), New Mexico (NM), Virginia (VA), Mississippi (MS), and North Carolina (NC). There was one project in Alaska (AK), Hawaii (HI), Ohio (OH), Connecticut (CT), Vermont (VT), Florida (FL), South Carolina (SC), and Washington (WA).

There are ten projects located outside of the US as shown in Figure 8; two in Canada, three in Germany, one in Japan, one in South Korea, and three in the United Kingdom (UK).

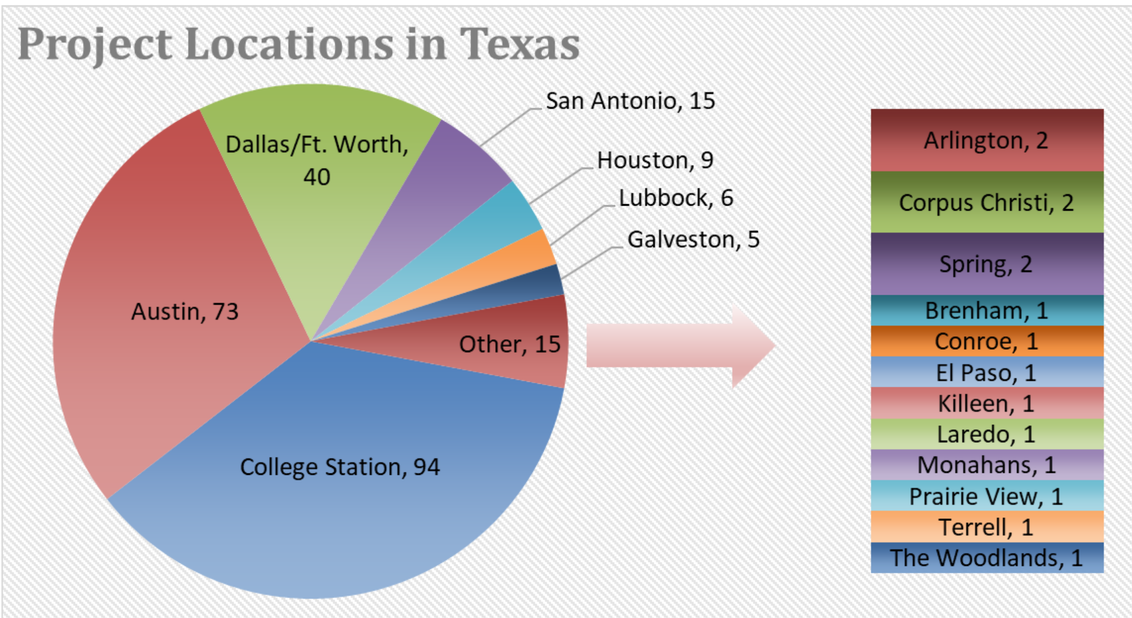

Figure 6. Project locations in the state of Texas

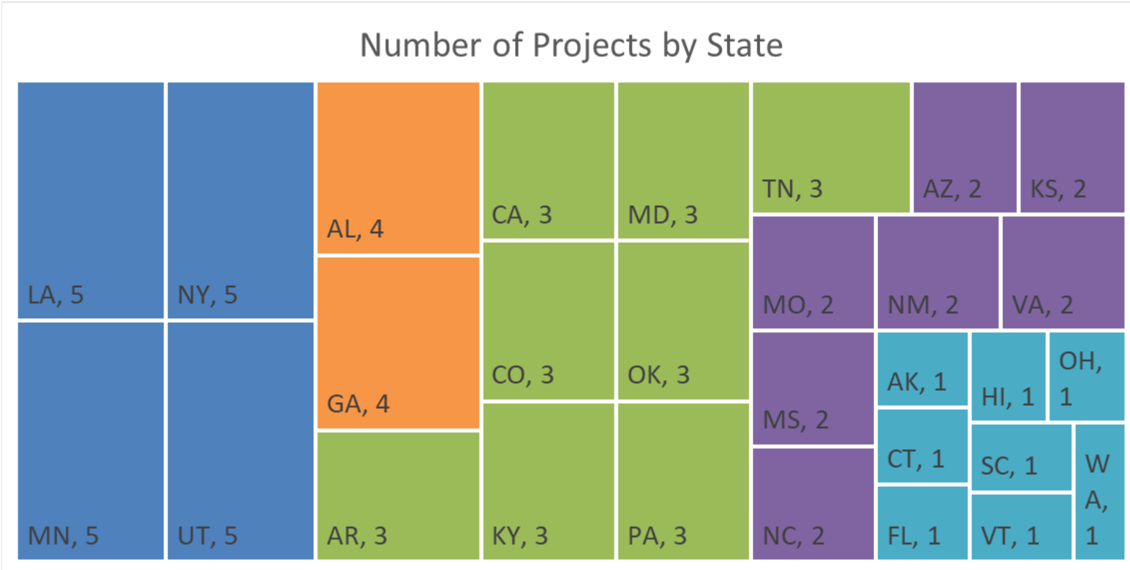

Figure 7. Number of projects by state (TX excluded)

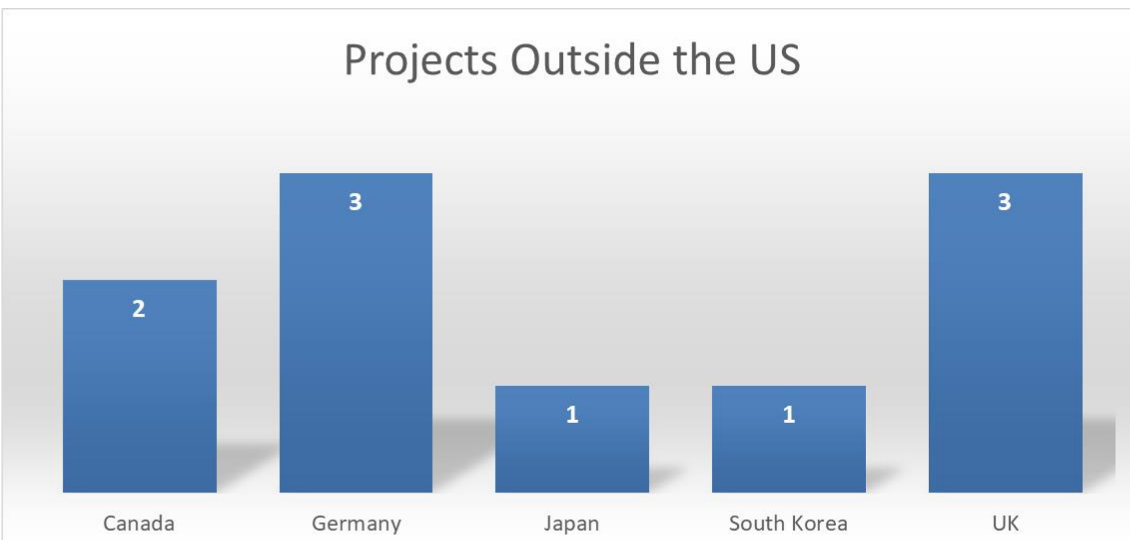

Figure 8. Projects in locations outside of the United States

3.3 Procedure

3.3.1 Impact of Continuous Commissioning

The impact of CC was determined from the reviewed CC projects. The energy and cost savings impact was quantified. The energy savings impact is presented as an overall annual energy cost savings as well as a cumulative cost savings. The costs were normalized to the year 2017. The energy cost savings that were not reported in the CC project documentation as annual savings were estimated from the reported savings or actual data. The non-energy impacts were identified and are presented as an overall number of occurrences. Specific examples of each type of non-energy impact will be discussed.

3.3.1.1 Cost Normalization Procedure

The CC energy cost savings available in the CC documentation are considered the reported cost savings. These cost values are either based on the utility rates at the time of the assessment (audit rates) or the actual monthly utility rates. The reported energy cost savings were normalized to year 2017 dollars using the U.S. Energy Information Administration (EIA) implicit price deflator. The base year for the deflators was adjusted from 2009 to 2017 by dividing the deflator value for each year by the 2017 deflator value provided in Appendix C of the EIA's August 2018 Monthly Energy Review. (EIA 2018) Table 1 shows the implicit price deflator (IPD) from 1990 to 2017. The normalized energy cost savings were obtained by multiplying the reported energy cost savings by the factor of the appropriate IPD divided by 100, as shown in the following equation.

$$Normalized\ Cost\ Savings = \ Reported\ Cost\ Savings\ x\,\frac{IPD}{100}$$

The appropriate IPD was chosen based on the year the savings occurred for annual savings and the last year the savings occurred for cumulative savings.

Table 1. Implicit Price Deflator from 1990 to 2017

Year	Implicit Price Deflator
1990	169.86
1991	164.39
1992	160.72
1993	156.99
1994	153.72
1995	150.58
1996	147.88
1997	145.39
1998	143.83
1999	141.66
2000	138.51
2001	135.42
2002	133.38
2003	130.77
2004	127.27
2005	123.30
2006	119.63
2007	116.53
2008	114.28
2009	113.42
2010	112.05
2011	109.79

Table 1. Continued

Year	Implicit Price Deflator
2012	107.80
2013	106.09
2014	104.22
2015	103.10
2016	101.80
2017	100.00

3.3.1.2 Annual Cost Savings Estimation

For projects with reported energy cost savings of less than 12 months the annual savings were estimated by using a monthly average. The average cost savings were determined from the total cost savings divided by the savings period (number of months). The following equation was used to determine the annual savings:

$$Annual\ Cost\ Savings = Reported\ Cost\ Savings + \frac{Reported\ Cost\ Savings}{n}\ x\ (12 - n)$$

Where n = number of months in savings period for reported cost savings of less than 12 months.

3.3.1.3 Cumulative Cost Savings Estimation

In order to determine the cumulative savings up to December 2017 the degradation functions developed by Toole (2010) were employed. The degradation functions were developed using a set of buildings that had heating, cooling, and electricity consumption data. It was necessary to adapt the degradation functions because the facilities encompassed in this research also include buildings with combined thermal consumption or electricity consumption only. The chilled water consumption (CHW) and heating hot water consumption (HHW) savings were added to determine a combined CHW + HHW degradation function. The original degradation functions for CHW, HHW, and electricity consumption as well as the adapted degradation function for combined CHW and HHW are presented in Table 2.

Table 2. Energy Consumption Degradation Functions

Energy Consumption	**Degradation Function**
Cooling*	$e^{-0.058x}$ (R^2=0.8847)
Heating*	$e^{-0.099x}$ (R^2=0.9527)
Cooling + Heating	$e^{-0.077x}$ (R^2=0.6359)
Electricity (non-cooling)*	$e^{-0.017x}$ (R^2=0.078)

*Expressions developed by Toole (2010).

The electricity degradation function was only used for non-cooling electricity but was not factored into the analysis of combining the savings for an all electric consuming facility or electricity and gas consuming facility. For an all electric consuming facility the combined cooling plus heating degradation function was used. For a facility which consumed electricity and gas the separate cooling and heating degradation functions were used respectively.

There are CC projects where only the cost savings have been reported. The energy consumption savings are unavailable. The percentage decrease of total cost savings for projects where the energy consumption savings have been degraded based on exponential functions was used to degrade the cost savings for projects where the energy consumption savings are unavailable. From the projects with energy consumption savings available the range of the savings percentage decrease per year was determined. Although the yearly percent difference for each energy commodity is constant, the yearly percent difference for the total cost decrease each year because the different energy commodities are degrading at different rates. The average savings percentage decrease was used to degrade the cost savings for projects where only cost savings is available.

3.3.2 Impact of CC by Building Type

The Commercial Buildings Energy Consumption Survey (CBECS) conducted by the U.S. Energy Information Administration separates commercial buildings by 16 different primary activities. CBECS defines commercial buildings as any building that uses at least 50% of the floor space for purposes other than residential, industrial, or agricultural. The 16 different primary activities are education, food sales, food service, inpatient health care, outpatient health care, lodging, mercantile – retail other than malls, mercantile – enclosed and strip malls, office, public assembly, public order and safety, religious worship, service, warehouse and storage, other, and vacant. (EIA, 2016)

In order to determine the impact of CC by building type the buildings were categorized based on primary use. The data set includes nine of the 16 CBECS building types; however the majority of the data set was represented by four different building types: educational, healthcare, laboratory, and office. The impact of CC was determined for these four building types. The educational category is further divided into K-12 schools, community colleges, and universities.

3.3.3 Impact of CC by Climate Zone

The impact of CC projects is evaluated according to the climate zones provided in ASHRAE Standard 169-2006 Weather Data for Building Design Standards. There are eight climate zones ranging from subarctic to very hot as provided in Table 3 and Figure 9. Zones one through six are further separated into two or three types: humid (A), dry (B), and marine (C).

Table 3. ASHRAE Standard 169-2006 Climate Zones

Zone #	Climate Zone (Type)
1A	Very Hot (Humid)
1B	Very Hot (Dry)
2A	Hot (Humid)
2B	Hot (Dry)
3A	Warm (Humid)
3B	Warm (Dry)
3C	Warm (Marine)
4A	Mixed (Humid)
4B	Mixed (Dry)
4C	Mixed (Marine)
5A	Cool (Humid)
5B	Cool (Dry)
5C	Cool (Marine)
6A	Cold (Humid)
6B	Cold (Dry)
7	Very Cold
8	Subarctic

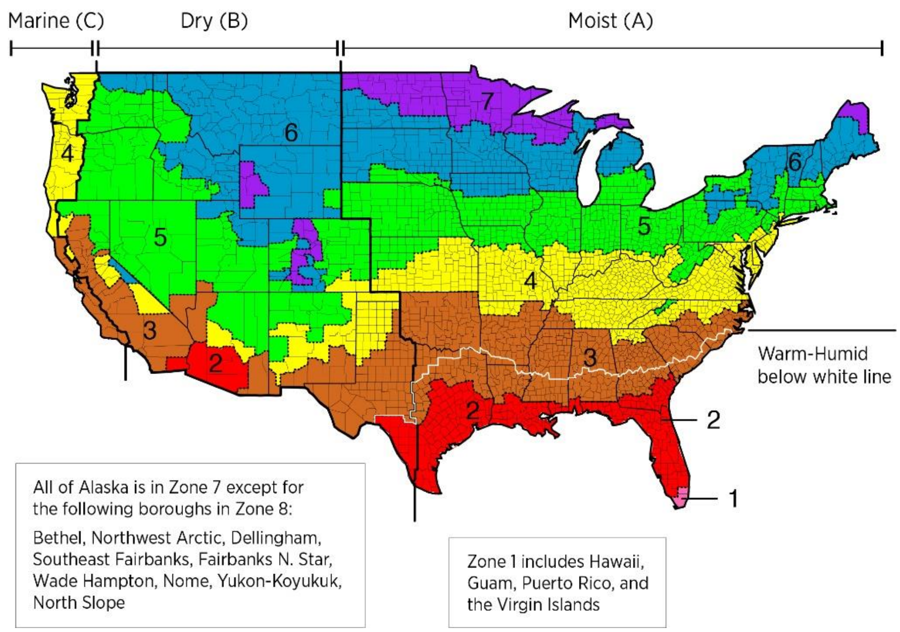

Figure 9. IECC US map with climate zones by county (ICC, 2012)

The climate zone comparison does not include projects outside of the United States. There are five U.S. Army Medical Command (MEDCOM) projects in Japan, South Korea, and Germany and two IBM projects in Canada, as shown in Table 4.

Table 4. CC Projects Not Included in Climate Comparison

#	Facility	Year Built	Area	Location
1	BG Crawford F. Sams U.S. Army Health Center	N/A	N/A	Camp Zama, Japan
2	Brian Allgood Army Community Hospital	mid 1970s	189,147	Yongsan, South Korea
3	Heidelberg Health Care Building 3613	~1935	248,256	Heidelberg, Germany
4	Landstuhl Regional Medical Center	1953	1,000,000	Landstuhl, Germany

Table 4. Continued

#	Facility	Year Built	Area	Location
5	Wiesbaden and Pulaski Barracks	1945, 1953, 2003	90,520	Wiesbaden, Kaiserslautern & Landstuhl, Germany
6	IBM Bromont & Viger	N/A	966,000	Montreal, Canada
7	IBM Toronto - 3500 Steeles	N/A	700,000	Toronto, Canada

3.3.4 CC Assessment Predictions Versus Actual Results

The CC assessment predictions were compared to the project results. The predicted energy cost savings based on CC assessments was compared to the actual energy cost savings from the completed CC project. The CC savings are compared based on the level of completeness of the CC project. The level of completeness is determined mainly based on the proposed CC measures compared to the measures that were actually implemented for those projects with CC assessment information available.

3.3.5 Case Studies

Several case studies are presented highlighting the impact of CC according to the four different building types (educational, healthcare, laboratory, and office) that represent the majority of the CC projects. Additionally, an airport facility is featured. The case studies are split up into two groups: multiple building and single building. The multiple building case studies include an airport, a community college district, and a K-12 school district. The first case study is a large airport, the Dallas/Fort Worth International (DFW) airport, located between the cities of Dallas and Fort Worth, Texas. The next case study is an education facility; the Alamo Colleges District, a community college district located in San Antonio, TX. Followed by another education facility, the Austin Independent School District, comprised of K-12 schools located in Austin, TX. The single building case studies include a hospital, a laboratory facility, and an office building. The fourth case study is the Reynolds Army Community Hospital located in Fort Sill, OK. Followed by a laboratory building, the Materials Research Institute at Pennsylvania State University, in State College, PA. The final case study is an office building, IBM Austin Building 045, located in Austin, TX.

3.4 Summary of Methodology

The research objectives of this study were accomplished by means of a comprehensive evaluation consisting of the aforementioned methodology. After a systematic review of CC projects there were several quantitative analysis and comparison tasks completed. The overall impact of Continuous Commissioning was analyzed. The impact of CC by building type (education buildings, health care facilities, laboratory facilities, and office buildings) was evaluated. The impact of CC by climate zone was evaluated using ASHRAE Standard 169-2006. The project objectives were compared to the project results. The CC energy cost savings were compared based on the level of project completeness. Lastly several case studies were presented highlighting the impact of CC.

CHAPTER IV

RESULTS

4.1 Impact of Continuous Commissioning

4.1.1 Annual Cost Savings

The Continuous Commissioning (CC) projects completed by the ESL and CC licensees have been compiled and reviewed. CC at the ESL began as O&M projects for the LoanSTAR program in the early 1990s. As of December 2016, there were 198 CC projects boasting more than $29.7 million (2017 $) in annual energy cost savings. These projects represent work at more than 600 buildings comprising at least 60 million square feet of building area. The annual cost savings are presented in 6 ranges: less than $10,000, $10,000 to $50,000, $50,000 to $100,000, $100,000 to $500,000, $500,000 to $1,000,000, and over $1,000,000. The number of projects per range are provided in Table 5. The percentage of annual cost savings per range are shown in Figure 10. The annual cost savings of 6 projects was more than $1,000,000 totaling $8.1 million (27.2% of the total annual cost savings). The annual cost savings of 7 projects was between $500,000 and $1,000,000 with a total of $4.1 million and 13.9% of the total annual cost savings. The majority (93%) of the projects had annual cost savings less than $500,000 representing total annual cost savings of over $17 million (59% of the total annual cost savings). Almost half of the total annual cost savings were produced by projects with cost savings in the range of $100,000 to $500,000.

Table 5. Ranges of Annual Cost Savings (# of projects per range)

Annual Cost Savings	# of Projects
less than $10,000	41
$10,000 to $50,000	49
$50,000 to $100,000	32
$100,000 to $500,000	63
$500,000 to $1,000,000	7
over $1,000,000	6

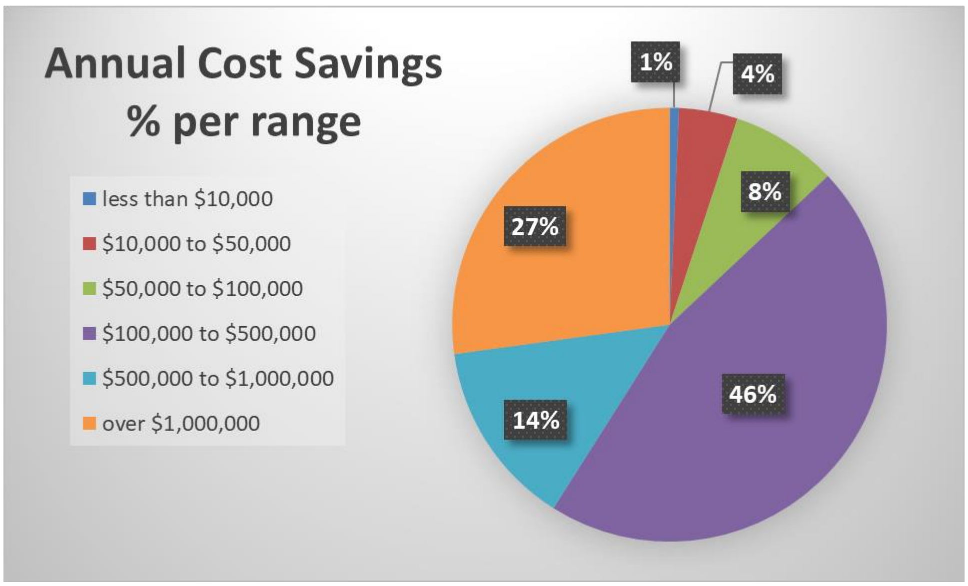

Figure 10. Ranges of annual cost savings (% per range)

4.1.2 Cumulative Cost Savings

The cumulative cost savings up to December 2017 are $390 million (2017 $), of which 37% are based on measured savings and the remainder have been extrapolated using the procedure described in Section 3.3.1. The cumulative cost savings of each CC project group are provided in Table 6. The largest cumulative cost savings in excess of

$150 million have been realized at Texas A&M University. The academic medical centers have produced over $55 million in cumulative cost savings. The MEDCOM sites (Army military hospitals) are responsible for close to $40 million in cost savings. The cost savings at the DFW airport were more than $34 million. The Alamo Colleges District achieved over $21 million. The Texas A&M University System various locations had cost savings greater than $19 million. All other project groups produced under $13 million in cumulative cost savings per project group. Most of the aforementioned project groups had a shorter scope or fewer buildings than the 6 project groups that represent 82% of the total cumulative cost savings.

Table 6. Cumulative Cost Savings of Each CC Project Group as of December 2017

CC Project Group	Cumulative Cost Savings
Texas A&M University	$151,866,850
Academic Medical Centers	$55,016,648
U.S. Army Medical Command (MEDCOM)	$39,264,072
Dallas/Fort Worth (DFW) Airport	$34,454,133
Alamo Colleges District	$21,459,498
Texas A&M University System	$19,085,990
Other Facilities	$12,121,521
Veteran's Affairs (VA) Hospitals	$11,002,836
IBM Facilities	$8,450,833
Austin Independent School District	$7,104,186
State of Texas	$6,142,427
Smith Seckman Reid, Inc. Commissioning Group (SSRCx)	$5,767,802
Tarrant County College District	$3,325,714
Texas Capitol Complex	$3,195,298
University of Texas Austin	$2,453,731

Table 6. Continued

CC Project Group	Cumulative Cost Savings
City of Austin	$2,318,830
Texas Tech University	$1,891,084
State of Utah	$1,798,930
The Pennsylvania State University	$1,515,005
Houston Airport System	$1,176,681
Conroe Independent School District	$485,012
Fort Worth Independent School District	$304,706
Total	**$390,201,788**

4.1.3 Non-energy Impacts

The most commonly reported non-energy impacts were found to be related to occupant comfort. According to the project reports, comfort issues were identified in 59 Continuous Commissioning projects some of which had multiple issues. Comfort issues are usually identified during the CC assessment process either as relayed by the facility personnel or from observation and measurements. There were 54 projects with thermal comfort issues identified: specifically too hot, too cold, and/or humid. The indoor air quality (IAQ) was a concern in nine projects. The biggest IAQ issue was a complaint of stuffiness or measured CO_2 levels that were high. Various noise complaints were reported in five projects. Appendix B contains a table of the type of comfort issues per project while the sources of this information are provided in the reference section.

