# THE EFFECTS OF EXTERNAL TEMPERATURE ON THE ENERGY CONSUMPTION OF HOUSEHOLD REFRIGERATOR-FREEZERS AND FREEZERS

A Thesis

by

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# ABSTRACT


Refrigerating units are a major end use of electricity across the residential sector. Specifically in the United States, many households utilize a second refrigerator or freezer in unconditioned spaces, such as a garage or basement. With efforts to improve efficiency and reduce consumption, it is important to understand how a unit behaves outside the design conditions. The forecasted annual energy consumption as published on the EnergyGuide sticker is determined by testing the unit at a specified external temperature that simulates the loads of an indoor kitchen and does not accurately reflect the consumption at either thermal extremes. During this project, dorm-size refrigerators, standard-size refrigerators, and chest freezers were tested at various external temperatures ranging from 33°F to 110°F to determine the trend of the annual energy consumption and related cost.

The results of these tests were that, in general, the consumption increases with increasing external temperature. There was interesting behavior at the lower temperatures that requires further research, but the defining trend followed a cubic regression, rather than linear. Housing a unit in a cooler environment will result in a lower energy consumption, but it is recommended that consumers do not store their refrigerators or freezers in areas that will experience temperatures above 90°F or below 55°F.

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# NOMENCLATURE

| | |
|---|---|
| A | Amperage (amperes) |
| C | Annual Energy Cost ($/yr) |
| CT | Time of Complete Defrost Cycle (hr) |
| EP | Energy Use in Test Period (kWh) |
| ET | Energy Use per Day (kWh/day) |
| EY | Energy Use per Year (kWh/yr) |
| ft | Length (feet) |
| hr | Time (hour) |
| Hz | Frequency (hertz) |
| I | Current (amperes) |
| k | Correction Factor |
| kWh | Energy (kilowatt-hour) |
| m | Slope |
| min | Time (minute) |
| PF | Power Factor |
| s | Time (seconds) |
| T | Test Period Time (min) |
| $T_{actual}$ | Actual Temperature (°F) |
| $T_{measured}$ | Thermocouple Measurement (°F) |

| | |
|---|---|
| U | Uncertainty |
| V | Voltage (volts) |
| yr | Time (year) |

*Symbols*

| | |
|---|---|
| $ | Currency (US Dollar) |
| Δ | Change in |
| ‘ | Length (foot) |
| “ | Length (inch) |
| / | Per |
| % | Percent |
| °F | Temperature (degrees Fahrenheit) |

# TABLE OF CONTENTS

Page

Page

Page

# LIST OF FIGURES

Page

Page

Page

Page

Page

Page

Page

# LIST OF TABLES

Page

# 1. INTRODUCTION

Reducing energy consumption is not a new concept, but novel methods to achieve higher efficiencies and prevent waste are increasingly sought after. One end use of electricity that has potential for a significant improvement is refrigeration. Specifically in the United States' residential sector, refrigeration uses nearly 10% of the electricity generated, which amounts to approximately 200 billion kWh [1]. According to a 2005 Department of Energy survey, 99.9% of U.S. households have refrigerators, and over 20% have more than one unit [2]. In the last 20 years, household refrigerators have become nearly twice as thermodynamically efficient in terms of energy consumed versus cooling provided [3]. However, investigating factors that influence the "ideal case" can provide insight into reducing the energy requirements even further.

Under the United States' Energy Labeling Rule, refrigerator companies, among other household appliance manufacturers, are required to disclose estimated annual energy consumption and usage costs to consumers. This information is made available by means of a bright yellow "EnergyGuide" label posted on the appliance. The forecasted energy usage is determined through experimental tests that follow the Department of Energy's (DOE) procedure, a derivative of the Association of Home Appliance Manufactures' (AHAM) standard HRF-1-2008: Energy and Internal Volume of Refrigerating Appliances.