The troubleshooting process resulted in recommendations for most issues using CC measures, equipment retrofit, as well as operation and maintenance (O&M) suggestions. The occupant comfort issues were resolved for at least 34 of the 59 projects.

The resolution was in progress at the time of the final report for one project. No recommendations were provided for six projects due to project scope (as with comfort issues identified at the end of the project timeline). It was not clear from the reports if the implemented or proposed CC measures improved the comfort issues for five projects. Equipment retrofit or replacement or O&M recommendations were made for 13 projects for which the status was unknown or not indicated at the time of the final report.

The following examples highlight each different type of comfort issue (thermal comfort, noise, and IAQ) and various resolutions. At the Texas A&M University Teague Annex Building located in College Station, TX (known as the Data Processing Center at the time of CC implementation) there were numerous cold complaints. It was determined that the thermostats were out of calibration. The thermostats were calibrated during the CC process and the thermal comfort improved. The hearing room of the Texas Capitol Complex Extension Building in Austin, TX had a comfort problem that was resolved by CC measures. Due to hot complaints during peak use, the temperature was kept between 66°F to 69°F even during unoccupied hours. Cold deck temperature and static pressure reset schedules were implemented maintaining the temperature between 70°F to 72°F and remedying the complaints. At the Walter Reed Army Institute of Research in Silver Spring, MD, there were noise complaints from some of the neighboring residents. Upon further inspection, airflow problems were causing AHU fans to continuously run at 100% speed. CC measures were implemented which reduced the AHU fan speeds as well as the outside air intake reducing the sound levels. At the Food Safety Inspection Service Training and Research Center building at Texas A&M, there was an IAQ concern due to lack of fresh air. Before commissioning, all of the outside air dampers were stuck closed. During CC implementation the damper problems were fixed allowing fresh air into the building.

The following example shows how one project can have multiple comfort issues with varying levels of resolution. Fayetteville VA Medical Center located in Fayetteville, AR had three comfort issues investigated. One was resolved with a simple adjustment. One required a change in equipment. One was left unresolved due to occupant differences. The simple adjustment occurred at a laboratory plagued with persistent hot and cold calls, which were found to be the result of low flow to the VAV box serving the area since the volume damper was closed. Once the damper was opened, the problem was fixed. The change in equipment was necessary for a basement area with frequent hot calls. It was determined that the fan motors had been undersized according to the flow requirements. The facility engineering staff had not replaced the motors by the time of the report. Lastly, an uncomfortable office space was investigated. The thermostat controlling the space was in an adjacent office and the occupants were satisfied at different temperatures therefore this issue was left unresolved as no amicable temperature could be found.

4.2 Impact of CC by Building Type

The impact of CC has been summarized for four different building types. The building types considered are educational, healthcare, laboratory, and office. The buildings are categorized based on their primary use. 159 of the completed CC projects are considered; 76 are categorized as educational, 46 as healthcare, 13 as laboratory, and 24 as office, as shown in Figure 11. There are 39 projects that will not be included in the comparisons by building type (labeled Other in Figure 11). These projects include facilities such as airports, data centers, event centers, and museums that are not primarily one of the four building types selected for comparison. The following sections present the overall impact for each building type as well as some examples.

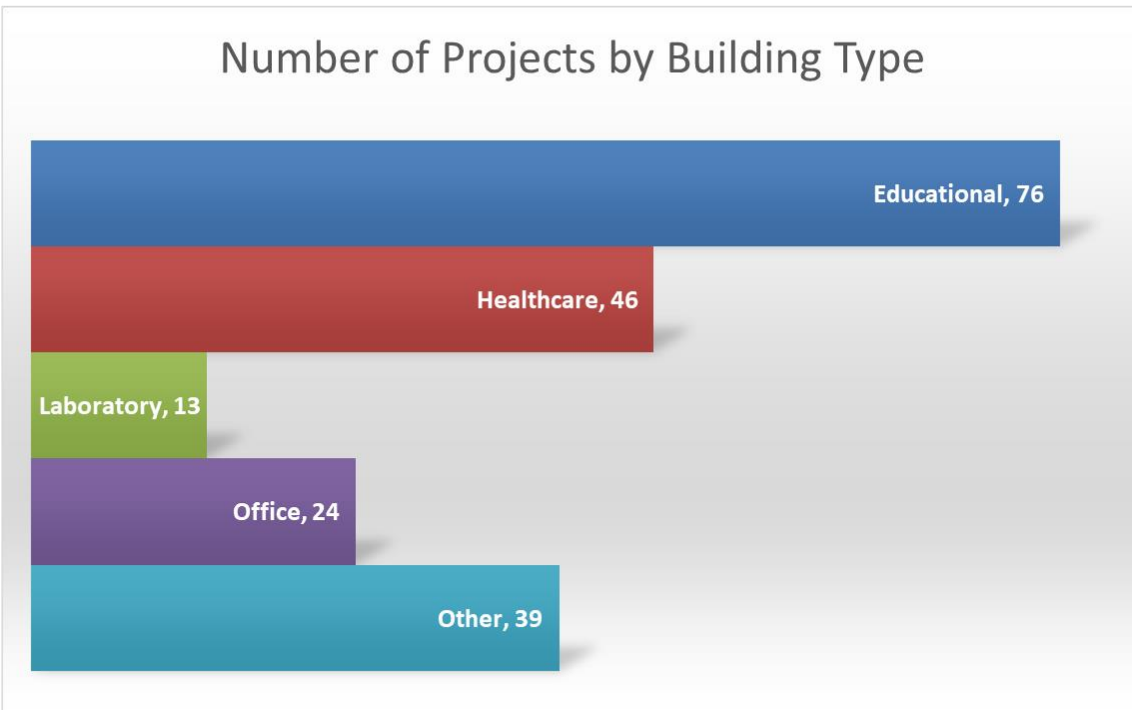

Figure 11. Number of projects by building type

4.2.1 Educational Buildings

The buildings classified as educational had \$9.4 million of annual savings (value known for 76 of 112 sites) and \$218 million of cumulative cost savings (from 11 project groups – includes laboratory and office buildings located at colleges and universities, as well as K-12 auxiliary centers). There are 15 buildings with savings under \$0.10/ft^2, 45 buildings had savings between \$0.10/ft^2 and \$0.60/ft^2, eight buildings with savings between \$0.60/ft^2 and \$1.10/ft^2, and eight buildings with savings greater than \$1.10/ft^2, as shown in Figure 12. The cost savings were between \$0.01/ft^2 and \$3.69/ft^2 with an average of \$0.48/ft^2. Figure 13 presents the annual energy cost savings and building area for the educational buildings. The average annual cost savings was \$124,542 (\$2,826 to \$1,548,102) and the average building area was 262,320 ft^2 (29,583 ft^2 to 3,560,000 ft^2). The educational buildings are further separated into K-12 schools (32 projects), community colleges (13 projects), and universities (31 projects), as shown in Figure 14.

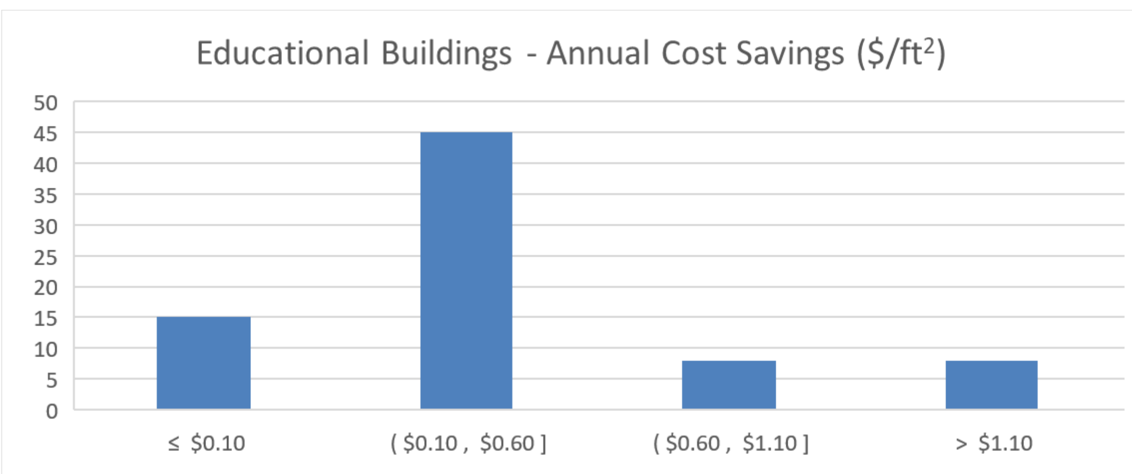

Figure 12. Educational buildings - ranges of annual energy cost savings (\$/ft^2)

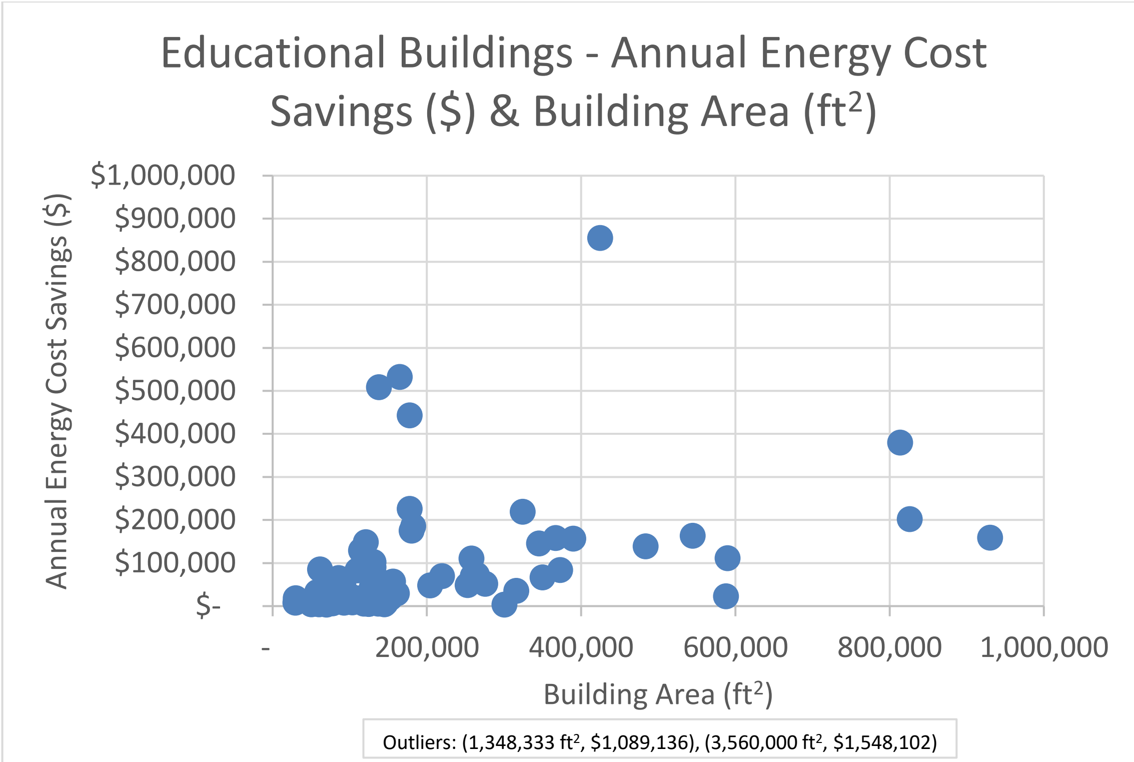

Figure 13. Educational buildings - annual energy cost savings ($) and building area (ft^2)

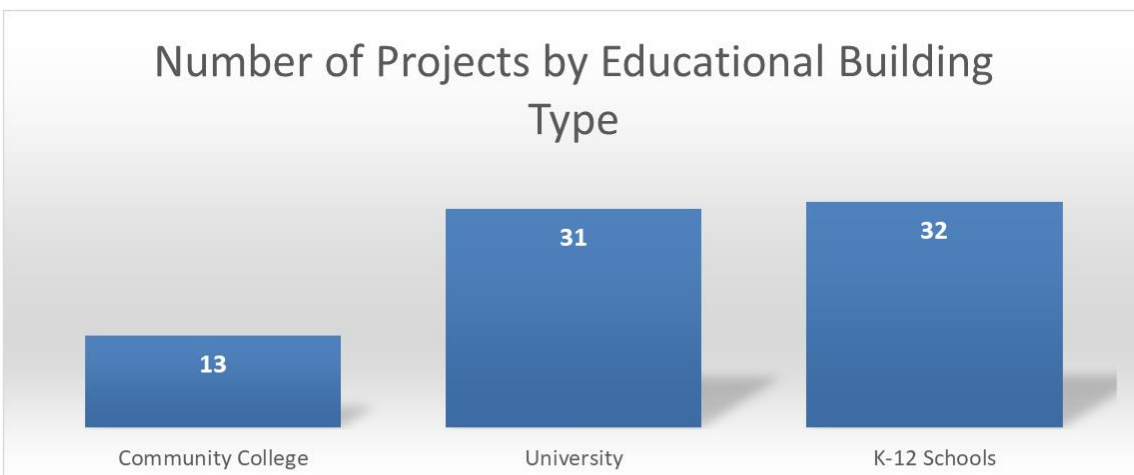

Figure 14. Number of projects by educational building type

4.2.1.1 K-12 Schools

The K-12 schools had approximately $876,000 of annual savings (32 sites, 46 buildings, 3,945,660 ft^2) and $7.9 million of cumulative cost savings up to December 2017 (three project groups[4]). All of the K-12 schools were located in Texas; specifically Austin, Conroe, and Fort Worth. Each city has its own independent school district. The earliest K-12 Continuous Commissioning project was completed at an elementary (62,400 ft^2) and a middle school (92,884 ft^2) in Fort Worth Independent School District (FWISD) in 1993. The annual cost savings were over $23,000 and the cumulative cost savings were $304,706. The CC project implemented at Conroe Independent School District (CISD) included two elementary schools, one junior high school, and one high school, totaling 732,053 ft^2. The annual savings were $121,990 and the cumulative cost savings were $485,012. The ESL began Continuous Commissioning implementation for the Austin Independent School District (AISD) in 2004 with a few schools and continued in different phases into 2013. The AISD completed CC projects include 34 schools (22 elementary, 7 middle, and 5 high schools) as well as 3 auxiliary service centers. The auxiliary service centers are not included in the K-12 comparisons since they are not considered educational buildings. The total building area is in excess of 4 million square feet. Some of the projects did not realize savings. The annual savings were $730,757 for 26 of the projects and the cumulative savings were $7,104,186.

[4] Total includes two auxiliary centers located within the Austin Independent School District.

The annual cost savings for all K-12 projects are shown in Figure 15. The largest annual savings was realized at a middle school ($101,955, 130,797 ft^2). The elementary and middle schools had annual cost savings under $40,000 except for a few outliers. The high schools had annual cost savings ranging between $35,000 and $84,000.

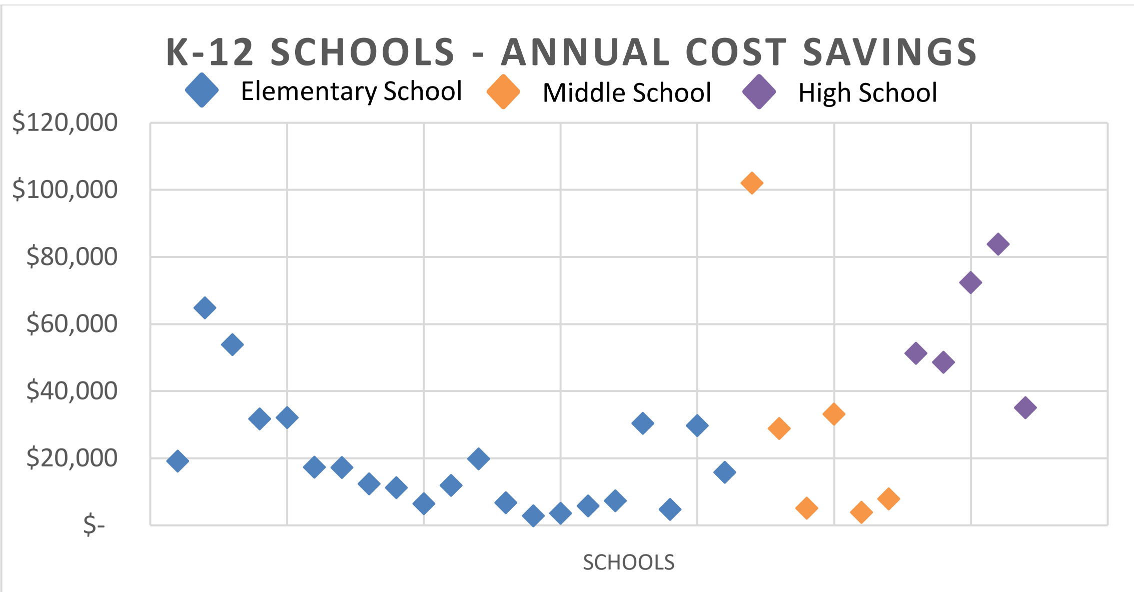

Figure 15. Annual cost savings for K-12 schools

The annual cost savings are presented as cost per square foot in Figure 16. The largest cost savings, $0.78/ft², occurred at Burnet Middle School of Austin Independent School District. Galindo Elementary School also of AISD followed closely with annual cost savings of $0.76/ft^2. The average annual cost savings for all K-12 schools was $0.23/ft², at the district level AISD is above the average at $0.25/ft², while both CISD ($0.16/ft^2) and FWISD ($0.17/ft²) were below the average.

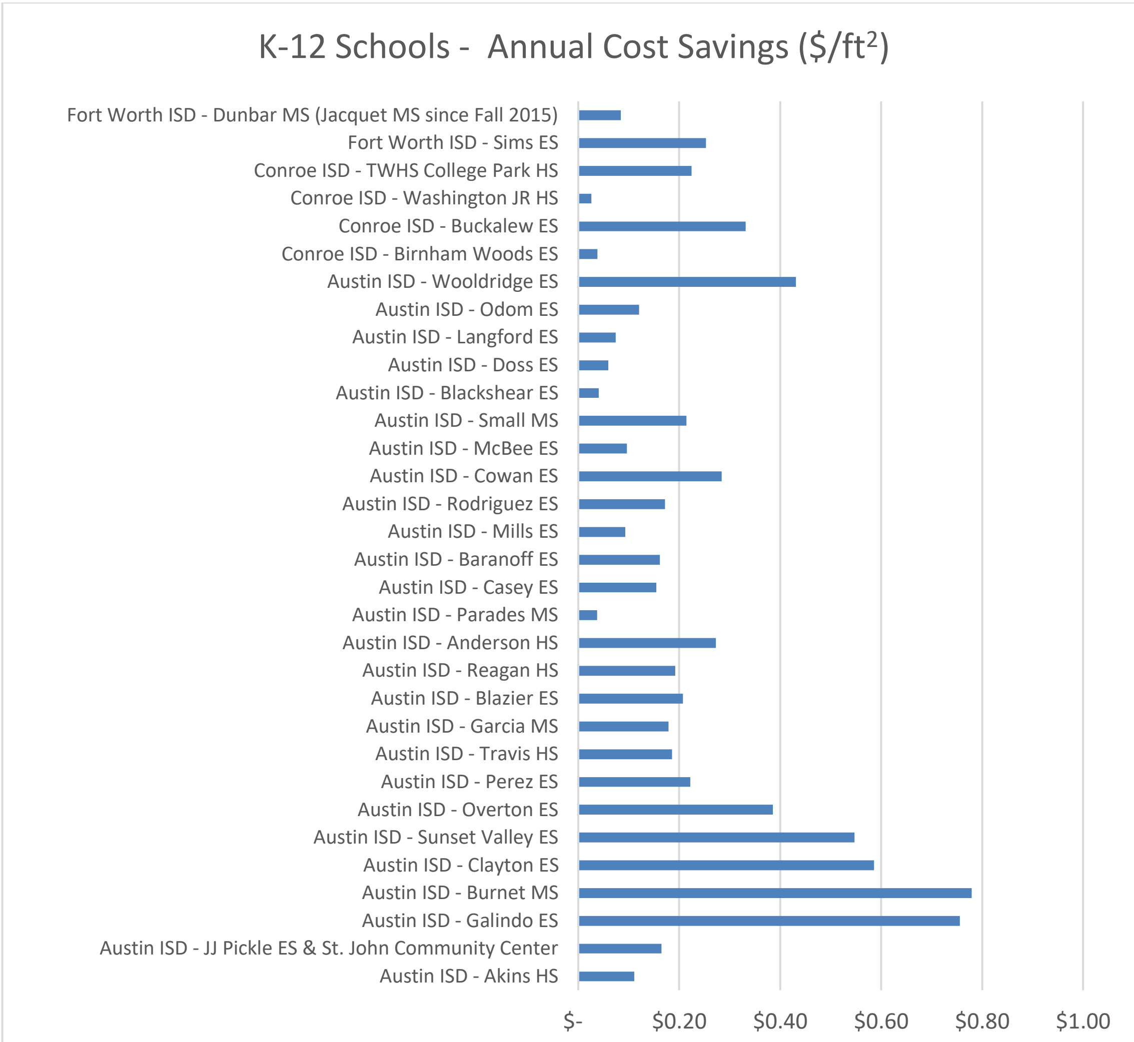

Figure 16. Annual cost savings for K-12 Schools ($\$/ft^2$)

4.2.1.2 Community Colleges

The community colleges had $1.8 million of annual savings (13 sites, 109 buildings, 4,815,715 ft^2) and $24.8 million of cumulative cost savings up to December 2017 (2 project groups – includes office buildings). The ESL implemented Continuous Commissioning at three community college districts: Alamo Colleges District (ACD) in

San Antonio, TX, South City Campus of Salt Lake Community College (SLCC) in Salt Lake City, UT, and two campuses of the Tarrant County College District (TCCD) which serves Tarrant County, TX. The South City Campus of SLCC was originally a high school built in the 1930s and was renovated and reopened as a community college in the 1980s. The building is 350,000 ft^2. The CC process was completed in 2003 and the annual cost savings were $66,688 and the cumulative cost savings were $469,062. The CC implementation at the Alamo Colleges District began in the early 2000s and is ongoing at the time of this study. The project will be discussed in more detail in section 4.5.1. The annual cost savings were $759,922 and the cumulative cost savings exceeded $21 million. The implementation of the Continuous Commissioning process at TCCD began at the Trinity River Campus (425,000 ft^2) in 2014, expanded to the Southeast Campus (590,000 ft^2) in 2016 and is continuing to add other campuses. The annual cost savings were $966,119 and the cumulative cost savings were $3,325,714.

For all Community College locations the annual cost savings and building area are presented in Figure 17. The average annual cost savings was approximately $140,000 and the average building area was 370,440 ft^2. The annual cost savings are presented as cost per square feet in Figure 18. The largest cost savings, $2.01/$ft^2$, were realized at TCCD Trinity River Campus and were over 5 times the average cost savings of all Community College sites. The majority of the sites had cost savings between $0.17/$ft^2$ and $0.43/$ft^2$ while the average at all Community College sites was $0.38/$ft^2$.

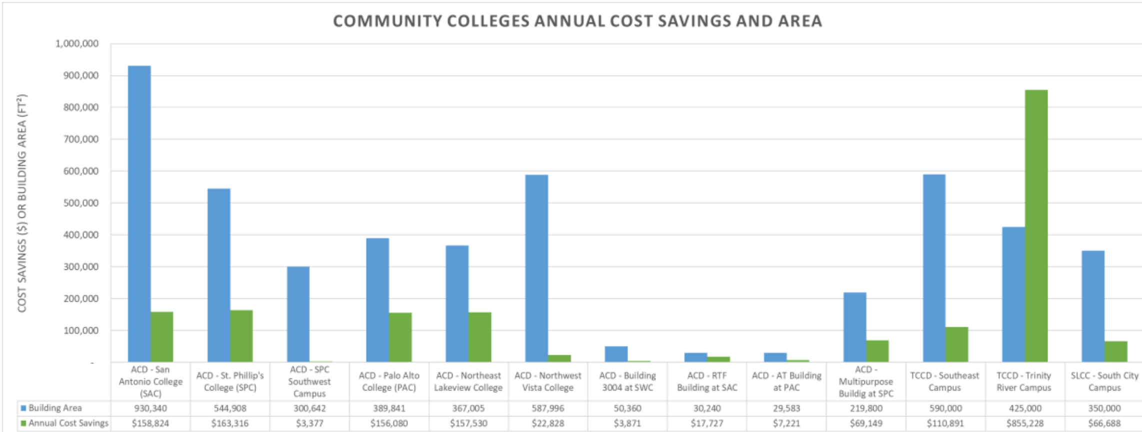

Figure 17. Annual energy cost savings and building area of community colleges

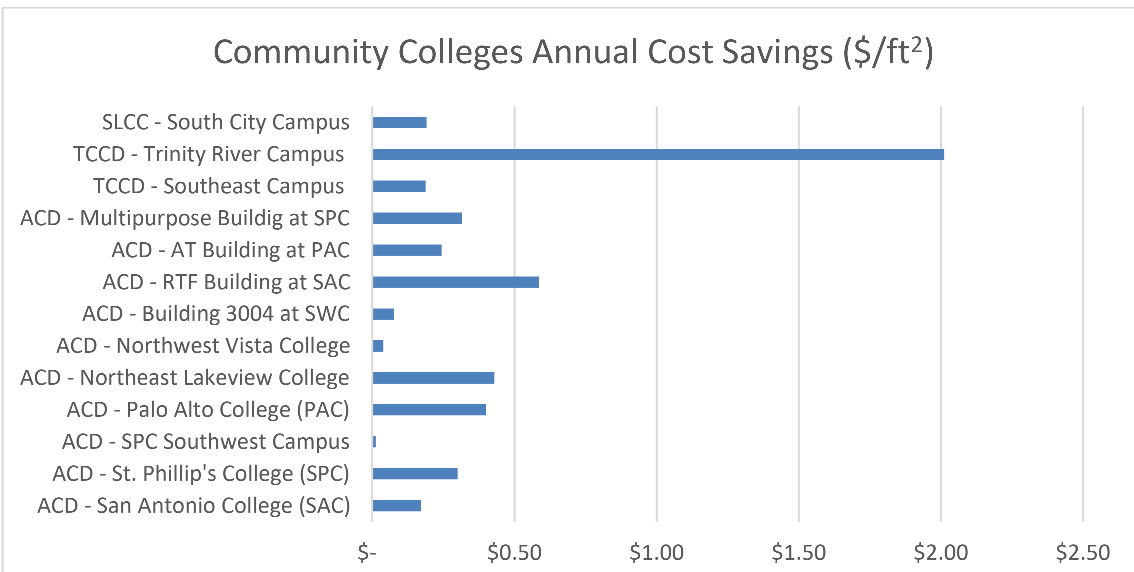

Figure 18. Annual cost savings ($/ft²) for community college projects

4.2.1.3 Four Year Universities

The four year universities had \$6.8 million of annual savings (31 sites, 176 buildings, 11,174,942 ft²) and \$185[5] million of cumulative cost savings (from 6 project groups – includes laboratory and office buildings located at universities). There were CC projects at 8 universities; Prairie View A&M University, Texas A&M International University, Texas A&M University, Texas A&M University Corpus Christi, Texas Tech University, University of Texas Arlington, University of Texas Austin, and University of Texas Medical Branch Galveston.

The CC implementation process at Prairie View A&M University occurred between 2003 and 2008. There were 21 buildings (1,348,333 ft²) commissioned which were built as early as 1939 and as late as 2005 (average vintage of 1977). The annual cost savings were \$1,089,136 and the cumulative cost savings were over \$10.6 million.

Texas A&M International University (TAMIU) located in Laredo, TX was commissioned in three phases; the first two in the early 2000s and the last phase was completed in 2010. There were 13 buildings commissioned with an area of 813,835 ft² and an annual cost savings of approximately \$380,000 and the cumulative savings over \$7.3 million.

The largest university CC project occurred over multiple years at Texas A&M University in College Station, TX including over 45 buildings with an area in excess of 6 million ft². The annual savings for 16 buildings (2,844,644 ft²) was over \$2.7 million and

[5] Cumulative savings include 28 buildings at Texas A&M University for which the annual savings are unknown.

is provided per building in Figure 19 along with the building area. The largest energy cost savings, over \$530,000, was realized at the Kleberg building which is a 165,031 ft² general academic building with classrooms, offices, and laboratories. The majority of the campus buildings had energy cost savings under \$200,000 though the average of all 16 buildings was approximately \$170,000. Although the annual savings were only available for a small portion of the buildings, the cumulative cost savings were determined from a whole campus approach indicating savings of nearly \$152 million.

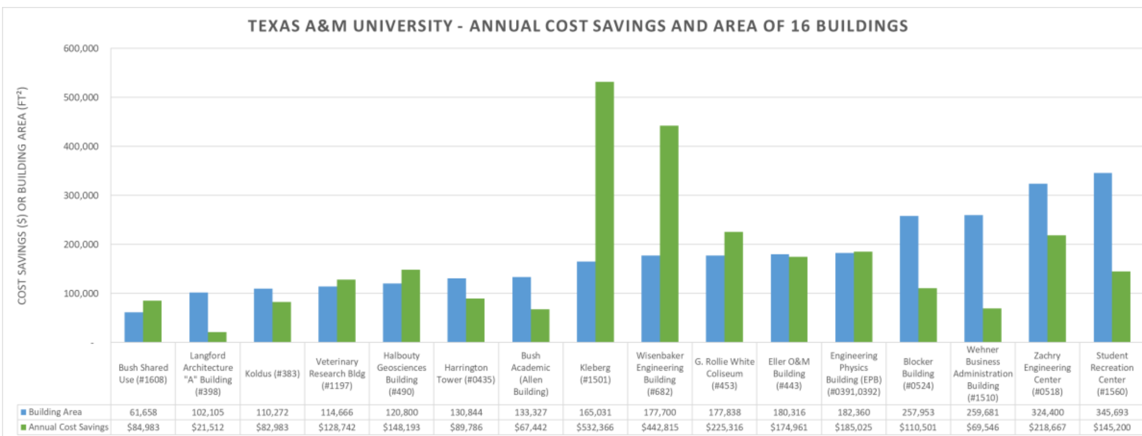

Figure 19. Annual energy cost savings and building area of 16 TAMU buildings.

From August 2001 to Dec 2002, there were 14 buildings (826,300 ft²) commissioned at Texas A&M University in Corpus Christi which was founded in 1947. The annual cost savings were \$201,580 and the cumulative cost savings were \$1,076,337.

The Continuous Commissioning process was implemented at six Texas Tech University buildings, located in Lubbock, TX, from March 2000 to August 2001 as part of the Texas LoanSTAR Program. The four general academic buildings (Biology, Business Administration, Science, and Law buildings) are included in this section for comparison with other university buildings however the two primarily laboratory buildings (Chemistry North and Chemistry South) are included in the comparisons of section 4.2.3. The area of the four general academic buildings is approximately 608,000 ft^2 and the annual cost savings were \$154,181, provided in Figure 20 separated by building, and the cumulative cost savings were \$1,591,165. The Biology, Business Administration, and Law buildings account for 97% of the cost savings but only 81% of the commissioned building area.

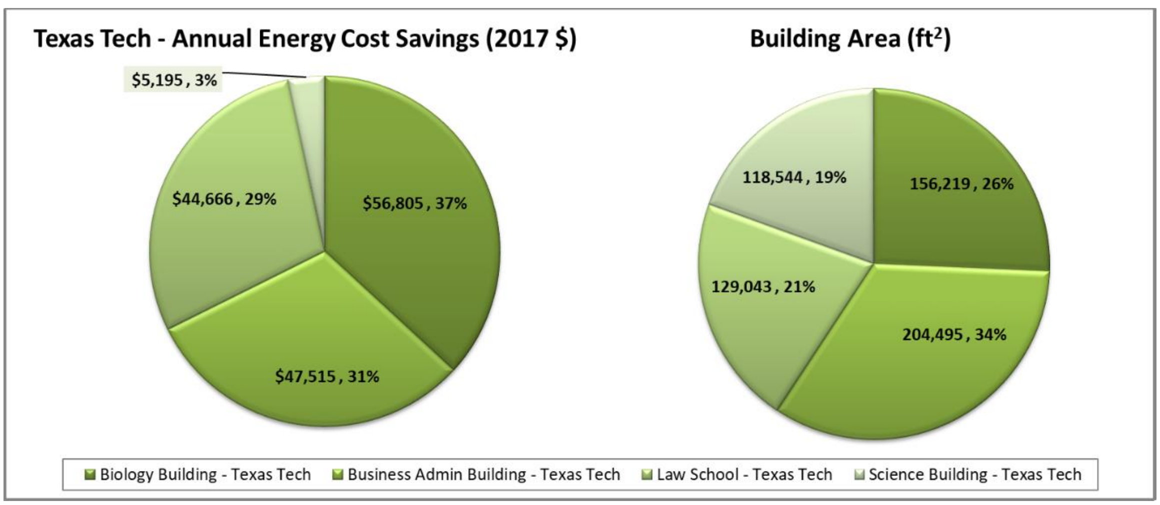

Figure 20. Texas Tech University annual energy cost savings (2017 \$) & building area (ft^2)

The University of Texas at Austin had six campus buildings commissioned as part of the Texas LoanSTAR Program in the 1990s. The buildings represent over 1 million square feet of building area with $187,619 of annual energy cost savings, as shown in Figure 21. The total annual energy cost savings is largely influenced by the savings at the Perry Castaneda Library ($138,384, 74% of the total) which represents less than half of the commissioned building area.

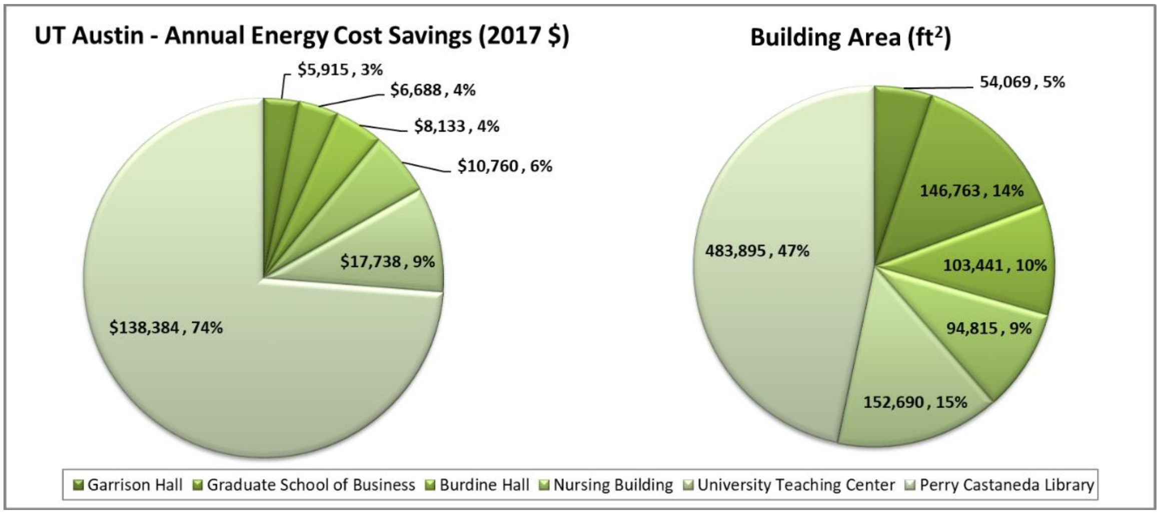

Figure 21. University of Texas at Austin - annual energy cost savings (2017 $) & building area (ft^2)

The annual energy cost savings per building area for all university buildings is presented in Figure 22. Most of the buildings had savings under $1.00/ft^2. The largest savings were realized at the Basic Sciences building at the University of Texas Medical Branch in Galveston. The Basic Sciences building was built in 1971, has an area of 137,856 ft^2, and had an annual energy cost savings of $3.69/ft^2 after the implementation of CC in 1993. The other 7 buildings with savings above $1.00/ft^2 were located at Texas A&M University.

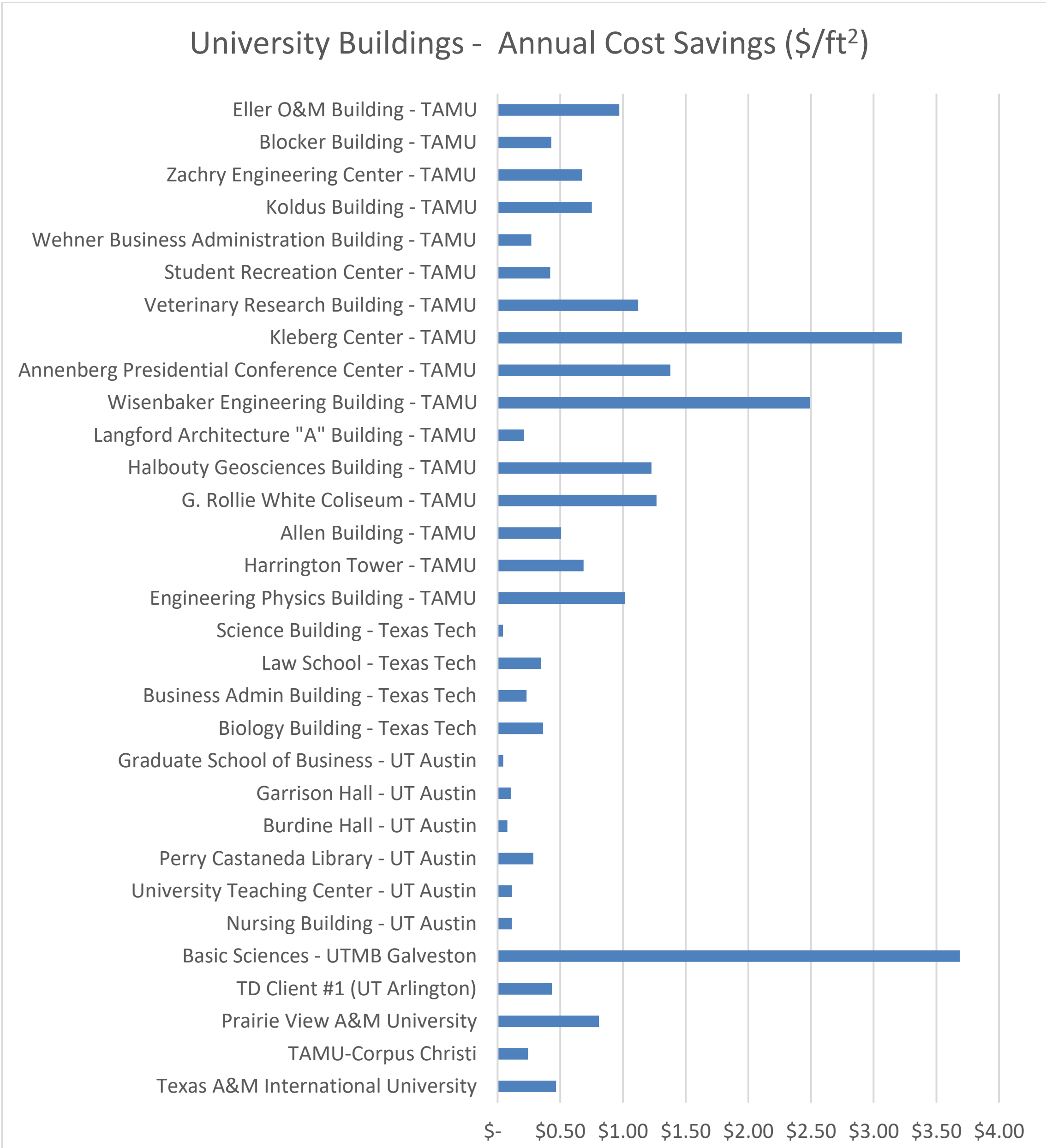

Figure 22. Annual cost savings, $/ft², of university buildings

4.2.2 Healthcare Facilities

The facilities designated as healthcare had $9.8 million of annual savings (46 sites, 143 buildings, 23,446,414 ft²) and $99.5 million of cumulative cost savings (from

4 project groups – includes laboratories and offices at academic medical sites). The annual cost savings for each facility is provided in Figure 23 with respect to building area. The average annual cost savings was $214,470 ($7,049 to $1,043,679) and the average building area was 532,873 ft^2 (37,000 ft^2 to 2,000,800 ft^2). The three main project groups containing healthcare facilities are Academic Medical (9 sites), MEDCOM (22 sites), and VA Hospital (9 sites) locations. There was also CC work at 6 other sites.

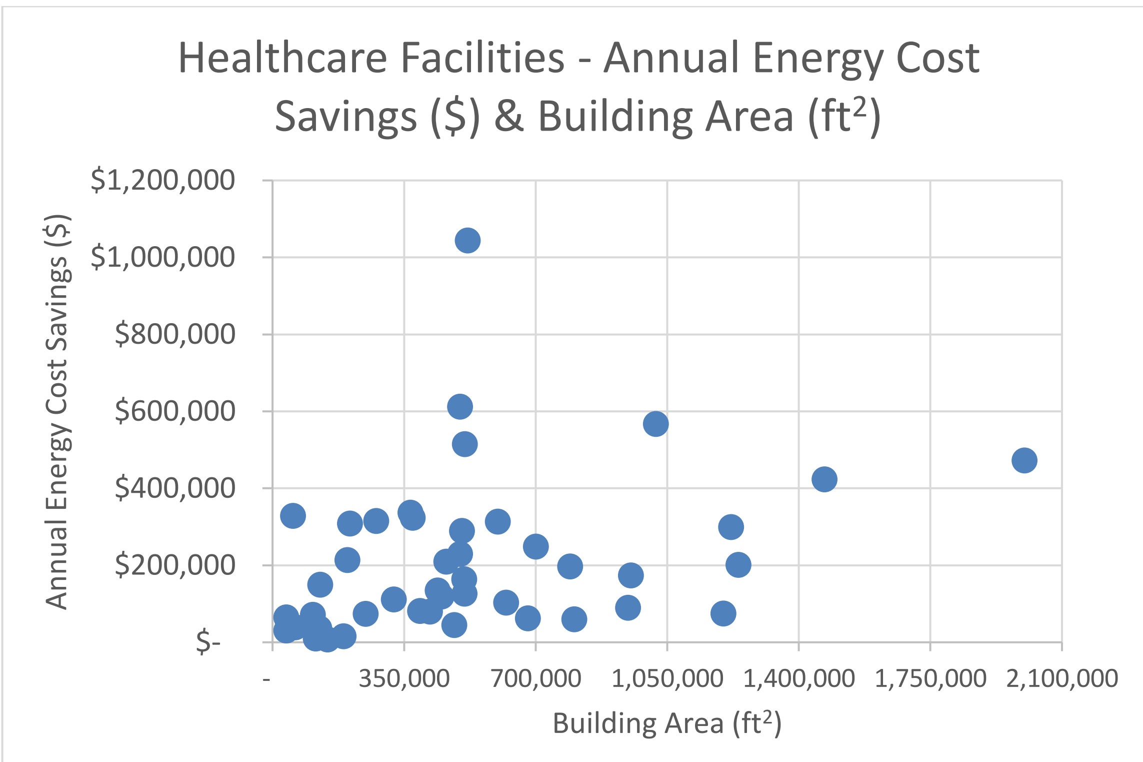

Figure 23. Healthcare facilities - annual energy cost savings ($) and building area (ft^2)

The Academic Medical sites include CC implementation at the UTHSC San Antonio, UTMDA Cancer Center, UTMB Galveston, and Fairview University Medical Center (FUMC). The total annual cost savings was approximately $2.2 million from 11 buildings with 2,959,220 ft^2 of building area. The annual cost savings and building area for each Academic Medical site is presented in Figure 24. The Dental School at UTHSC San Antonio, TX was built in 1972 and is 484,019 ft^2. The site was commissioned in late 1992 and the annual energy cost savings were $43,964. The UTMDA Cancer Center is located in Houston, TX and the three buildings commissioned in 1994 and 1995 were built between 1950 and 1973 (775,479 ft^2). The total annual energy cost savings for the three buildings was $926,375. At the UTMB Galveston location there were three healthcare buildings commissioned in 1993, 1994, and 1995. The three buildings totaled 552,449 ft^2 and were built between 1970 and 1978. The total annual energy cost savings for the three buildings was $686,842. The Fairview University Medical Center is comprised of inpatient and outpatient facilities and is located in Minneapolis, MN. Three of the facilities buildings and the central plant have been commissioned: Riverside North (37,273 ft^2, unknown vintage) in 1999, Unit J (600,000 ft^2, built in 1981) in 2001, and Riverside East and Central Plant (510,000 ft^2, built in 1957) in 2002. The total annual energy cost savings for these three facilities was $540,661.

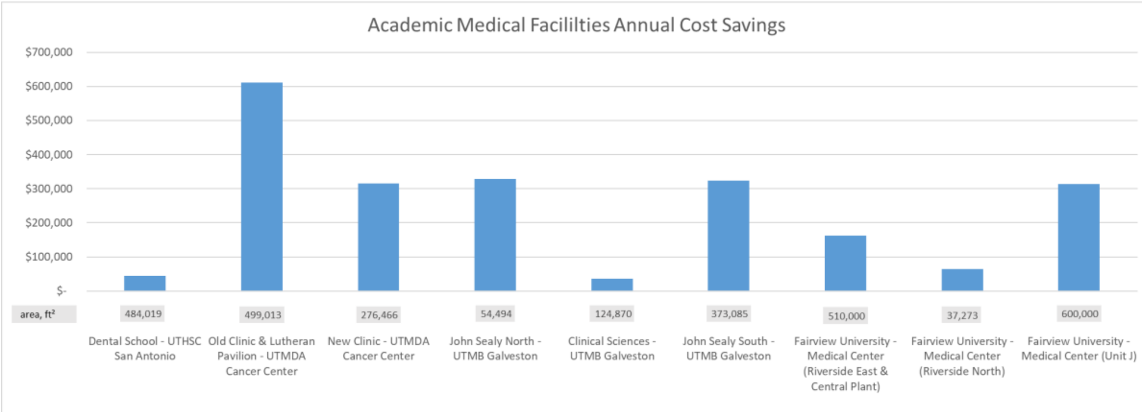

Figure 24. Annual energy cost savings ($) and building area ($ft^2$) at academic medical facilities

The 22 MEDCOM healthcare facilities had a total energy cost savings of almost $5 million with an average of approximately $227,000 per site. The annual energy cost savings with respect to building area is provided in Figure 25 for each site. The Walter Reed Army Institute of Research which is a 520,000 ft^2 facility, located in Silver Spring, MD produced some of the highest annual energy cost savings, which were over $1 million. The largest MEDCOM facility commissioned was Brooke Army Medical Center (BAMC) which is a 1,468,592 ft^2 hospital and research facility located at Fort Sam Houston in San Antonio, TX. The annual cost savings at BAMC were $423,133. The majority of the MEDCOM facilities were less than 700,000 ft^2 and had annual energy cost savings under $600,000.

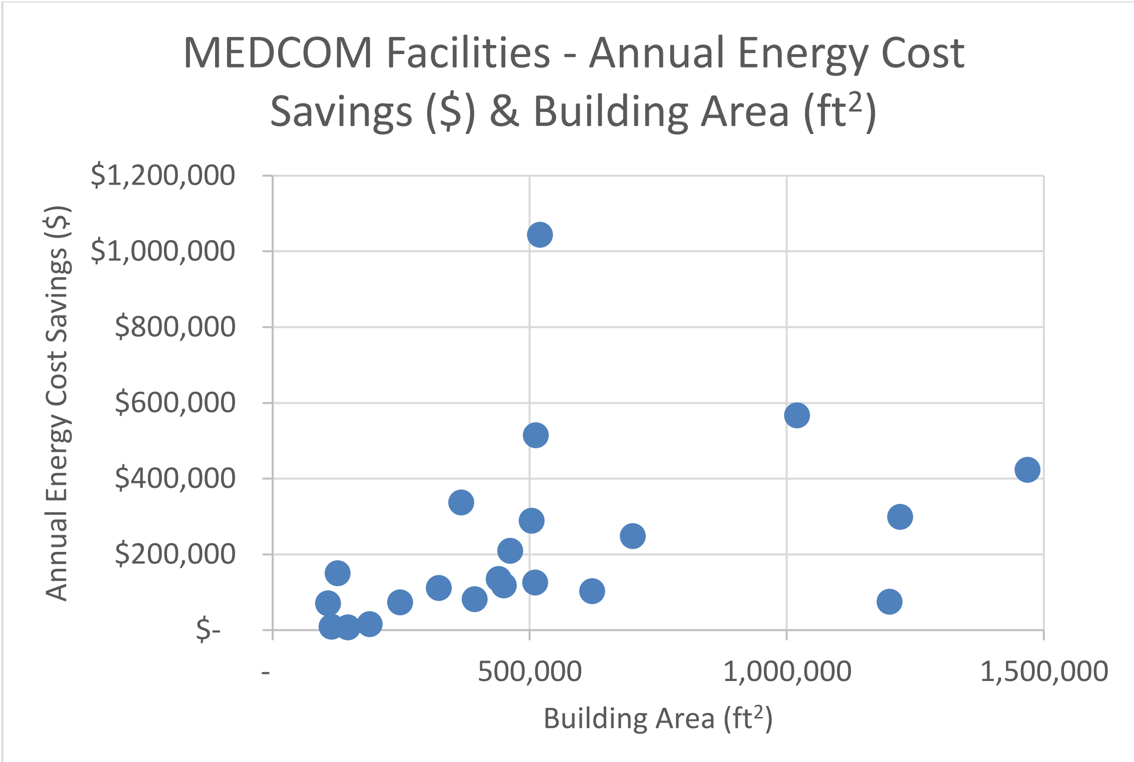

Figure 25. MEDCOM facilities - annual energy cost savings ($) and building area ($ft^2$)

There were nine VA hospitals commissioned with a total energy cost savings of over $1.8 million with an average of approximately $211,000 per site. The annual energy cost savings and building area at each hospital are provided in Figure 26. The smallest VA hospital commissioned was the Joint Ambulatory Care Center located in Pensacola, FL. The 206,000 ft^2 building is an outpatient clinic with offices and support. The CC implementation period was September 2010 to September 2011 and the annual energy cost savings were $307,745. The largest VA hospital commissioned was the Michael E. DeBakey VA Medical Center in Houston, TX. The annual energy cost savings were $471,814 (also the largest savings for VA hospitals). DeBakey VA has 12 buildings with over 2 million square feet of area.

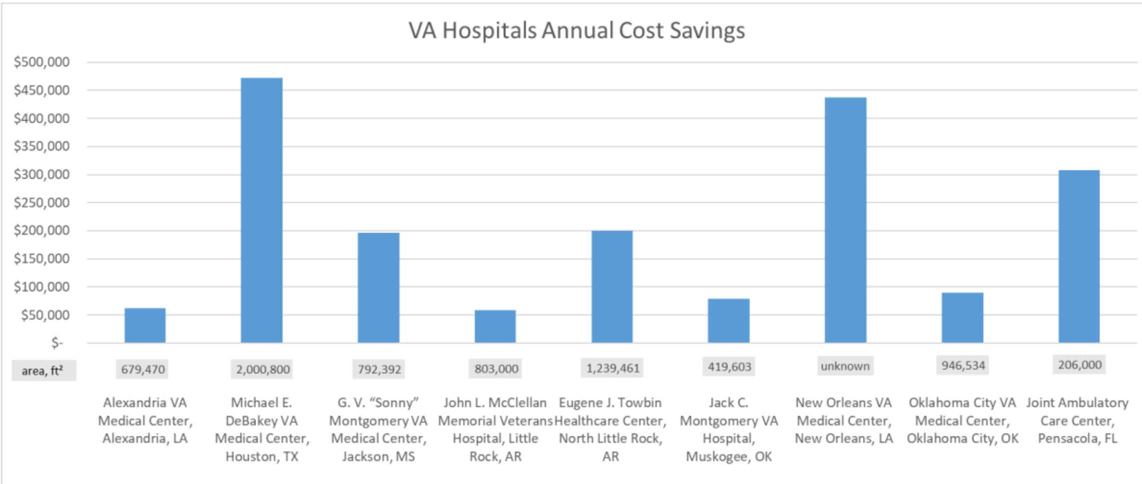

Figure 26. Annual energy cost savings ($) and building area (ft²) at VA hospitals

One of the first non-academic hospitals commissioned was the Ward Memorial Hospital in Monahans, TX. The hospital was built in 1980 and is 37,000 ft². It was commissioned in early 1996 and had an annual energy cost savings of $29,709. In 1998, CC began at Terrell State Hospital (13 buildings, 499,356 ft²) which is a psychiatric inpatient facility that was built in 1960 in Terrell, TX. The annual cost savings were $229,243.

The CC licensee, SSRCx, commissioned four hospitals between the mid-2000s and mid-2010s; Covenant Health Morristown-Hamblen (area unknown, built in 1955 with various additions and renovations through the 2000s) in Morristown, TN, Franklin Foundation Hospital (61,000 ft², built in 2005) in Franklin, LA, Mobile Infirmary

Medical Center (953,705 ft^2, unknown vintage) in Mobile, AL, Thomas Hospital (200,000 ft^2, built in 1960 with additions in 2009) in Fairhope, AL. The total annual energy cost savings for these sites was $506,040.

The annual cost savings for healthcare facilities with available building area information are presented as cost per square foot in four ranges as shown in Figure 27 and for each location shown in Figure 28. There are eight facilities with savings under $0.10/$ft^2$, 22 facilities with savings between $0.10/$ft^2$ and $0.60/$ft^2$, seven facilities with savings between $0.60/$ft^2$ and $1.10/$ft^2$, and seven facilities with savings greater than $1.10/$ft^2$. The cost savings were between $0.05/$ft^2$ and $6.02/$ft^2$ with an average of $0.64/$ft^2$.

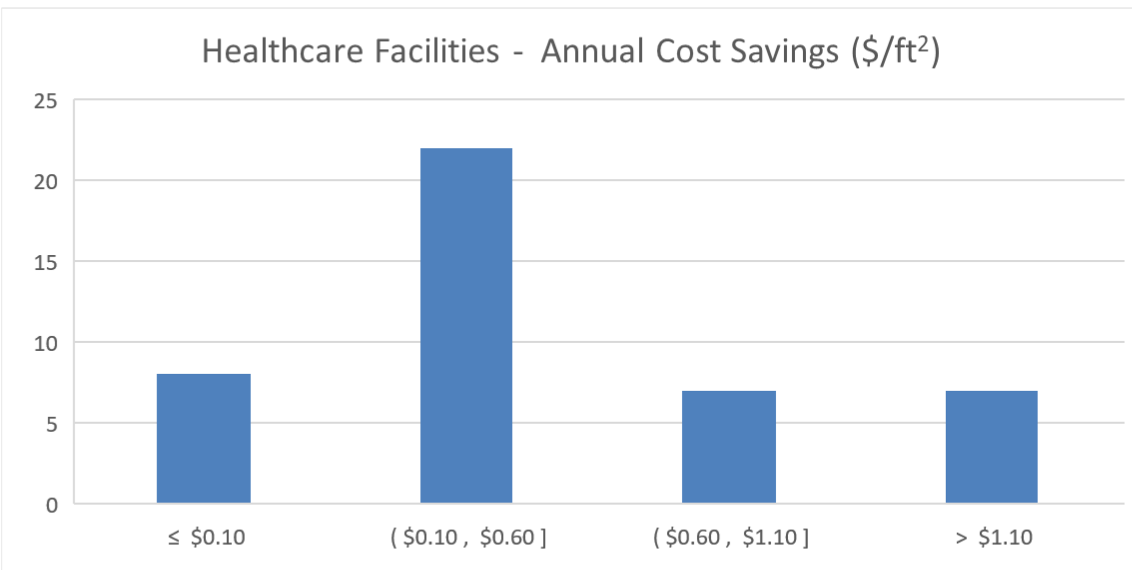

Figure 27. Healthcare facilities - ranges of annual energy cost savings ($/$ft^2$)

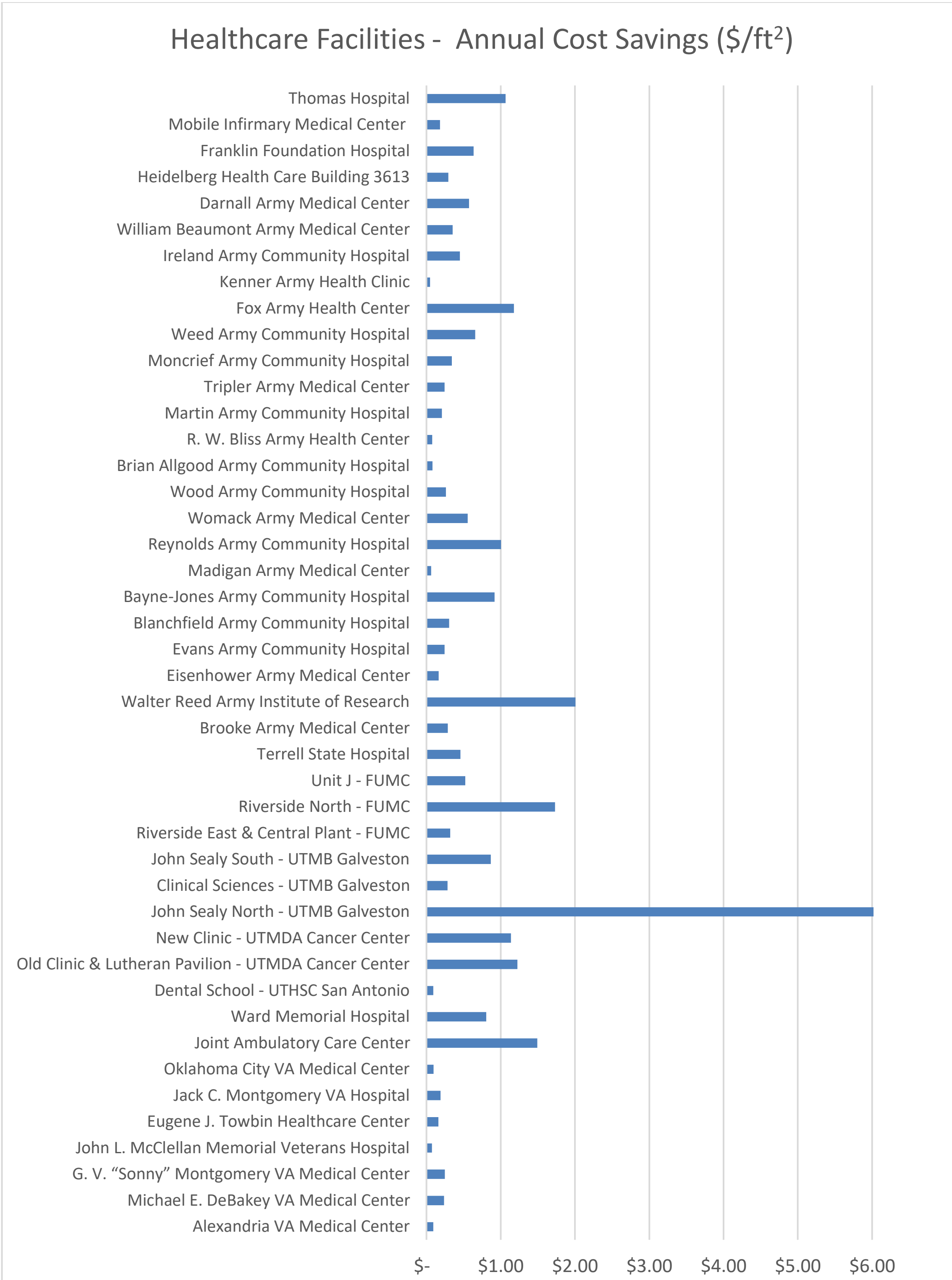

Figure 28. Annual cost savings, $/ft², of healthcare facilities

4.2.3 Laboratory Buildings

The buildings classified as laboratories had \$3.2 million of annual savings (13 buildings, 2,257,786 ft^2). All of the laboratories are included in educational or healthcare project groups; therefore the cumulative savings have been included with the respective groups. The project groups represented include Texas A&M University, Penn State University, Texas Tech University, and two Academic Medical sites (UTMDA Cancer Center and UTHSC Houston). The annual cost savings and building area are presented in Figure 29 for each laboratory building. Figure 30 shows the annual cost savings with respect to building area. The average annual cost savings was approximately \$247,000 (\$4,200 to \$1,351,350) and the average building area was 173,676 ft^2 (53,500 ft^2 to 877,187 ft^2).

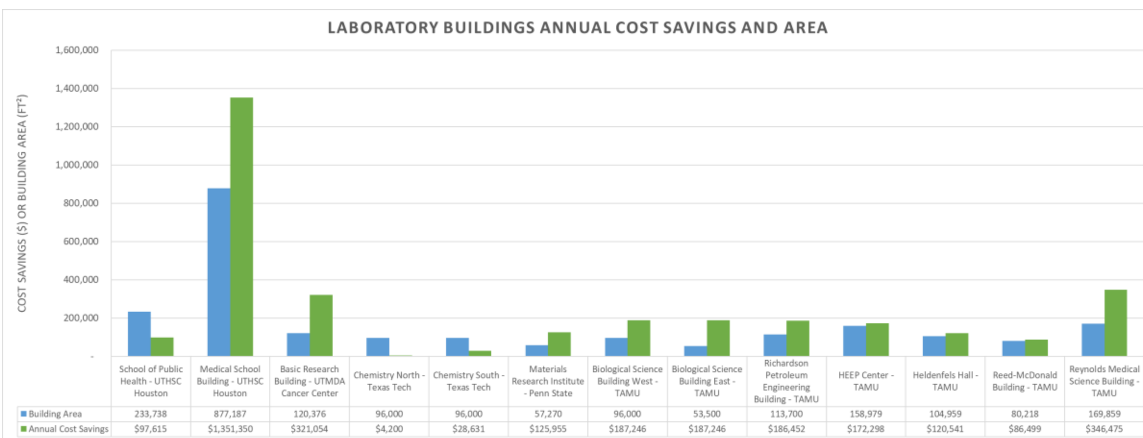

Figure 29. Annual energy cost savings and building area of laboratory buildings

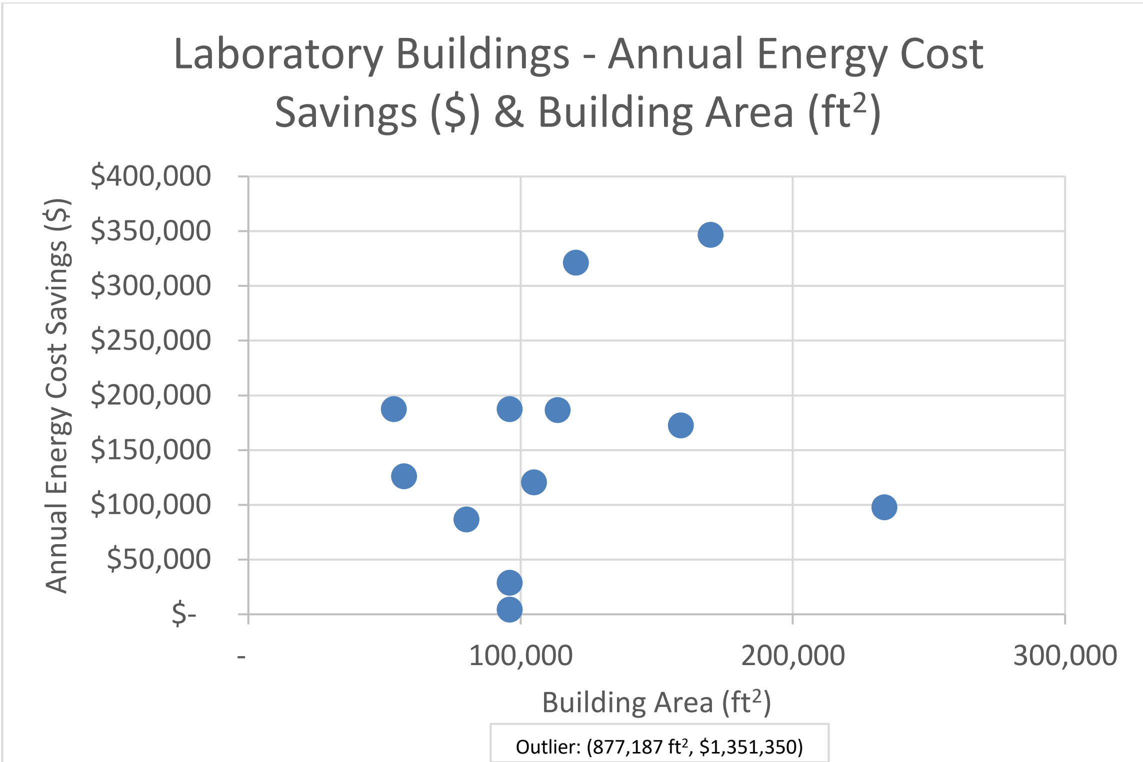

Figure 30. Laboratory buildings - annual energy cost savings ($) and building area (ft^2)

The annual energy cost savings is presented as cost per square foot in three ranges, Figure 31, and for each location, Figure 32. There are three buildings with savings under $1.04/ft^2, four buildings with savings greater than $2.00/ft^2, and the other six buildings had savings between $1.04/ft^2 and $2.00/ft^2. The cost savings were between $0.04/ft^2 and $3.50/ft^2 with an average of $1.51/ft^2. The largest savings at a lab building were realized at the UTHSC Houston Medical School Building which is also the largest of the lab buildings with 877,187 ft^2 built between 1974 and 1976. The building was commissioned in 1994 and had an annual energy cost savings of over $1.35 million ($1.54/ft^2). A significantly smaller lab building was also commissioned in 1994 at the UTMDA Cancer Center in Houston, TX. The Basic Research Building (BRB) was built in 1986 with an area of 120,376 ft^2. The annual energy cost savings at BRB were \$321,054 (\$2.67/ft^2). Both of these examples had higher annual energy cost savings than the average of all 13 laboratory buildings which was \$247,351.

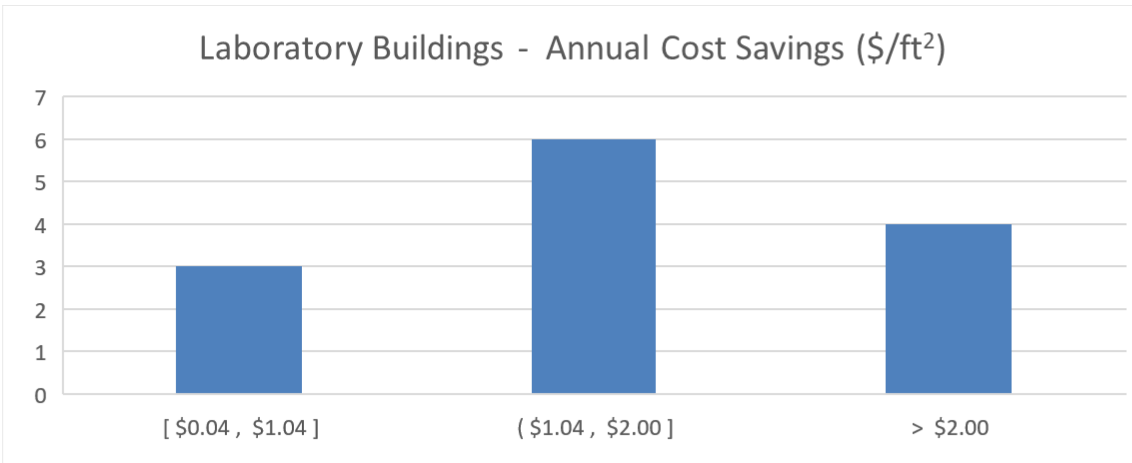

Figure 31. Laboratory buildings - ranges of annual energy cost savings (\$/ft^2)

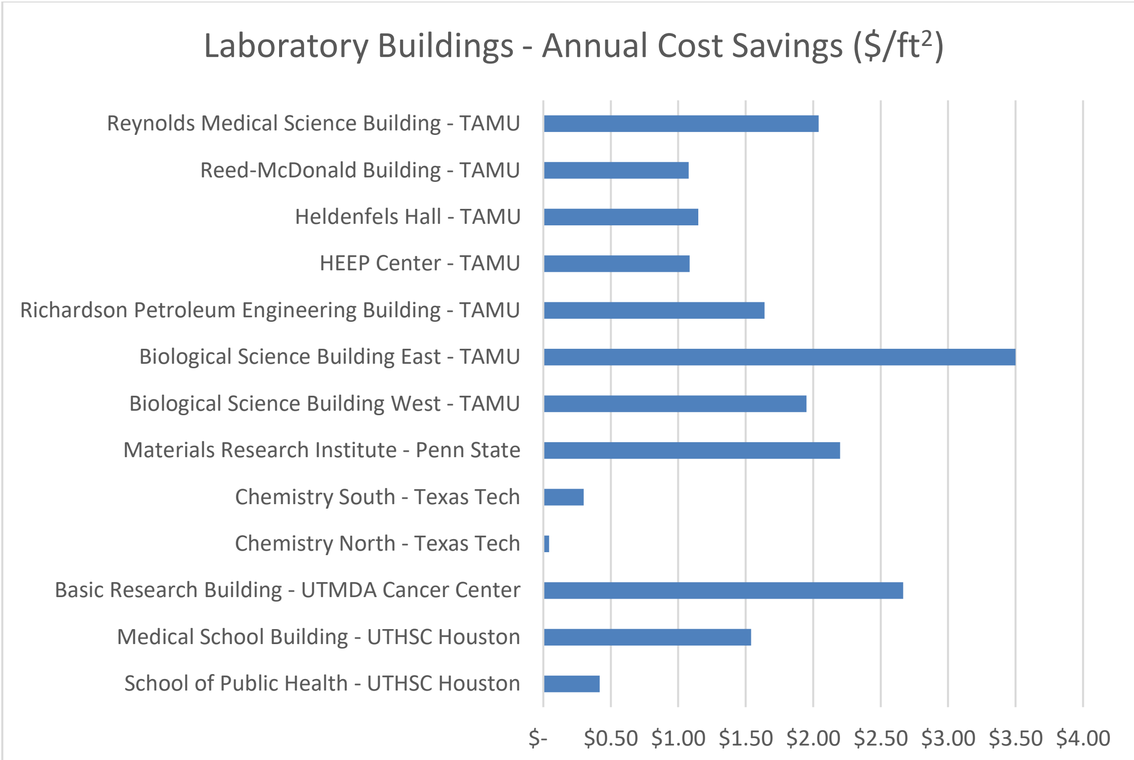

Figure 32. Laboratory buildings - annual energy cost savings ($/ft^2)

4.2.4 Office Buildings

The buildings classified as office buildings had $1.7 million of annual savings (24 sites, 33 buildings, 3,958,085[6] ft^2). The average annual cost savings were approximately $71,300 ($253 to $431,954) and the average building area was 172,091 ft^2 (9,600 ft^2 to 730,491 ft^2). The annual energy cost savings with respect to building area is provided in Figure 33 for each building. The office buildings are located within several project groups. The largest set of office buildings are part of the City of Austin,

[6] Total building area for 23 sites.

TX project group. These seven office buildings were commissioned between 2009 and 2013 and have an area of 884,732 ft^2 with a total annual energy cost savings of $218,274. One of the earliest office buildings commissioned was the Capitol Extension Building of the Texas Capitol Complex located in Austin, TX. The building has 360,000 ft^2 of conditioned floor area, was built in 1992, and commissioned between 1995 and 1996. The annual energy cost savings were $217,888.

The annual cost savings for office buildings are presented as cost per square foot in five ranges as shown in Figure 34 and per location in Figure 35. There are seven buildings with savings under $\$0.25/ft^2$, six buildings with savings between $\$0.25/ft^2$ and $\$0.50/ft^2$, four buildings had savings between $\$0.50/ft^2$ and $\$0.75/ft^2$, three buildings with savings between $\$0.75/ft^2$ and $\$1.00/ft^2$, and three buildings with savings greater than $\$1.00/ft^2$. The cost savings were between $\$0.002/ft^2$ and $\$1.12/ft^2$ with an average of $\$0.49/ft^2$.

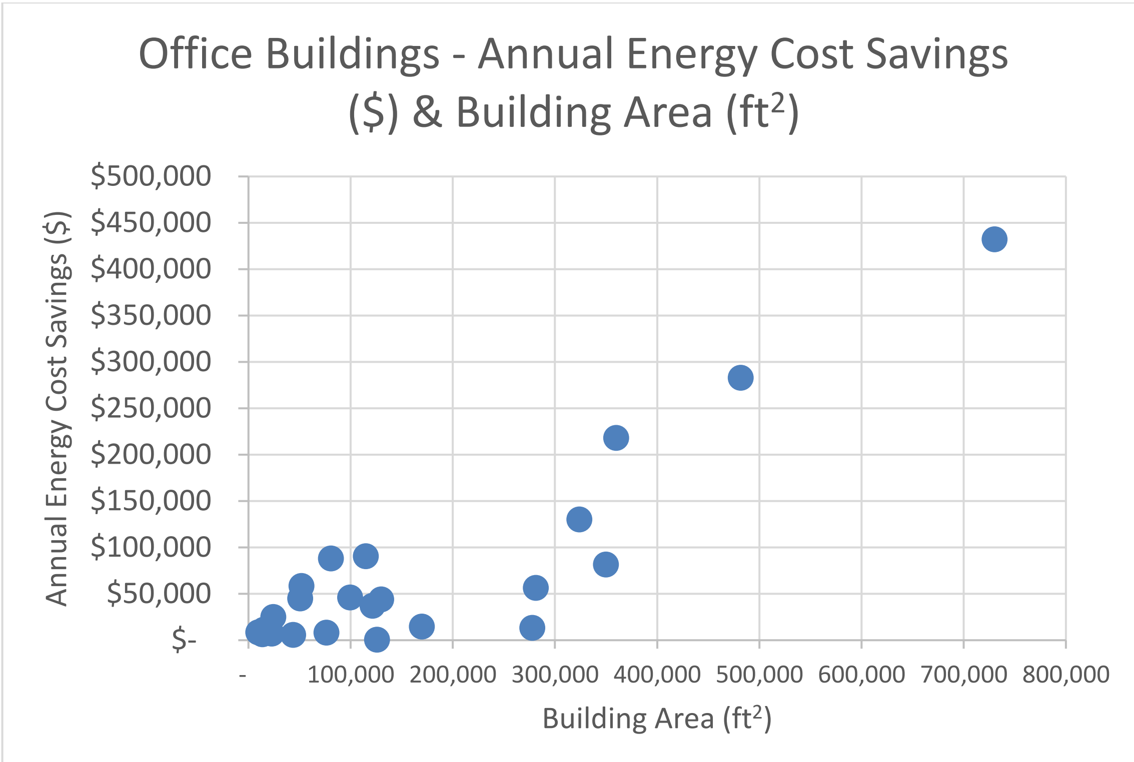

Figure 33. Office buildings - annual energy cost savings ($) and building area (ft^2)

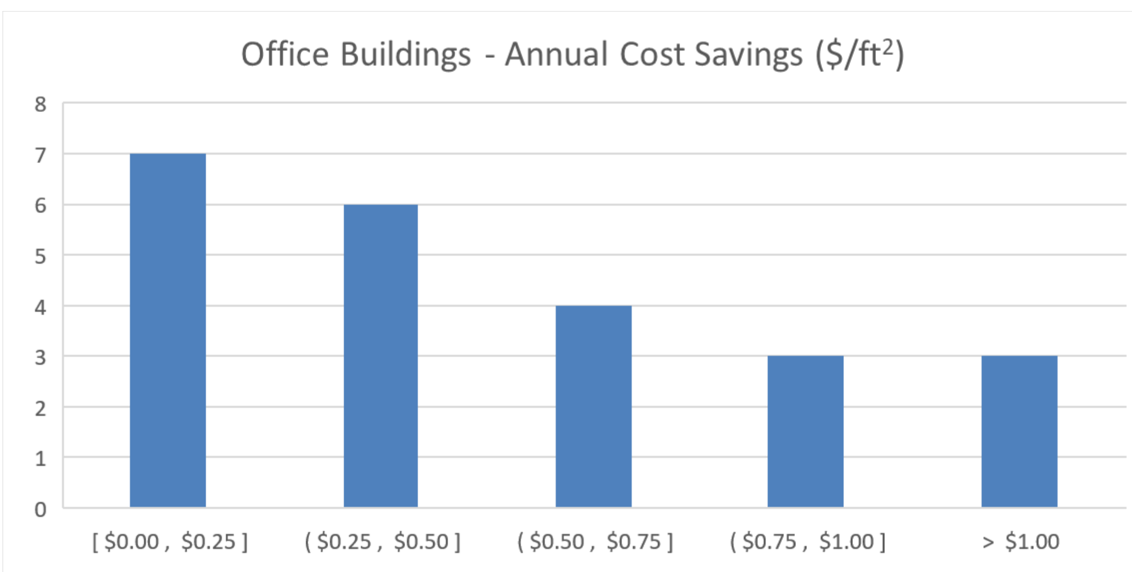

Figure 34. Office buildings - ranges of annual energy cost savings ($/ft^2)

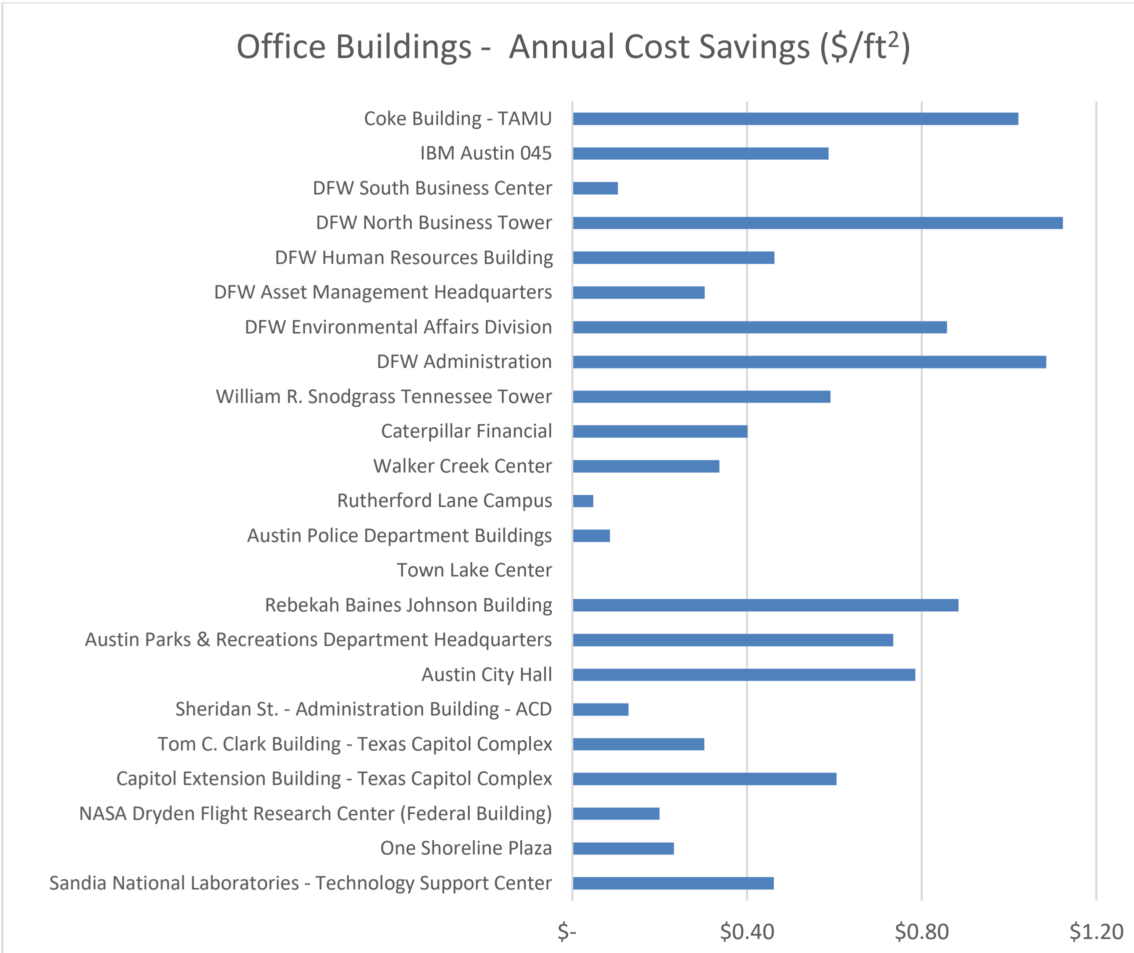

Figure 35. Office buildings - annual energy cost savings ($/ft^2)

4.3 Impact of CC by Climate Zone

The impact of 196 CC projects according to the climate zone designations in ASHRAE Standard 169-2006 Weather Data for Building Design Standards is summarized in Table 7. Of the eight climate zones only zones one through six are represented by the commissioned buildings. The majority of the total annual energy cost savings, about 90%, is from buildings within climate zones 2a, 3a, and 4a. Climate zone 2a which is hot and humid had the largest number of sites (115 sites and 281 buildings) and the largest total annual energy cost savings, over $15 million (average of $0.68/ft²). Climate zone 3a, warm and humid, was represented by 47 sites and 226 buildings with an area of 15,899,691 ft². The total annual energy cost savings for zone 3a were $9,015,772 (average of $0.55/ft²). Climate zone 4a is mixed and humid. There were 8 sites with 10 buildings and over 3 million square feet in zone 4a with an annual cost savings of over $2.1 million (average of $0.58/ft²). The average annual cost savings across all climate zones is $0.51/ft² ranging from $0.06/ft² for climate zone 4c (mixed marine) to $1.18/ft² for climate zone 5a which is cool and humid. Although climate zone 5a has the greatest average annual energy cost savings per square foot, the results are an average of only two sites one with a savings of $2.20/ft² and the other with a savings of $0.16/ft².

Table 7. Summary of Impact of CC by Climate Zone

Climate Zone	# of Sites	Building Area (ft^2)	# of Buildings	2017 $ Cost savings (annual)	2017 $ Cost savings (avg. ann. - $/ft²)
1a - Very Hot (Humid)	1	1,220,465	1	$298,721	$0.24
2a - Hot (Humid)	115	27,341,952	281	$15,369,397	$0.68
2b - Hot (Dry)	2	1,418,615	16	$628,712	$0.44
3a - Warm (Humid)	47	15,899,691	226	$9,015,772	$0.55
3b - Warm (Dry)	12	2,404,969	46	$669,751	$0.30
4a - Mixed (Humid)	8	3,073,147	10	$2,154,708	$0.58
4b - Mixed (Dry)	1	99,579	1	$45,943	$0.46
4c - Mixed (Marine)	1	1,200,000	1	$74,589	$0.06
5a - Cool (Humid)	2	1,257,270	5	$315,369	$1.18
5b - Cool (Dry)	4	3,681,000	21	$477,029	$0.20
6a - Cold (Humid)	3	1,147,273	4	$540,661	$0.86
Totals	**196**	**58,743,961**	**612**	**$29,590,652**	**$0.51**

The annual cost savings, as cost per square foot, is presented for each climate zone in Figure 36, where the maximum, median, average, minimum, and outlier values are indicated. On the plot, for each zone, the x represents the average and the line represents the median. Only climate zones 2a, 3b, and 4a had outliers. Zone 2a had eight outliers whereas zones 3b and 4a only had one outlier each. The climate zones with less than 5 projects are only represented by the average value since the statistical significance of these zones is minimal. All of the climate zones had average annual cost savings below $0.70/ft^2 except zone 5a with an average of $1.18/ft^2 and zone 6a with an average of \$0.86/ft^2. Figure 37 highlights the annual average cost savings, \$/ft^2, in each climate zone.

Figure 36. Annual cost savings (\$/ft^2) by climate zone

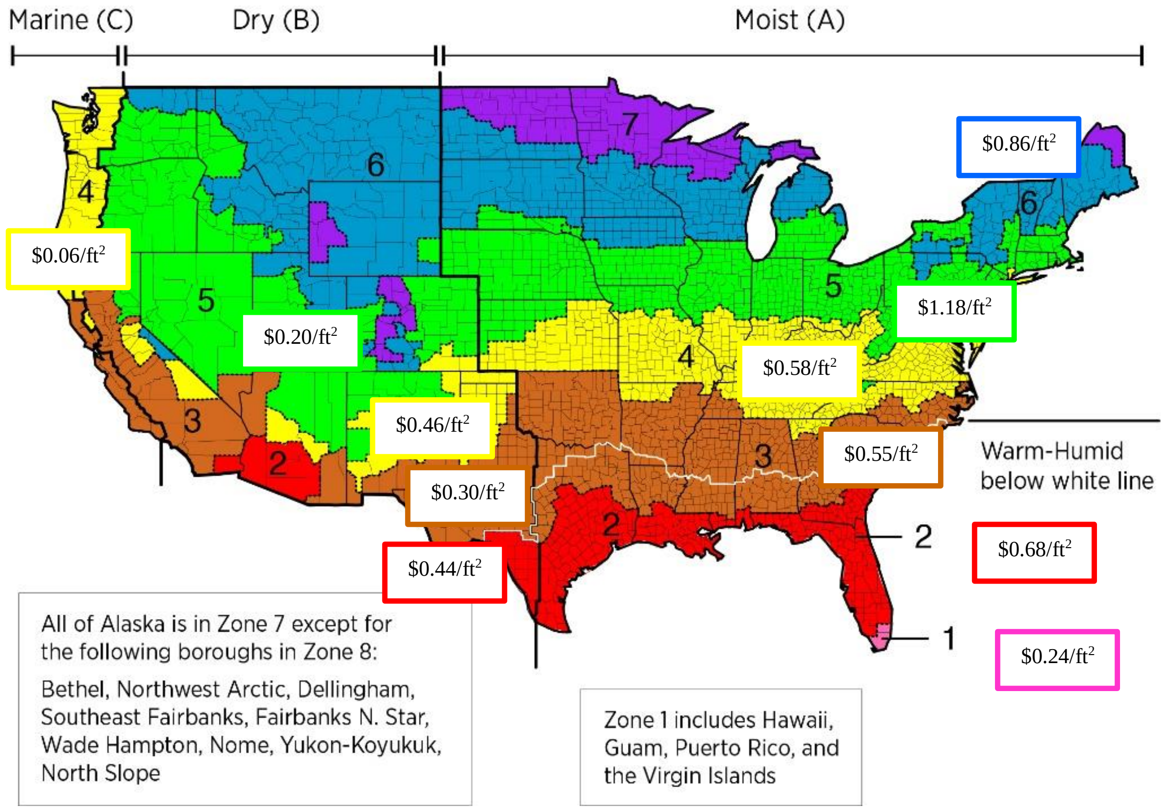

Figure 37. IECC US map with average annual cost savings by climate zone (ICC, 2012)

4.4 CC Assessment Predictions versus Actual Results

The predicted energy cost savings based on CC assessments is compared to actual energy cost savings from the completed CC projects. As of December 2016, there was information available for 156 CC assessment projects with a potential of more than $29.8 million in annual energy cost savings. These projects represent audits at 452 buildings with over 58 million square feet of building area. Of these assessments there were 77 projects where the completed CC information was available as well. These projects represent work at 223 buildings (28,409,638 ft^2) with a predicted energy cost savings of $13.2 million and an actual energy cost savings of $12.4 million. The savings is presented as a fraction of predicted savings achieved.

The actual energy costs savings were less than the predicted energy cost savings for 42 projects ($9.2 million predicted versus $4.9 million actual). Figure 38 shows a comparison of projects with less than predicted energy cost savings. There were three projects with actual energy cost savings greater than 95% of the predicted amount and 12 projects with savings between 65% and 95%. There were 13 projects in both the ranges of 35% to 65% and 5% to 35%. There was only one project with an actual energy cost savings that was less than 5% of the predicted amount.

For 35 projects, the predicted energy costs savings were exceeded ($4.0 million predicted versus $7.5 million actual). Figure 39 shows a comparison of projects with exceeded predicted energy cost savings. There were 12 projects with actual energy cost savings that were up to 1.5 times greater than the predicted savings and 8 projects that were between 1.5 and 2 times greater. There were 6 projects each in the ranges of 2 to 2.5 times greater and 2.5 to 3 times greater than the predicted energy cost savings. There were 3 projects with actual energy cost savings that exceeded the predicted energy cost savings by more than 3 times.

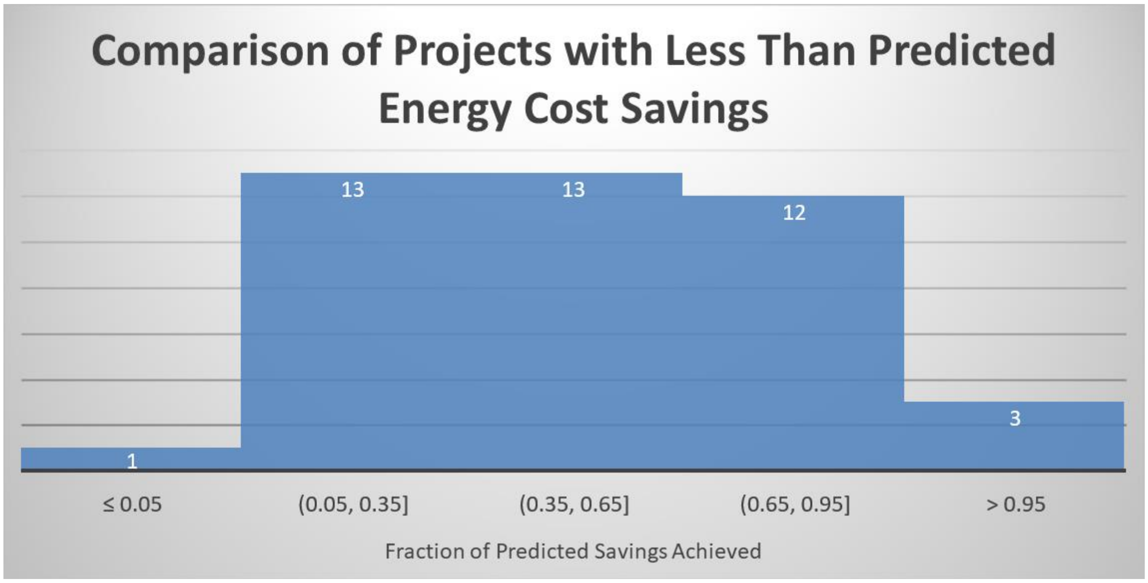

Figure 38. Comparison of projects with less than predicted energy cost savings

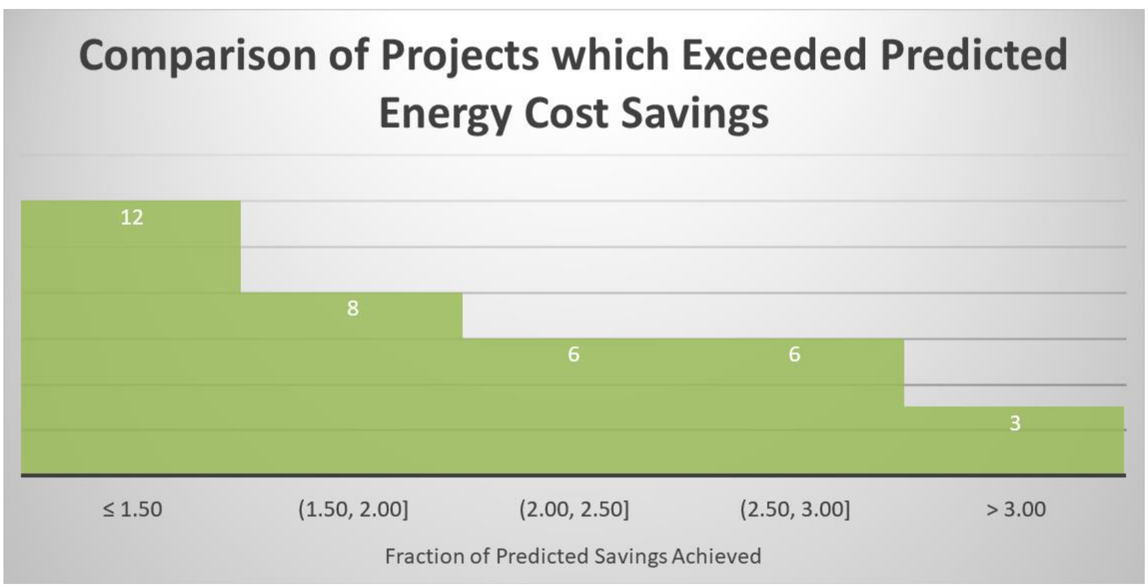

Figure 39. Comparison of projects which exceeded predicted energy cost savings

The level of completeness as determined by the portion of proposed CC measures that were implemented was compared to the level of CC savings. There were 51 projects with sufficient information to compare proposed and actual CC measures; the actual savings were less than predicted for 32 projects and exceeded in 19 projects. For the projects where the savings achieved were less than predicted, the level of CC implementation compared to the fraction of predicted cost savings achieved is presented in Figure 40. For the majority of projects with actual cost savings less than predicted cost savings the percent of CC measures implemented ranged from 40% to 80%. Two of the six projects with less than predicted savings and CC implementation greater than 80% have reported reasons for lower than expected savings. According to the final CC report for the Alexandria VA Medical Center, Alexandria, LA all measures were implemented but the scope of the project was too short to realize the projected savings as some measures were implemented later in the project. At the Town Lake Center, Austin, TX the percent of CC measures implemented was 87.5% but the level of actual cost savings was only 0.4% of the predicted amount. The final report for Town Lake Center indicated two major reasons for the relatively low savings: insufficient cooling capacity for a critical zone and a return air CO_2 sensor failed at 2000 ppm. The percent of CC measures implemented compared to the fraction of predicted savings achieved is presented in Figure 41 for projects which exceeded the predicted cost savings. For the majority of projects that exceeded the predicted savings, the percent of CC measures implemented was greater than 60%. Four of the five projects with CC implementation less than 60% had actual cost savings more than twice the predicted cost savings.

Tables including the project group, site name, fraction of predicted savings achieved, percent of CC measures implemented, and comments about CC implementation are provided in Appendix C.

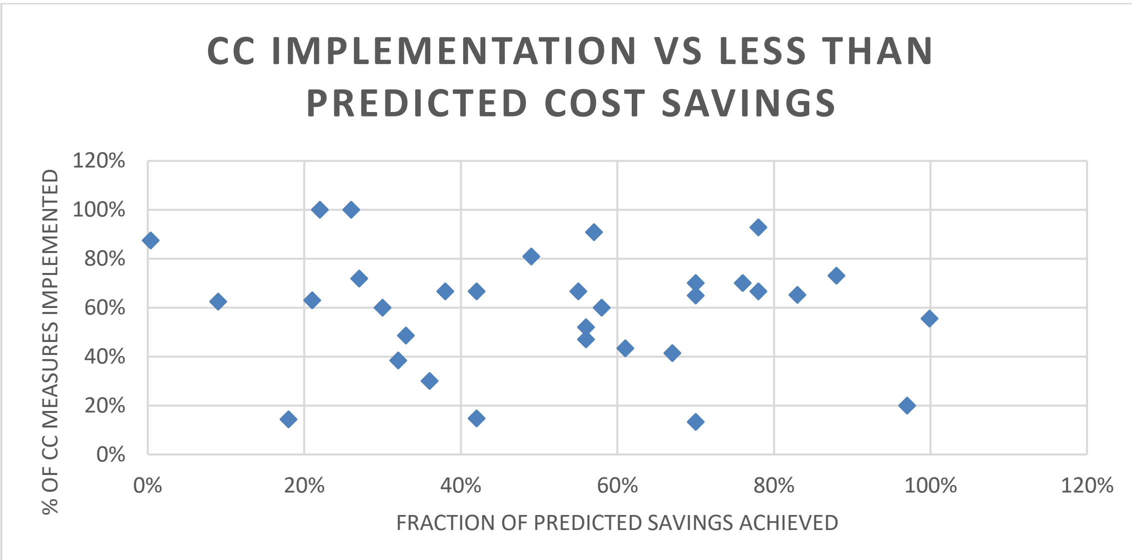

Figure 40. Percent of CC measures implemented compared to fraction of predicted savings achieved for projects with less than predicted savings

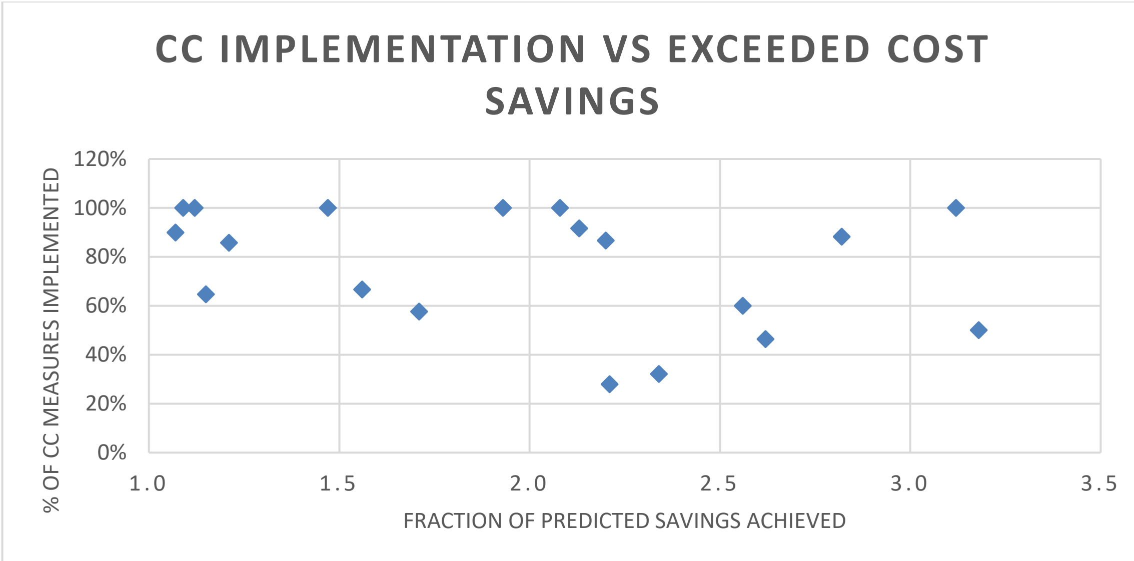

Figure 41. Percent of CC measures implemented compared to fraction of predicted savings achieved for projects which exceeded predicted cost savings

4.5 Case Studies

A brief case study is presented representing each of the building types that were summarized in section 4.2, educational buildings (community college and K-12 schools), healthcare facilities, laboratory buildings, and office buildings, as well as an airport facility. The first three case studies (airport, community college, and K-12 schools) represent projects with multiple buildings. The impact of CC at a large airport over multiple years is exhibited by the Dallas/Fort Worth International Airport case study. The impact of CC at a community college over multiple years is featured in the Alamo Colleges District, San Antonio, TX case study. The impact of CC at K-12 schools is highlighted by the case study of the Austin Independent School District (AISD), Austin, TX. The last three case studies (healthcare facility, laboratory, and office building) represent single building projects. The Reynolds Army Community Hospital located in Fort Sill, OK is included as a case study to feature the impact of CC at a healthcare facility. The Materials Research Institute at Pennsylvania State University, in State College, PA case study demonstrates the impact of CC at a laboratory building. The IBM Austin Building 045, located in Austin, TX, case study highlights the impact of CC at an office building. The savings information presented in this section are 2017 dollars.

4.5.1 Multiple Building Case Studies

4.5.1.1 Case Study 1 – DFW Airport

The Dallas/Fort Worth International (DFW) Airport opened in 1974 and is the fourth largest U.S. airport according to the 65.7 million passengers served in 2016. (Airport Council International, 2017) The CC work at DFW began with an assessment of the 130,000 ft^2 Rent-A-Car (RAC) facility in August 2004. At the time, RAC, which was built in the late 1990s, had the third highest energy consumption of any facility managed by DFW. The CC at RAC began a partnership with the ESL that went beyond CC work; including an energy savings assessment and advanced lighting technologies testing at Terminal B as well as a study of airport O&M practices. The next facility that was commissioned at DFW was the Airport Administration Building in 2007. The CC work at Terminal D also began in 2007 followed by the Energy Plaza in 2008 and Terminal E and Eastside Plant in 2009. The RAC, Administration Building, Energy Plaza, and Terminals D and E are responsible for the majority of the savings at DFW. Several other facilities were added to the scope of the project each year from 2010 to 2015. The DFW sites are separated into five groups and presented in the following tables: Terminals (Table 8), Emergency Response (Table 9), Office (Table 10), Maintenance (Table 11), and Other (Table 12). Each table contains the annual cost savings, building vintage and area, and the start of the CC process.

Table 8. DFW Terminal Summary

Terminals	Year Built	Area, ft^2	Start of CC Process	Annual Savings
Terminal D	2005	1,600,408	2007	$1,730,135
Terminal E	1974	781,000	2009	$182,858

Table 9. DFW Emergency Response Facility Summary

Emergency Response	Year Built	Area, ft^2	Start of CC Process	Annual Savings
AOC/EOC	--	15,900	2012	$20,023
DPS Station 2	--	18,094	2012	$2,178
DPS Station 3	--	8,000	2012	$2,902
DPS Station 4	--	8,000	2012	$2,222
DPS Station 5	--	21,761	2012	$18,006
DPS Station 6	--	--	2013	$377
Fire Training Center	--	--	2013	--

Table 10. DFW Office Building Summary

Office	Year Built	Area, ft^2	Start of CC Process	Annual Savings
Administration	~1987	80,956	2007	$87,875
Environmental Affairs Division	--	9,600	2012	$8,235
Asset Management Headquarters	1974	23,000	2011	$6,965

Table 10. Continued

Office	Year Built	Area, ft^2	Start of CC Process	Annual Savings
Human Resources Building	1989	13,859	2011	$6,414
North Business Tower	1978	52,000	2011	$58,401
Corporate Aviation	--	27,300	2012	$3,177
South Business Center	--	--	2014	$8,002

Table 11. DFW Maintenance Facility Summary

Maintenance	Year Built	Area, ft^2	Start of CC Process	Annual Savings
Rental Car Bus Maintenance Facility	--	--	2012	$7,140
Car Wash Fuel Island	--	--	2012	$120
New Shops Groups*	--	18,000	2011	$11,431
Skylink MSF (Maintenance Storage Facility)	1974	105,844	2011	$76,654
Transportation Facility	1996	23,500	2011	--

*Includes Building B and Warehouse Maintenance D

Table 12. DFW Other Facilities Summary

Other	Year Built	Area, ft^2	Start of CC Process	Annual Savings
Rent-a-Car Facility	~1999	130,000	2004	$162,142
Eastside Plant	--	--	2009	$21,750
Energy Plaza	--	15,900	2008	$1,293,424
Wellness Center	2007	--	2014	--
Data Center (3rd floor Verizon Building)	--	10,800	2012	--
Purchasing Graphic Warehouse	1988	64,000	2011	$8,545
North Remote Parking	--	--	2013	$4,142

Table 12. Continued

Other	Year Built	Area, ft^2	Start of CC Process	Annual Savings
South Remote Parking	--	--	2013	$969
A-B Skybridge	--	--	2014	$29,335
C-D Skybridge	--	--	2014	$5,420
North Control Plaza	--	--	2015	$340
South Control Plaza	--	--	2015	$3,965

The annual cost savings at Terminal D and Terminal E were $1.91 million. The emergency response sites had a total annual cost savings of approximately $45,700. The office buildings had a total annual cost savings of about $179,000. The annual cost savings at the maintenance facilities was slightly above $95,000. The other buildings combined to $1.53 million of annual cost savings. The annual cost savings are presented, in Figure 42, as dollars per square foot for the 20 DFW facilities with available area information. The annual cost savings ranged from $0.10/ft^2 to $1.26/ft^2 with an average of $0.60/ft^2. Five facilities, the Administration building, Rent-a-Car facility, Terminal D, Airport Operations Center/Emergency Operations Center (AOC/EOC), and the North Business Tower, had annual cost savings greater than $1.00/ft^2. The total annual cost savings at DFW was $3.76 million. As of December 2017, the cumulative cost savings were over $34 million.

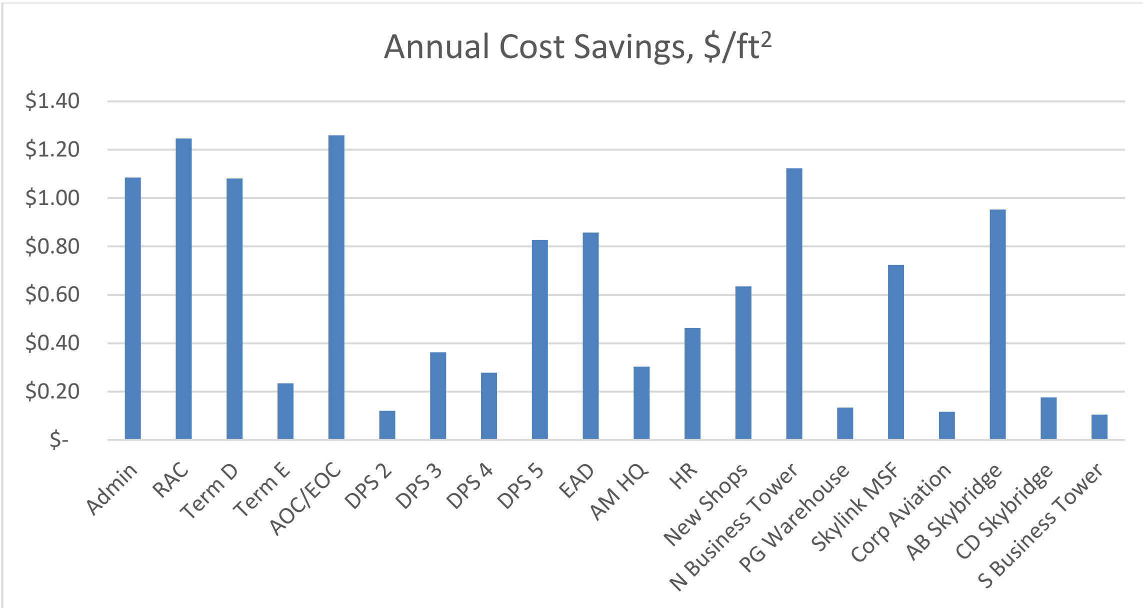

Figure 42. DFW annual cost savings summary

4.5.1.2 Case Study 2 – Alamo Colleges District

The Alamo Colleges District[7] is a network of community colleges located in and around San Antonio, TX. The Alamo Colleges District is comprised of five main campuses: San Antonio College (SAC), Palo Alto College (PAC), St. Philip's College (SPC), Northwest Vista College (NVC), and Northeast Lakeview College (NLC). SPC includes a main campus, the Martin Luther King (MLK) campus, and a satellite campus at a different location, Southwest Campus (SWC). The Alamo Colleges District also has district administration offices and district operations buildings designated as District. Implementation of the CC process at the Alamo Colleges District initially began in 2002 with some of the campuses and administrative buildings totaling 2.2 million square feet. The annual energy cost savings in 2002 was approximately $525,000. Additional buildings and campuses have continuously been added to the scope of the project. As of December 2017, the total campus area is over 5 million square feet and the cumulative cost savings were over $21 million. The annual energy cost savings have been over $2 million since 2013. Additional energy management services have been incorporated beyond CC implementation including a four day work week, demand reduction program, as well as the addition of solar panels and thermal storage tanks. CC is one of the energy management services provided to the Alamo Colleges District by the ESL. The energy cost savings reflect all efforts and the percentage of CC savings cannot be separated.

[7] The Alamo Colleges District was known as the Alamo Community College District or ACCD at the onset of the CC process. The district name was changed to the Alamo Colleges and then to the Alamo Colleges District.

The initial CC process implementation at the Alamo Colleges District began with SAC, PAC, SPC, SWC, and the administrative buildings at Houston and Sheridan Streets. The second group of facilities commissioned included one more campus, NVC, as well as three buildings at other campuses. The new construction warranty period was ending at the time of the assessment in August 2006 for these buildings. The three buildings were the Radio, Television, and Film (RTF) Building at SAC, the Applied Technology (AT) Building at PAC, and Building 3004 at SWC. The scope of the project expanded in 2010, with the addition of the newest campus at the time, NLC, as well as additional buildings at SAC, SPC, PAC, and NVC. The multi-purpose building at SPC was included starting in 2012.

The annual cost savings per campus or building as well as the vintage, building area, and start of the CC implementation process are included in Table 13. The annual cost savings are based on the second year of savings after CC implementation. The annual cost savings ranged from \$0.01/ft^2 to \$0.59/ft^2 with an average of \$0.25/ft^2. The administration buildings are excluded from the average for comparison purposes since they are office buildings. There were no savings realized at the administration building located at Houston St. The administration buildings located at Sheridan St. realized low annual savings of \$0.13/ft^2 compared to the average of \$0.47/ft^2 for all office building projects. The annual savings at SWC during the first year after the CC process implementation were about 4.5 times higher than the savings realized in the second year. The RTF building at SAC had the highest annual savings, \$0.59/ft^2, followed by the Northeast Lakeview College, \$0.43/ft^2.

Table 13. Alamo Colleges District Summary

Campus/Building	**Vintage**	**Area, ft^2**	**Start of CC process**	**Annual Savings, $\$/ft^2$**
San Antonio College	1915-1991	930,340	2002	\$0.17
St. Phillip's College	1942-1993	544,908	2002	\$0.30
Palo Alto College	1987-1991, 1997	389,841	2002	\$0.40
SPC - Southwest Campus	1937, 1940	300,642	2003	\$0.01
Houston St. - Administration Building	1910	30,280	2003	--
Sheridan St. - Administration Building	1960	43,892	2003	\$0.13
Northeast Lakeview College	2008-2010	367,005	2009	\$0.43
Northwest Vista College	1998-2004	587,996	2009	\$0.04
Building 3004 at SWC	2005	50,360	2007	\$0.08
RTF Building at SAC	2004	30,240	2007	\$0.59
AT Building at PAC	2005	29,583	2007	\$0.24
Multipurpose Building at SPC	2009	219,800	2012	\$0.31

The annual cost savings have increased at each of the main campuses by as much as \$0.58/ft^2 (average of \$0.33/ft^2) from the second year of CC savings compared to 2017 savings, as shown in Figure 43. SPC Multipurpose Building is combined with the SPC main campus because the savings analysis was combined after the second year of savings as it was determined that the two central utility plants combined to serve the campus. In order to present the savings on a campus level, the individual buildings were added to their respective campuses; Building 3004 added to SWC total, RTF building added to SAC total, and AT building added to PAC total. Figure 44 shows the change in area of each campus from the second year savings period to 2017. The greatest change in area was at SAC which also realized the greatest change in annual cost savings. However, the increase at PAC was $0.33/ft^2, NLC was $0.44/ft^2, and NVC was $0.32/ft^2 and only PAC had a significant change in area out of these three campuses.

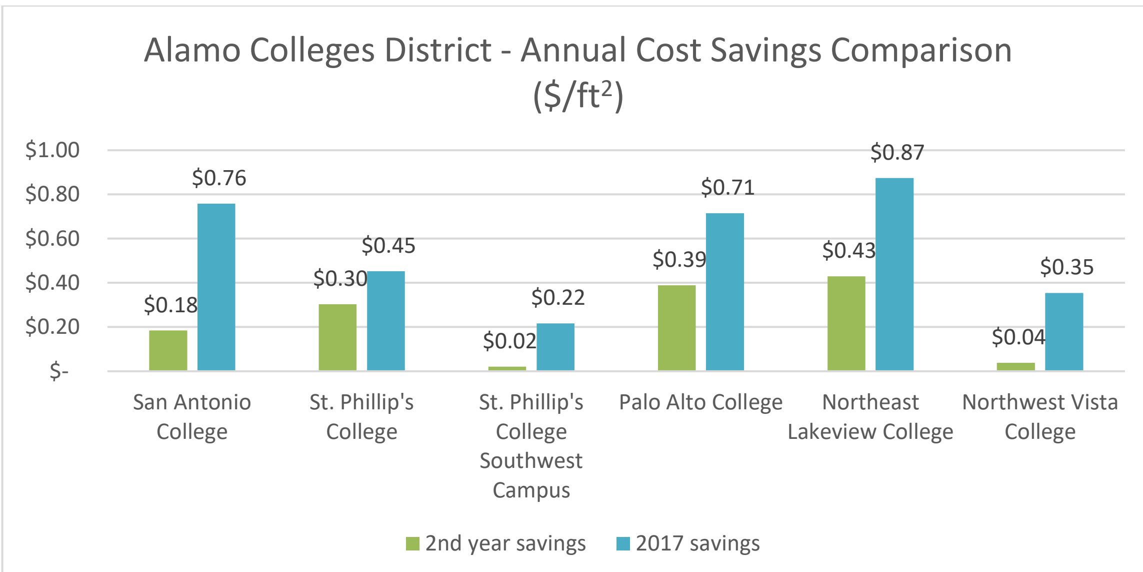

Figure 43. Alamo Colleges District annual cost savings comparison

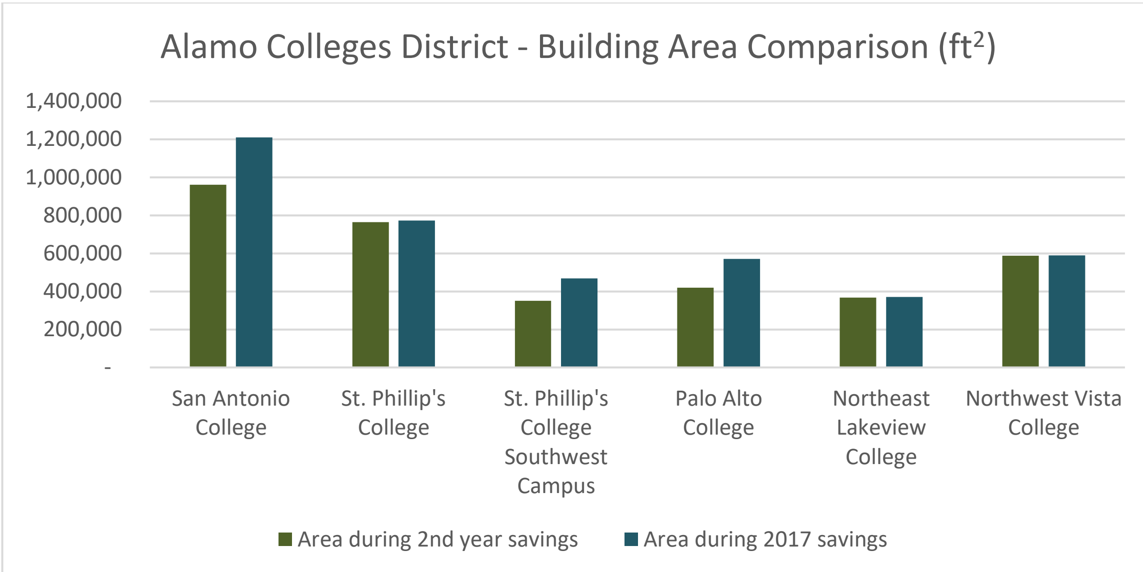

Figure 44. Alamo Colleges District building area comparison

4.5.1.3 Case Study 3 – Austin ISD

The ESL began CC implementation at the Austin Independent School District (AISD) in 2004 with three schools: Akins High School, Galindo Elementary and JJ Pickle Elementary (which includes St. John Community Center). Several projects were completed at various AISD locations up to 2013. In total 37 AISD sites were commissioned: 22 elementary schools, 7 middle schools, 5 high schools and 3 auxiliary service centers totaling about 4.3 million square feet. The annual cost savings were approximately $865,000 for the 29 locations that realized savings and the cumulative cost savings were $7.1 million up to December 2017. The annual cost savings per location as well as the vintage, building area, and CC implementation period are included in Table 14 for the high schools, Table 15 for the middle schools, Table 16 for the elementary schools, and Table 17 for the auxiliary service centers. The annual cost savings for the high schools ranged from \$0.11/ft^2 to \$0.27/ft^2 with an average of \$0.19/ft^2. The annual cost savings for the middle schools averaged \$0.30/ft^2 (ranging from \$0.04/ft^2 to 0.78/ft^2). The elementary schools had annual cost savings ranging from \$0.04/ft^2 to 0.76/ft^2 (average of \$0.25/ft^2). Of the three auxiliary service centers, the St. John Community Center is a part of J.J. Pickle Elementary School building and therefore not considered separately. The other two auxiliary service centers had very different annual cost savings although the buildings have similar areas, one slightly above and one slightly below 35,000 square feet. The Clifton Career Development Center realized \$0.35/ft^2 of annual cost savings while the Delco Activity Center reached \$3.42/ft^2 of savings, the highest of any AISD site despite the fact the center is one of the smallest buildings (35,571 ft^2). Before the CC implementation at the Delco Activity Center there were four air conditioning units running during daytime activities where only 50 to 150 people were present although the units were designed to serve approximately 5,000 people.

Although the high schools are the larger facilities (over 250,000 ft^2) of the district the annual cost savings per square footage is higher on average at the elementary and middle schools. The average annual cost savings for all AISD schools (\$0.25/ft^2, excluding auxiliary service centers) was higher than the average for all K-12 school projects (\$0.23/ft^2).

Table 14. AISD High School Summary

High School	Year Built	Area, ft^2	CC Implementation Period	Annual Savings, $/ft^2$
Akins	2000	316,175	Nov 2005 - Nov 2006	$0.11
Travis	1953	275,890	~Sep - Nov 2012	$0.19
Reagan	--	252,842	May - Aug 2011	$0.19
Anderson	--	265,180	Dec 2011 - Mar 2012	$0.27
Lanier	1966	274,842	Mar 2013 - Aug 2013	--

Table 15. AISD Middle School Summary

Middle School	Year Built	Area, ft^2	CC Implementation Period	Annual Savings, $/ft^2$
Burnet	opened 1961	130,797	Feb - Jun 2009	$0.78
Garcia	--	161,147	~Feb - Sep 2012	$0.18
Parades	opened Jan 2000	137,127	Mar 2007 - Feb 2008	$0.04
Small	1998	154,680	Mar 2007 - Feb 2008	$0.21
Bedichek	--	132,285	Feb 2013 - Oct 2013	--
Webb	1968	120,985	Feb 2013 - Nov 2013	--
Lamar	--	130,714	Mar 2013 - Aug 2013	--

Table 16. AISD Elementary School Summary

Elementary School	Year Built	Area, ft^2	CC Implementation Period	Annual Savings, $/ft^2$
JJ Pickle *	2001	116,000	2005	$0.16
Galindo	1986	85,703	2005	$0.76
Baldwin	opened Aug 2010	86,896	--	--
Clayton	opened Fall 2006	91,960	May 2009 - Mar 2010	$0.59
Sunset Valley	1970,1984,1996	58,063	Jun 2008 - Jun 2009	$0.55
Overton	--	83,365	Aug 2009 - Dec 2010	$0.39
Perez	--	78,000	Mar - Dec 2010	$0.22
Blazier	opened 2007	82,897	Start Nov 2010	$0.21

Table 16. Continued

Elementary School	Year Built	Area, ft^2	CC Implementation Period	Annual Savings, $\$/ft^2$
Casey	opened Aug 1999	80,300	Mar 2007 - Feb 2008	$0.15
Baranoff	opened Aug 1999	69,322	Mar 2007 - Feb 2008	$0.16
Mills	1998	69,610	Mar 2007 - Feb 2008	$0.09
Hart	--	69,610	Mar 2007 - Feb 2008	--
Rodriguez	--	69,342	Mar 2007 - Feb 2008	$0.17
Cowan	opened 1999	69,900	Mar 2007 - Feb 2008	$0.28
McBee	--	70,200	Mar 2007 - Feb 2008	$0.10
Barrington	1969	75,385	Feb 2013 - Oct 2013	--
Blackshear	1948	70,071	Feb 2013 - Oct 2013	$0.04
Cook	1974	67,355	Mar 2013 - Oct 2013	--
Doss	1970	60,521	Jan 2013 - Oct 2013	$0.06
Langford	--	77,748	Feb 2013 - Oct 2013	$0.07
Odom	--	61,009	Mar 2013 - Aug 2013	$0.12
Wooldridge	1969	70,474	Feb 2013 - Oct 2013	$0.43

*Includes St. John Community Center.

Table 17. AISD Auxiliary Center Summary

Auxiliary Center	Year Built	Area, ft^2	CC Implementation Period	Annual Savings, $\$/ft^2$
Delco Activity Center	2003	35,571	Mar - Jun 2008	$3.42
Clifton Career Development Center	Dedicated 1977	35,198	Dec 2011 - Mar 2012	$0.35
St. John Community Center	2001	Included with JJ Pickle ES		

4.5.2 Single Building Case Studies

4.5.2.1 Case Study 4 – Reynolds Army Community Hospital

The Reynolds Army Community Hospital located in Fort Sill, OK is part of the MEDCOM CC project group. The 512,000 ft^2 hospital was built in 1989. The CC assessment was completed in 2002. The first phase of CC implementation occurred between October 2004 and September 2007 with follow up work completed in 2010. The annual savings were approximately $514,000. The annual savings per building area was $1.00/ft^2, greater than the average of all MEDCOM sites ($0.47/ft^2) and the average for all healthcare sites ($0.64/ft^2). The cumulative cost savings were $2.5 million up to December 2017.

4.5.2.2 Case Study 5 – Penn State Materials Research Institute

The Materials Research Institute, MRI, is located on Pennsylvania State University campus in State College, PA. The MRI is primarily a laboratory building, built around 1990, which is 57,270 ft^2. The CC implementation period was from May to September 1998. The annual savings were about $126,000 and the cumulative savings up to December 2017 were $1.5 million. The annual savings per building area was $2.20/ft^2, greater than the average of all laboratory buildings ($1.51/ft^2)

4.5.2.3 Case Study 6 – IBM Austin Building 045

The IBM Austin Building 045, an office building located in Austin, TX, is 481,892 ft^2 with an unknown vintage. The CC assessment for Building 045 occurred from July 28 to July 30, 2004, followed by CC implementation for an unknown period. The annual savings were almost \$283,000 which were less than the predicted savings of \$331,000. However, IBM decided to quit implementation before the project was complete since the measures that were not implemented were expected to provide a lower return on investment than the initial measures implemented. The annual savings of \$0.59/ft^2 is greater than the average for all office buildings, \$0.49/ft^2. The cumulative cost savings were \$2.7 million up to December 2017.

4.6 Summary of Results

The impact of Continuous Commissioning was evaluated and analyzed in several ways. The overall impact of CC was presented as both annual and cumulative energy cost savings. The occupant comfort issues were identified and highlighted by examples. The impact of CC according to building type and climate zone was summarized. Comparisons between assessment predictions and achieved results were made. Several case studies were presented for different building types highlighting the impact of CC.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

The primary goal of this study was to quantify the impact of Continuous Commissioning® since the inception of the process in the early 1990s. A comprehensive evaluation of the impact of CC projects implemented primarily by the Texas A&M Engineering Experiment Station's Energy Systems Laboratory was completed after a systematic review of the CC projects. 340 projects were compiled and reviewed.

Several quantitative analysis and comparison tasks were completed to accomplish the research objectives. The overall impact of Continuous Commissioning was analyzed including the energy cost savings both annual and cumulative as well as identification of non-energy impacts. The evaluation of the impact of CC by building type included education buildings, health care facilities, laboratory facilities, and office buildings. ASHRAE Standard 169-2006 was employed for the analysis of the impact of CC by climate zone. The project objectives were compared to the project results using the predicted and actual energy cost savings. The CC energy cost savings were compared based on the level of project completeness as determined by the proposed and implemented CC measures. The impact of CC was presented for several case study projects.

5.2 Conclusions

The 340 CC projects that were compiled and reviewed include 920 buildings of which 895 had building area data available representing over 98 million square feet of building area. The annual energy cost savings, as of December 2016, were more than \$29.7 million (2017 \$), for 198 CC projects of the 340 compiled. The total area of these projects was greater than 60 million square feet at over 600 buildings. There were 13 projects with annual cost savings over \$500,000 while the majority of the projects had annual cost savings under \$500,000. The projects with the larger cost savings generally had more facilities (higher building area) or a longer, more in depth project scope. The cumulative cost savings up to December 2017 are \$390 million (2017 \$). The largest cumulative cost savings in excess of \$150 million have been realized at Texas A&M University. According to the project reports, there were comfort issues identified in 59 CC projects some of which had multiple issues. There were 54 projects with thermal comfort issues identified, nine projects with indoor air quality concerns, and five projects with noise complaints. The comfort issues were resolved for at least 34 of the projects.

The impact of CC has been summarized for four different building types. The building types considered are educational, healthcare, laboratory, and office. For these building types, there were 159 completed CC projects with annual cost savings data. The 76 buildings categorized as educational had an average annual cost savings of \$0.48/ft^2. The 46 healthcare facilities had an average annual cost savings of \$0.64/ft^2. The average annual cost savings for 13 laboratory facilities was \$1.51/ft^2. There were 24 offices with an average annual cost savings of \$0.49/ft^2. The impact of CC projects according to the climate zone designations in ASHRAE Standard 169-2006 Weather Data for Building Design Standards was evaluated. The 196 CC projects which occurred in the U.S. were considered. The majority of the total annual energy cost savings, about 90%, is from buildings within climate zones 2a hot and humid, 3a warm and humid, and 4a mixed and humid. The average annual energy cost savings was \$0.68/ft^2 for climate zone 2a, \$0.55/ft^2 for climate zone 3a, and \$0.58/ft^2 for climate zone 4a.

As of December 2016, there was information available for 156 CC assessment projects (from the 340 CC projects compiled) comprised of 452 buildings in excess of 58 million square feet of building area. The predicted annualized energy cost savings were greater than \$29.8 million for these projects. The completed CC information was available for 77 of the assessments, representing CC implementation at 223 buildings with over 28 million square feet of building area. The combined predicted annual energy cost savings of these 77 projects was \$13.2 million and the actual energy cost savings were \$12.4 million. The actual energy cost savings were less than the predicted energy cost savings for 42 of the 77 projects (\$9.2 million predicted versus \$4.9 million actual). The proposed and implemented CC measures were compared for 32 of those 42 projects with available information and for the majority the percent of CC measures implemented ranged from 40% to 80%. For 35 of the 77 projects with completed CC information available, the actual energy cost savings exceeded the predictions (\$4.0 million predicted versus \$7.5 million actual). The actual energy costs were more than doubled for 16 of these projects. There was sufficient information to compare proposed and implemented measures for 19 of the 35 projects with cost savings greater than predicted and it was found that for the majority of those projects, more than 60 percent of the CC measures were implemented.

In conclusion, for over two decades the Continuous Commissioning projects implemented primarily by the Texas A&M Engineering Experiment Station's Energy Systems Laboratory have resulted in significant energy and cost savings as evident by the achievement of over $29.7 million in annualized energy cost savings and over $390 million in cumulative energy cost savings.

5.3 Future Work

The results of this study will continue to be useful on an ongoing basis once transitioned into a database that can be updated and maintained as Continuous Commissioning projects are completed. It is recommended that the impact of Continuous Commissioning be systematically compared to the impact of existing building commissioning implemented by other providers. The meta-analysis prepared by Mills, et al. (2004) which was later expanded in 2009 (Mills, 2009) is the largest known compilation of commissioning projects. Since the meta-analysis contains CC projects it will be necessary to extract the CC project data. It is also advisable to select some commissioning projects for comparison that have occurred in the last several years (since the Mills 2009 update).

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[9] A version of this report contains a title page added in 2006 with the registered sign for CC.
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APPENDIX A

BUILDING LISTS

Table A-1. Academic Medical Centers, Various Locations

Building Name	Year Built	Area (ft^2)
Basic Research - UTMDA Cancer Center	1986	120,376
Basic Sciences - UTMB Galveston	1971	137,856
Biomedical Research Building - University of Colorado HSC	1992	202,000
Clinical Sciences - UTMB Galveston	1970	124,870
Dental School - UTHSC San Antonio	1972	484,019
Fairview University - Corporate Building	--	30,000
Fairview University - Medical Center (Riverside East & Central Plant)	1957	510,000
Fairview University - Medical Center (Riverside North)	--	37,273
Fairview University - Medical Center (Unit J)	1981	600,000
John Sealy North - UTMB Galveston	1978	54,494
John Sealy South - UTMB Galveston	1978	373,085
Medical School Building - UTHSC Houston	1974, 1976	877,187
Moody Library - UTMB Galveston	1972	67,380
New Clinic - UTMDA Cancer Center	1973	276,466
Old Clinic & Lutheran Pavilion - UTMDA Cancer Center	1950 - 1973	499,013
School of Public Health - UTHSC Houston	1975,1985	233,738
TAMU Health Science Center - Houston - Institute of Biosciences and Technology building	1992	228,420

Table A-2. Alamo Colleges District, San Antonio, TX

Building Name	Year Built	Area (ft^2)
San Antonio College (SAC)	1915 - 1991	930,340
St. Phillip's College (SPC)	1942 - 1993	544,908
SPC - Southwest Campus (SWC)	1937, 1940	300,642
Palo Alto College (PAC)	1987-1991, 1997	389,841
Houston St. - Administration Building	1910	30,280
Sheridan St. - Administration Building	1960	43,892

Table A-2. Continued

Building Name	Year Built	Area (ft^2)
Northeast Lakeview College	2008 - 2010	367,005
Northwest Vista College	1998 - 2004	587,996
Building 3004 at SWC	2005	50,360
RTF Building at SAC	2004	30,240
AT Building at PAC	2005	29,583
Multipurpose Building at SPC	2009	219,800

Table A-3. Austin Independent School District, TX

Building Name	Year Built	Area (ft^2)
Akins High School	2000	316,175
JJ Pickle Elementary School	2001	116,000
Galindo Elementary School	1986	85,703
Baldwin Elementary School	opened Aug 2010	86,896
Burnet Middle School	opened 1961	130,797
Clayton Elementary School	opened Fall 2006	91,960
Delco Activity Center	2003	35,571
Sunset Valley Elementary School	1970,1984,1996	58,063
Overton Elementary School	--	83,365
Perez Elementary School	--	78,000
Travis High School	1953	275,890
Garcia Middle School	--	161,147
Blazier Elementary School	opened 2007	82,897
Reagan High School	--	252,842
Anderson High School	--	265,180
Clifton Career Development Center	dedicated 1977	35,198
Gorzycki Middle School	opened Fall 2009	169,045
Parades Middle School	opened Jan 2000	137,127
Casey Elementary School	opened Aug 1999	80,300
Baranoff Elementary School	opened Aug 1999	69,322
Mills Elementary School	1998	69,610
Hart Elementary School	--	69,610
Rodriguez Elementary School	--	69,342

Table A-3. Continued

Building Name	Year Built	Area (ft^2)
Cowan Elementary School	opened 1999	69,900
McBee Elementary School	--	70,200
Small Middle School	1998	154,680
Barrington Elementary School	1969	75,385
Bedichek Middle School	--	132,285
Blackshear Elementary School	1948	70,071
Cook Elementary School	1974	67,355
Doss Elementary School	1970	60,521
Langford Elementary School	--	77,748
Lanier High School	1966	274,842
Odom Elementary School	--	61,009
Webb Middle School	1968	120,985
Lamar Middle School	--	130,714
Wooldridge Elementary School	1969	70,474

Table A-4. City of Austin, TX

Building Name	Year Built	Area (ft^2)
Austin-Bergstrom International Airport (ABIA), AUS	opened 1999	686,023
Austin City Hall	2004	115,000
Pearson Education Building 905	1999	226,076
George Washington Carver Museum & Cultural Center	--	36,000
Mexican American Cultural Center	2007	32,000
Austin Parks & Recreations Department HQ	--	15,041
Palmer Events Center and Parking Garage	2001 & 2002	131,000
Rebekah Baines Johnson Building	1968	50,809
Town Lake Center	1985	126,000
One Texas Center	1983	224,626
JH Faulk Central Library	1978	110,633
Austin History Center	1933	76,176
APD HQ, APD Patrol Building, COA Municipal Court Building	1981,1981,1954	169,882
Rutherford Lane Campus	N/A	278,000
Walker Creek Center	--	130,000
Millennium Youth Center	1998	55,000

Table A-5. College Station Independent School District, TX

Building Name	**Year Built**	**Area (ft^2)**
Rock Prairie Elementary School	--	--
College Station Junior High School	--	140,000

Table A-6. Conroe Independent School District, TX

Building Name	**Year Built**	**Area (ft^2)**
Birnham Woods Elementary School, Spring, TX	2009	124,527
Buckalew Elementary School, Spring, TX	1998	89,600
Washington Junior High School, Conroe, TX	1954	144,966
TWHS College Park High School, The Woodlands, TX	2005	372,960

Table A-7. Dallas/Fort Worth International Airport, TX

Building Name	**Year Built**	**Area (ft^2)**
Administration	~1987	80,956
Rent-a-Car Facility	~2000	130,000
Terminal B	1972, renovations/additions 1998, 1999, 2004	784,131
Terminal D	2005	1,600,408
Terminal E	1974	781,000
Eastside Plant	--	--
Energy Plaza	--	15,900
Wellness Center	2007	--
AOC/EOC	--	15,900
Data Center (3rd floor of Verizon Building)	--	10,800
DPS Station 2	--	18,094
DPS Station 3	--	8,000
DPS Station 4	--	8,000
DPS Station 5	--	21,761
Rental Car Bus Maintenance Facility	--	--
Environmental Affairs Division	--	9,600
Car Wash Fuel Island	--	--
Asset Management Headquarters	1974	23,000

Table A-7. Continued

Building Name	Year Built	Area (ft^2)
Human Resources Building	1989	13,859
New Shops Groups (Building B & Warehouse Maintenance D)	--	18,000
North Business Tower	1978	52,000
Purchasing Graphic Warehouse	1988	64,000
Skylink MSF (Maintenance Storage Facility)	1974	105,844
Transportation Facility - Vehicle maintenance	1996	23,500
Corporate Aviation	--	27,300
DPS Station 6	--	--
Fire Training Center	--	--
North Remote Parking	--	--
South Remote Parking	--	--
Taxi Q Building	--	--
A-B Skybridge	--	--
C-D Skybridge	--	--
South Business Center	--	--
North Control Plaza	--	--
South Control Plaza	--	--

Table A-8. Fort Worth Independent School District, TX

Building Name	Year Built	Area (ft^2)
Sims Elementary School	dedicated 1989	62,400
Dunbar Middle School (renamed Jacquet MS - Fall 2015)	~1952	92,884

Table A-9. Houston Airport System, Houston, TX

Building Name	Year Built	Area (ft^2)
William P. Hobby Airport, HOU	1940	633,833
George Bush Intercontinental Airport, IAH, Terminal A	1969	826,806

Table A-10. IBM, Various Locations

Building Name	Year Built	Area (ft^2)
IBM Austin 901	--	216,000
IBM Austin 045	--	481,892
IBM 041/042	--	182,640
IBM 903 & 905	--	386,535
IBM Atlanta	1977,1987,1998, &2003	1,074,000
IBM Boulder	1964-1987	2,400,000
IBM East Fishkill	--	4,792,552
IBM Poughkeepsie site - Building B/008, B/715 and the central utility plant (B/020)	--	172,000
IBM Rochester	--	--
IBM Silicon Valley Lab & Almaden Research Facility	--	600,000
IBM Southbury	--	1,200,000
IBM Tucson	1979	604,780
IBM UK - Greenford, North Harbour	--	578,138
IBM UK - Warwick	--	231,693
IBM UK - Hursley	--	721,182
IBM Burlington	--	434,000
IBM Columbus	--	220,000
IBM Gaithersburg	--	260,000
IBM Hazelwood Data Center	--	1,090,041
IBM Austin - Building 902,904 & 906	--	--
IBM Raleigh-Durham	--	--
IBM Bromont & Viger	--	966,000
IBM Dallas	--	168,000
IBM Toronto - 3600 Steeles	--	700,000
IBM Riverside, Ottawa, ON Canada	--	--
IBM Somers	--	1,200,000
IBM NY	--	--
IBM Toronto - 8200 Warden & 245 Consumers Rd	--	--
IBM Toronto - 3500 Steeles, 100 Gough, 3755 Riverside	--	--

Table A-11. U.S. Army Medical Command (MEDCOM), various locations

Building Name	Year Built	Area (ft^2)
Brooke Army Medical Center	1994	1,468,593
Walter Reed Army Institute of Research	--	520,000
Eisenhower Army Medical Center	--	622,000
Evans Army Community Hospital	1980s	511,000
Blanchfield Army Community Hospital	1979	440,000
Bayne-Jones Army Community Hospital	1983	367,000
Madigan Army Medical Center	1992	1,200,000
Reynolds Army Community Hospital	1989, 1994	512,100
Womack Army Medical Center	2000	1,020,000
Wood Army Community Hospital	1965 w/renovations	449,834
Winn Army Community Hospital	1983	332,872
Lyster Army Community Hospital	1963, 1983 addition	248,684
BG Crawford F. Sams U.S Army Health Center	--	--
Brian Allgood Army Community Hospital	mid 1970s	189,147
R. W. Bliss Army Health Center	--	115,000
Martin Army Community Hospital	1958, 1975 addition, 1980 renovation	393,233
Tripler Army Medical Center	1948	1,220,465
Moncrief Army Community Hospital	1972	323,280
Guthrie Ambulatory Clinic & associated support buildings	1990	122,329
Weed Army Community Hospital & associated buildings	1966	108,000
Keller Army Community Hospital	--	134,140
Fox Army Health Center -- Redstone Army Arsenal	1978	126,986
Kenner Army Health Clinic	1961	146,412
Ireland Army Community Hospital	1955, 1976 addition	462,410
Irwin Army Community Hospital	1955, 1975 expansion	380,736
William Beaumont Army Medical Center	1972, 1982 addition, 1995	700,955

Table A-11. Continued

Building Name	**Year Built**	**Area (ft^2)**
Darnall Army Medical Center	1965, 1984 renovation (doubled size)	504,202
Heidelberg Health Care Building 3613	~1935	248,256
Kimbrough Ambulatory Care Center	1960	168,694
McDonald Army Community Hospital	1962,1972 renovations	129,874
Bassett Army Community Hospital	2007	313,202
Munson Army Health Center	1985	100,000
Landstuhl Regional Medical Center	1953	1,000,000
Wiesbaden and Pulaski Barracks	1945, 1953, 2003	90,520

Table A-12. The Pennsylvania State University, State College, PA

Building Name	**Year Built**	**Area (ft^2)**
Agricultural Sciences Building Complex	--	164,037
Bryce Jordan Center	1995	410,096
Materials Research Institute	1990	57,270

Table A-13. Smith Seckman Reid, Inc. Commissioning Group (SSRCx)

Building Name, Location	**Year Built**	**Area (ft^2)**
Caterpillar Financial, Nashville, TN	--	--
Covenant Health Morristown-Hamblen Hospital, Morristown, TN	--	--
Franklin Foundation Hospital, Franklin, LA	--	61,000
Mobile Infirmary Medical Center, Mobile, AL	--	953,705
Thomas Hospital, Fairhope, AL	--	--
William R Snodgrass Tennessee Tower, Nashville, TN	--	730,491

Table A-14. State of Texas Facilities, Various Locations

Building Name, Location	Year Built	Area (ft^2)
Terrell State Hospital, Terrell, TX	1960	499,356
Brenham State School (now Brenham State Supported Living Center), Brenham, TX	opened 1974	362,249

Table A-15. State of Utah, Salt Lake City, UT

Building Name, Location	Year Built	Area (ft^2)
Salt Lake Community College (South City Campus)	1930s, renovated/ reopened 1980s	350,000
Government Office Buildings	1977 - 1996	1,337,170
Tax Commission Building	--	206,000
Work Force Services Administration Building	--	143,500
Matheson Courthouse	1997	420,000

Table A-16. Tarrant County College District, Tarrant County, TX

Building Name, Location	Year Built	Area (ft^2)
Southeast Campus, Arlington, TX	1996	590,000
Trinity River Campus, Ft. Worth, TX	2003, 2008 renovated	425,000

Table A-17. Texas A&M University System (TAMUS), Various Locations

Building Name, Location	Year Built	Area (ft^2)
Texas A&M University-Corpus Christi, TX	founded 1947	826,300
Prairie View A&M University, Prairie View, TX	1939 - 2001	1,348,333
Texas A&M International University, Laredo, TX	Building info in separate table	

Table A-18. Texas A&M University, College Station, TX

Building Name	Year Built	Area (ft^2)
Biological Science Building West (#449)	1967	96,000
Biological Science Building East (#467)	1950	53,500
Wing 86 Chemistry Complex (#376) (CHAN - Chemistry Addition)	1986	115,797
Wing 72 Chemistry Complex (#484)	1972	63,000
Richardson Petroleum Engineering Building (#387)	1989	113,700
Heep Center (#1502)	1977	158,979
Heldenfels (#521)	1977	104,959
Reed McDonald (#436)	1967	80,218
Reynolds Medical Science (#1504)	1983	169,859
Board of Regents (#455)	1972	21,000
Bright Aerospace (#353)	1989	148,837
Engineering Physics Building, EPB (#391,392)	1986	182,360
Harrington Tower (#435)	1973	130,844
Harrington Annex (Education Center) HECC (#438)	1974	61,680
Bush Academic (Allen Building)	1997	133,327
G. Rollie White Coliseum (#453)	1955, AC system add 1966	177,838
McKenzie Airport Terminal at Easterwood Airport, CLL (#1262)	1957, 1990	32,600
Halbouty Geosciences Building (#490)	1932	120,800
Langford Architecture "A" Building (#398)	1974	102,105
Wisenbaker Engineering Building (#682)	1983	177,700
Bush Shared Use	1997	61,658
Biophysics and Biochemistry Building (#1507)	1990	150,000
Mitchell Institute and Physics Building (#296-297)	2009	189,617
Jack E Brown CHEM Building (#386)	2005	205,000
Kleberg (#1501)	1978	165,031
Evans Library (#468)	1968, 1979 addition, 1998 renovation	712,093
Interdisciplinary Life Sciences Building (#1530)	2006	218,540
Veterinary Research Building (#1197)	1993	114,666
Vet Med Research Building Addition (#1811)	2010	48,700
Student Recreation Center (#1560)	1995	345,693

Table A-18. Continued

Building Name	Year Built	Area (ft^2)
Veterinary Small Animal Hospital (#1085)	1981	103,440
Wehner Business Administration Building (#1510)	1995, 2002 addition	259,681
Veterinary Large Animal Hospital (#1194)	1993	140,865
Laboratory Animal Care Building (LARR) (#972)	1978	46,972
Bush Library: Museum & Archive (#1606)	1997	121,678
Sanders Corps of Cadets (#384)	1992	19,363
Coke Building (#461)	1951	24,466
Gilchrist TTI (#1600)	1999	67,143
Duncan Dining (#450)	1939, 2004 renovations	128,482
Sbisa (#495)	1912	94,233
Price Hobgood AG Engineering Research Lab (#1508)	1983	27,666
Leonard Hall Dorm 7 (#406)	1938	36,893
Haas Residence Hall (#549)	1979	69,668
Koldus (#383)	1992	110,272
Underwood Residence Hall (#349)	1981	81,730
Texas A&M Institute for Pre-Clinical Studies (TIPS) Building (#1904)	2009	113,559
Zachry Engineering Center (#0518)	1972	324,400
Reed Arena (#1554)	opened 1998	230,000
Rudder Tower and Rudder Theatre Complex (#0446)	1974	302,240
Cox-McFerrin Center (#1558)	opened 2006	68,000
McNew Laboratory (#0740)	1967	20,904
Blocker Building (#0524)	1981	257,953
Horticulture/Forest Science Building (#1506)	1984, 1987	118,648
Heaton Hall (#0481)	1925, 1977 renovation	13,640
Veterinary Medical Science Building (#0507)	1953	69,367
Office of the State Chemist (#1810)	2006	19,132
Doherty Building (#0513)	1960	42,336
Luedecke (Cyclotron) Building (#0434)	1967, 2012 addition	80,464
Peterson Building (#0444)	1962	84,831

Table A-18. Continued

Building Name	Year Built	Area (ft^2)
Borlaug Center for Southern Crop Improvement (#1513)	1991, 1997 addition	68,739
Veterinary Medicine Administration Building (#1026)	1968	94,680
Henderson Hall (#0425)	1958, 1974 renovation	22,185
Cain Hall (#0439)	1974, 2004 renovation	92,812
West Campus Library (#1511)	1994	68,125
Butler Hall (#465)	1916	29,699
Eller O&M Building (#443)	1973	180,316
Computer Services Center (#0516)	1959	30,014
Data Processing Center (DPC Annex #0517)	1966	26,220
Donald L Houston Building (FSIS) (#1603)	2002	--
Texas Vet Med Diagnostic Lab (#1041)	1969	55,169
Animal Industries (#472)	1932	44,856
Anthropology (#0477)	1952	51,592
CE/TTI Building (#0385)	1987	157,844
Moore-Connally Building (#3200)	1991	--
Cushing Library (#0468)	1929	--
Francis Hall (#0476)	1922	36,850
J.K. Williams Administration Building (#0473)	1932	69,898
Kreuger Residence Hall (#0441)	1972	112,133
Kyle Field (#0367)	1927	489,000
McFadden Hall (#0550)	1979	62,156
Mosher Hall (#0433)	1976	155,430
Memorial Student Center Complex (#0454)	1951	--
Nagle Hall (#0506)	1909	32,306
Read Athletic Building (#0369)	1979	153,886
Teague Building or Research Center (#0445)	1966	62,515
Langford Architecture "B" Building (#0359)	1963	28,545
Langford Architecture "C" Building (#0432)	1963	73,020
Glasscock History Building (#0470)	1921	39,887
Civil Engineering Building (#0492)	1932	56,537
MSC Annex (#0581)	--	--
Physical Plant Complex (#1156)	1987	101,704
Rudder Residence Hall (#0291)	1989	67,283

Table A-19. Texas A&M International University, Laredo, TX (grouped with TAMUS)

Building Name	Year Built	Area (ft^2)
Building L - Lamar Science	2005	79,000
Building K - Fine and Performing Arts	2001	121,745
Building M - Kinesiology and Recreation	2007	47,973
Building D - Central Utility Plant	1995	9,840
Building A - Library	1995	168,427
Building I - Western Hemispheric Trade Center	2001	58,000
Building J - Student Development	2002	99,000
Building B - Bullock Hall	1995	33,728
Building C - Cowart Hall	1995	33,728
Building E - Pellegrino Hall	1997	44,685
Building F - Canseco Hall	1997	44,755
Building G - Old Kinesiology	1997	55,682
Building H - Physical Plant	1997	17,272

Table A-20. Texas Capitol Complex, Austin, TX

Building Name	Year Built	Area (ft^2)
John H Winters Building	--	482,584
Lyndon B Johnson Building	1969	299,512
Lorenzo de Zavala Archives & Library	1960	111,244
James E. Rudder Building	Original unknown, 1988 remodel/renovation	77,880
John H. Reagan Building	1961	161,787
Stephen F. Austin Building	1973	418,103
Tom C. Clark Building	1956	121,654
William B. Travis Building	1985	466,440
State Insurance Building	--	102,000
Central Services Building	--	97,030
Capitol Extension Building	1992	360,000

Table A-21. Texas Tech University, Lubbuck, TX

Building Name	Year Built	Area (ft^2)
Chemistry North	Original N/A, renovation late 1980s	96,000
Chemistry South	1968	96,000
Biology Building	--	156,219
Business Administration Building	--	204,495
Law School	--	129,043
Science Building	--	118,544

Table A-22. The University of Texas at Austin, TX

Building Name	Year Built	Area (ft^2)
Nursing Building	1973	94,815
University Teaching Center	1984	152,690
Perry Castaneda Library	1974 or 1977	483,895
Burdine Hall	1970	103,441
Garrison Hall	1926	54,069
Graduate School of Business	1975	146,763

Table A-23. Veteran's Affairs Hospitals, Various Locations

Building Name	Year Built	Area (ft^2)
Alexandria VA Medical Center, Alexandria, LA	--	679,470
Eugene J. Towbin Healthcare Center, North Little Rock, AR	1880s,1920s, 1944	1,239,461
Fayetteville VA Medical Center, Fayetteville, AR	--	246,761
G. V. "Sonny" Montgomery VA Medical Center, Jackson, MS	--	792,392
Jack C. Montgomery VA Hospital, Muskogee, OK	--	419,603
John L. McClellan Memorial Veterans Hospital, Little Rock, AR	--	803,000
Joint Ambulatory Care Center, Pensacola, FL	2008	206,000
Michael E. DeBakey VA Medical Center, Houston, TX	--	2,000,800
New Orleans VA Medical Center, New Orleans, LA	--	--

Table A-23. Continued

Building Name	Year Built	Area (ft^2)
Oklahoma City VA Medical Center, Oklahoma City, OK	--	946,534
Overton Brooks Medical Center, Shreveport, LA	1950	593,446
VA Gulf Coast Veterans Health Care System, Biloxi, MS	--	917,882
Veterans Administration Medical Facility, Albuquerque, NM (Raymond G. Murphy VA Medical Center)	--	595,000

Table A-24. Other Buildings

Building Name	Year Built	Area (ft^2)
Sandia National Laboratories Technology Support Center 6585, Albuquerque, NM	1995	99,579
One Shoreline Plaza, Corpus Christi, TX	1989	350,000
Christus Santa Rosa Health Care, San Antonio, TX	--	--
All Saints Health Care Systems/ Cityview Hospital, Fort Worth, TX	1986	106,841
NASA Dryden Flight Research Center (Federal Building), Edwards, CA	--	281,464
Austin Energy Control Center, Austin, TX	--	40,700
Solectron Austin - West Building, Austin, TX	1999	240,000
Cincinnati/Northern Kentucky International Airport (CVG), Hebron, KY	1946	2,163,051
TD Client #1 (UT Arlington), Arlington, TX	--	--
Ward Memorial Hospital, Monahans, TX	1980	37,000

APPENDIX B

COMFORT ISSUES SUMMARY TABLE

Table B-1. Comfort Issues Summary

#	**Building/Facility/Campus**	**Type of Concern**	**Details**
1	TAMU-Corpus Christi	Noise	
2	Prairie View A&M University	thermal comfort	hot, cold
3	Alexandria VA Medical Center, Alexandria, LA	thermal comfort	unspecified, humid
4	Fayetteville VA Medical Center, Fayetteville, AR	thermal comfort	hot/cold calls
5	Eugene J. Towbin Healthcare Center, North Little Rock, AR	thermal comfort	hot
6	Jack C. Montgomery VA Hospital, Muskogee, OK	thermal comfort	hot
7	New Orleans VA Medical Center, New Orleans, LA	thermal comfort	warm, hot, humid
8	Oklahoma City VA Medical Center, Oklahoma City, OK	thermal comfort	hot/cold calls
9	One Shoreline Plaza	thermal comfort	hot
10	NASA Dryden Flight Research Center (Federal Building)	thermal comfort	cold
11	Fairview University - Medical Center (Riverside East & Central Plant)	thermal comfort, IAQ	hot, stuffy
12	Terrell State Hospital	thermal comfort	hot
13	Brenham State School (now Brenham State Supported Living Center)	thermal comfort	humid
14	Capitol Extension Building - Texas Capitol Complex	thermal comfort	hot
15	Austin ISD - Galindo Elementary	thermal comfort	cold
16	Austin ISD - Travis HS	thermal comfort	hot, cold
17	Brooke Army Medical Center	thermal comfort	hot, cold
18	Walter Reed Army Institute of Research	Noise	
19	Blanchfield Army Community Hospital	thermal comfort, IAQ	high CO_2, humid, cold
20	RACH - Reynolds Army Community Hospital	thermal comfort	hot, humid

Table B-1. Continued

#	Building/Facility/Campus	Type of Concern	Details
21	GLWACH - Wood Army Community Hospital	thermal comfort	hot
22	MACH - Martin Army Community Hospital	thermal comfort	hot, cold
23	WACH - Weed Army Community Hospital & associated buildings	thermal comfort	hot
24	KAHC - Kenner Army Health Clinic	IAQ	lack of airflow
25	WBAMC - William Beaumont Army Medical Center	thermal comfort	hot
26	Biology Building - Texas Tech	thermal comfort	hot
27	Austin-Bergstrom International Airport (ABIA) (AUS)	thermal comfort	humid
28	Mexican American Cultural Center	thermal comfort, noise	unspecified, cold
29	Palmer Events Center and Parking Garage	thermal comfort	cold
30	Town Lake Center	thermal comfort	unspecified, hot
31	TCCD - Trinity River Campus (TRC)	thermal comfort	hot, cold
32	IBM 041/042	thermal comfort	cold
33	IBM 903 & 905	thermal comfort	cold
34	IBM Boulder	thermal comfort	hot, cold
35	State of Utah - Salt Lake Community College (South City Campus)	thermal comfort, noise	humid, hot
36	TAMU - Wing 86 Chemistry Complex (#0376) (CHAN - Chemistry Addition)	thermal comfort, noise	humid, cold, hot
37	TAMU - Heep Center (#1502)	thermal comfort, IAQ	hot, cold, stuffy
38	TAMU - Heldenfels (#0521)	thermal comfort, IAQ	hot, cold, stuffy, odor
39	TAMU - Reynolds Medical Science (#1504)	thermal comfort	unspecified, humid
40	TAMU - Bright Aerospace (#0353)	IAQ	high CO_2

Table B-1. Continued

#	Building/Facility/Campus	Type of Concern	Details
41	TAMU - Harrington Tower (#0435)	thermal comfort	humid, hot, cold
42	TAMU - Harrington Annex (Education Center) HECC (#0438)	thermal comfort, IAQ	warm, stuffy (high CO_2)
43	TAMU - McKenzie Airport Terminal at Easterwood Airport (CLL) (#1262)	thermal comfort	humid, hot
44	TAMU - Bush Shared Use (#1608)	thermal comfort	cold
45	TAMU - Biophysics and Biochemistry Building (#1507)	thermal comfort	warm, cold
46	TAMU - Kleberg (#1501)	thermal comfort	hot, cold
47	TAMU - Evans Library (#468)	thermal comfort	very hot
48	TAMU - Veterinary Large Animal Hospital (#1194)	thermal comfort	hot/cold calls
49	TAMU – Koldus (#383)	thermal comfort	cold
50	TAMU - Butler Hall (#465)	thermal comfort	hot/cold calls
51	TAMU - Data Processing Center (DPC Annex #0517)	thermal comfort	cold
52	TAMU - Food Safety Inspection Service (FSIS) Training and Research Center (#1603)	IAQ	no fresh air
53	TAMU - Glasscock History Building (#0470)	thermal comfort	hot/cold calls
54	TAMU - Civil Engineering Building (#0492)	thermal comfort, IAQ	hot/cold calls, high CO_2
55	DFW Terminal E	thermal comfort	hot/cold calls
56	DFW DPS Station 2	thermal comfort	unspecified
57	DFW DPS Station 3	thermal comfort	unspecified
58	DFW DPS Station 4	thermal comfort	unspecified
59	DFW Corporate Aviation	thermal comfort	unspecified

APPENDIX C

LEVEL OF COMPLETENESS

The level of completeness was determined by comparing the proposed Continuous Commissioning measures with those that were implemented and presented as a percentage of CC measures implemented. The percent of CC measures implemented was compared to the factor of predicted savings achieved for the 51 projects that had available information. The summarized results were presented in section 4.4 and the following tables present more detailed information for each project. The actual savings were less than predicted in 32 projects, presented in Table D-1. The actual savings exceeded the predictions in 19 projects, presented in Table D-2.

Table C-1. Summary of Projects with Less Than Predicted Savings

Project Group	**Building/Facility/Campus**	**Factor of savings achieved**	**% of CC measures implemented**
VA Hospital	Alexandria VA Medical Center, Alexandria, LA	0.22	100%
	All measures implemented but the scope of the project was too short to realize projected savings since some measures were implemented later in the project		
VA Hospital	Michael E. DeBakey VA Medical Center, Houston, TX	0.42	15%
	18 measures were proposed, 3 were deemed unsuitable, 3 needed repairs or upgrades before implementation, 2 had 60% imp., 4 had 30% imp., 1 had 100% implementation at 1 of 5 buildings, the remaining measures were not implemented		
VA Hospital	G. V. “Sonny” Montgomery VA Medical Center, Jackson, MS	0.42	67%
	10 of 15 measures were implemented, 1 was implemented however equipment failure required replacement to achieve optimization		

Table C-1. Continued

Project Group	Building/Facility/Campus	Factor of savings achieved	% of CC measures implemented
VA Hospital	John L. McClellan Memorial Veterans Hospital, Little Rock, AR 12 measures proposed during assessment, 3 more identified during CC, most were implemented above 90% completion, there were 2 @ 85%, 1 @ 75%, and 4 at 30% and below	0.27	72%
VA Hospital	Eugene J. Towbin Healthcare Center, North Little Rock, AR 15 measures proposed, 1 invalid, 5 not imp. due to field condition and time constraints (6 measures - 1 invalid, 5 not implemented - savings calculated from 2 measures as whole building analysis deemed inappropriate	0.58	60%
VA Hospital	Jack C. Montgomery VA Hospital, Muskogee, OK 11 measures proposed, 2 more identified during CC, 7 100% complete, 3 50-75% complete, 3 incomplete, implemented measures represent more than 50% of proposed savings	0.38	67%
VA Hospital	Oklahoma City VA Medical Center, Oklahoma City, OK 7 measures identified (11 measures combined into 7), 2 partially implemented, the rest were not implemented due to equipment replacement during CC process	0.18	14%
Other Individual	NASA Dryden Flight Research Center (Federal Building) 25 proposed measures for 3 buildings, only 5 measures implemented in two buildings	0.97	20%
Academic Medical	Fairview University - Medical Center (Riverside East & Central Plant) 6 out of 20 measures were not implemented due to maintenance issues, required time, and/or waiting on approval due to safety concerns. Also project scope did not allow for fine tuning/optimizing of implemented measures during entire heating/cooling seasons	0.70	70%

Table C-1. Continued

Project Group	Building/Facility/Campus	Factor of savings achieved	% of CC measures implemented
MEDCOM	EAMC - Eisenhower Army Medical Center 3 of 6 measures implemented, part of 1 measure implemented, 3 other measures were implemented not originally identified	0.78	67%
MEDCOM	EACH - Evans Army Community Hospital 10 of 11 measures implemented, unable to implement 1 measure due to upgrades within the boiler plant	0.57	91%
MEDCOM	Blanchfield Army Community Hospital 4 of 8 measures implemented, part of 1 more implemented, 4 additional measures implemented	0.70	65%
MEDCOM	Madigan Army Medical Center 6 of 11 measures implemented, 5 additional measures implemented however significant construction & expansion was indicated	0.21	63%
MEDCOM	Womack Army Medical Center 7 of 11 implemented, 1 additional measure and additional CC implementation at 3 clinics	0.83	65%
MEDCOM	GLWACH - Wood Army Community Hospital 5 of 9 measures implemented, part of 1 more implemented, 3 additional measures	0.55	67%
MEDCOM	RWBAHC - R. W. Bliss Army Health Center All 5 measures implemented although CC not originally recommended. 2 additional measures implemented however several O&M issues may have impacted predicted savings.	0.26	100%
MEDCOM	MACH - Martin Army Community Hospital 11 measures originally implemented, 14 measures appear to have been implemented during original CC implementation only including 2 originals. Several measures were adjusted by facility personnel in between original CC implementation process and follow up.	0.56	47%

Table C-1. Continued

Project Group	Building/Facility/Campus	Factor of savings achieved	% of CC measures implemented
MEDCOM	TAMC - Tripler Army Medical Center 5 of 11 original measures implemented, 5 additional measures	0.99	55.56%
MEDCOM	MACH - Moncrief Army Community Hospital 7 of 10 original measures implemented	0.76	70%
MEDCOM	KAHC - Kenner Army Health Clinic 5 of 8 original measures implemented	0.09	63%
MEDCOM	IACH - Ireland Army Community Hospital 9 of 24 original measures implemented, 5 additional measures implemented. Most measures reversed by the time of follow up in 2010	0.61	43%
MEDCOM	WBAMC - William Beaumont Army Medical Center 3 of 24 original measures implemented, 12 additional measures implemented, some measures reversed by the time of follow up in 2010	0.36	30%
MEDCOM	DAMC - Darnall Army Medical Center Partial implementation of 5 of 11 original measures, 7 additional measures implemented. Report provides reasons some measures were not implemented.	0.67	41%
Austin City	Austin City Hall 8 of 13 measures implemented, 3 others partially implemented	0.88	73%
Austin City	Palmer Events Center and Parking Garage 7 of 8 measures implemented, 12 additional measures	0.78	93%
Austin City	Town Lake Center 7 of 8 measures implemented, however report indicates reasons for low savings	0.004	87.5%
Austin City	Austin History Center (JH Faulk Library and Austin History Center) 4 of 10 original measures implemented (1 deemed not needed), however 5 additional measures implemented (recommended in CC Implementation Plan)	0.56	52%

Table C-1. Continued

Project Group	Building/Facility/Campus	Factor of savings achieved	% of CC measures implemented
Austin City	Austin Police Department Headquarters, Patrol Building, and City of Austin Municipal Court Building	0.33	49%
	4 of 13 original measures implemented (unable to implement 2) however 9 additional measures implemented (recommended in CC Implementation Plan)		
Austin City	Rutherford Lane Campus	0.30	60%
	5 of 9 original measures implemented, 2 additional measures implemented		
Austin City	Walker Creek Center	0.49	81%
	8 of 10 original measures implemented (unable to implement 1), 1 additional measure implemented		
IBM	IBM 903 & 905	0.32	38%
	2 of 6 measures implemented, the rest required major hardware modifications or retrofits not desirable to client at the time, 1 additional measure implemented		
IBM	IBM Tucson	0.70	13%
	2 of 15 measures implemented		

Table C-2. Summary of Projects with Exceeded Predicted Savings

Project Group	Building/Facility/Campus	Factor of Savings Achieved	% of CC measures implemented
VA Hospital	New Orleans VA Medical Center, New Orleans, LA 3 of 12 original measures plus 1 additional, 9 not implemented due to campus constraints	2.21	28%
VA Hospital	Joint Ambulatory Care Center, Pensacola, FL 9 of 10 original measures implemented	1.07	90%
Other Individual	Sandia National Laboratories - Technology Support Center 6585 6 of 9 original measures implemented, 1 unable to implement because of damper problem	1.56	67%
Academic Medical	John Sealy North - UTMB Galveston 3 measures implemented	3.12	100%
Academic Medical	Basic Sciences - UTMB Galveston 1 measure implemented	2.08	100%
MEDCOM	Bayne-Jones Army Community Hospital 4 of 14 measures implemented, 1 partially implemented. Some measures changed or removed by the time of follow up in 2010.	2.34	32%
MEDCOM	RACH - Reynolds Army Community Hospital 6 of 14 measures implemented, 1 partially implemented	2.62	46%
MEDCOM	WACH - Weed Army Community Hospital & associated buildings 4 of 5 measures implemented, plus 4 additional measures	1.21	86%
MEDCOM	FAHC - Fox Army Health Center -- Redstone Army Arsenal 6 of 10 measures implemented, limited plant EMCS control prevented implementation of some measures, 3 additional measures implemented	2.56	60%
Austin City	George Washington Carver Museum & Cultural Center 6 original measures implemented plus 3 additional	1.12	100%

Table C-2. Continued

Project Group	Building/Facility/Campus	Factor of Savings Achieved	% of CC measures implemented
Austin City	Mexican American Cultural Center 2 of 10 original measures implemented, 5 more implemented partially or for only 1 AHU, unable to implement 2 because unreliable sensor and point not in Building Automation System, 6 additional measures implemented	1.71	58%
Austin City	Austin Parks & Recreations Department Headquarters 5 of 6 original measures implemented, plus 5 additional measures implemented	2.82	88%
Austin City	Rebekah Baines Johnson Building 2 of 7 original measures implemented, 4 more implemented partially, plus 3 additional measures implemented	1.15	65%
Austin City	JH Faulk Central Library (JH Faulk Library and Austin History Center) 3 of 10 original measures implemented, 1 more implemented partially, 1 deemed not required, 6 additional measures implemented	3.18	50%
Austin City	Millennium Youth Center 4 of 5 original measures implemented, 1 more implemented partially, 2 additional measures implemented	2.13	92%
Conroe ISD	CISD - Buckalew ES All 20 measures implemented	1.93	100%
Conroe ISD	CISD - TWHS College Park HS All 20 measures implemented	1.09	100%
Tarrant County College District	TCCD - Southeast Campus (SEC) 10 original measures implemented plus 4 additional measures	1.47	100%
Tarrant County College District	TCCD - Trinity River Campus (TRC) 13 of 15 measures implemented	2.2	87%