A key parameter affecting the energy consumption of a household refrigeration unit is the design exterior temperature. For example, a unit kept in a kitchen will be exposed to moderate temperatures around 70°F while a unit in an unconditioned space, such as a garage, may experience both high and low temperature extremes depending on the season and geographic location. HRF-1-2008 specifies an ambient testing temperature of 90° F with no door openings to simulate load conditions synonymous to a 70° F room temperature with door openings. No other ambient testing temperatures are given, so the relationship between temperature and energy consumption is not considered in the EnergyGuide forecast.

With many American households utilizing a secondary refrigerator-freezer (also referred to as just "refrigerator") or freezer stored in an unconditioned space (e.g. garage, basement, vacation home, etc.), understanding the impact of extreme environmental conditions on energy performance is of significant value. Therefore, the objective of this project was to determine the effects of external temperatures, ranging from 33°F to 110° F, on the energy consumption of a miniature/dorm-size refrigerator, a standard-size refrigerator, and a chest freezer.

# 2. REVIEW OF LITERATURE

The performance of household refrigerators and freezers in unconditioned environments is not a heavily researched area. There exists a general consensus among consumers with the support of refrigerator and freezer manufacturers that it is better to keep the unit within a controlled environment, but real data on the behavior of a unit in an unconditioned space is minimal.

## 2.1 Review of Technical Reports

A paper published in 1995 by Alan Meier who was working in the Energy and Environment Division at Lawrence Berkeley National Laboratory (LBNL) briefly addresses the discrepancy of the energy use of a refrigerator under controlled lab tests versus in the home [4]. In general, this LBNL paper was written to show that refrigerators actually use slightly less energy than the published values when inside a home. It does not address the consumption in extreme, unconditioned spaces. Meier goes into detail about three standards for testing refrigerators: the Department of Energy (DOE), the International Standards Organization (ISO), and the Japanese Industrial Standards (JIS). The paper mentions that the DOE appears to have the most conservative approach, overestimating by about 10% [5].

In Section 7 of the paper, a bar chart is given that shows the published (laboratory) and measured (in field) annual energy consumption values versus the number of units within a certain energy use range [6]. The chart is useful to see that more units are labeled at higher consumption values while more units have measured lower consumption values. However, the chart does not compare the laboratory results and field results of the same unit. Additionally, it is originally from a 1991 report (by Meier), which makes it significantly outdated given the improvements to refrigerators just in the last decade.

P.K. Bansal, an American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) member at the University of Auckland in New Zealand, wrote a paper in 2003 for the International Journal of Refrigeration [7]. Bansal's paper also looks into the various testing standards and proposes new methods for improving such energy tests. To start, Bansal points out that the ambient testing temperature of all the standards does not accurately reflect the temperature in a kitchen [8]. For example, the DOE testing procedure is at 90ºF, whereas a kitchen is typically around 70-75ºF.

Two plots are given showing the effect of ambient temperature on the annual energy consumption from experiments performed by the author at approximately 55ºF, 80ºF, and 90ºF. The trend of all units is very similar and fairly linear, but data was only taken at those three temperatures [9].

A report over a metering study conducted in 2003-2004 shed a lot of light on the number of refrigerating units kept in unconditioned spaces [10]. The study was conducted on 160 older refrigerators and 30 new/replacement refrigerators in consumer homes, and a major finding was that 80% of older units and 83% of new/replacement units were actually located in the kitchen. They also determined that all older units used more than the published annual energy while the new/replacement models used less [11]. However, the study did not look at units specifically outside the kitchen.

### 2.2 DOE/ENERGY STAR®

The DOE has set forth a standard for determining and reporting the estimated annual energy consumption of household appliances, including refrigerators and freezers. Their standard is actually a derivative from the Association of Home Appliance Manufacturers (AHAM) standard for testing that will be detailed in the following section [12].

The requirements for ENERGY STAR® certification are in conjunction with DOE standards and test method. To be eligible, refrigerators “must be 20% more efficient than required by the minimum federal standard,” and freezers of capacity 7.75 $ft^3$ or greater must be 10% more efficient [13]. The minimum federal requirement is determined by applying an equation based on the unit type and capacity [14].

### 2.3 AHAM HRF-1-2008

AHAM’s standard gives a very detailed outline as to how one may collect data to produce an annual energy consumption estimate based upon the type of unit and defrost settings [15]. In the energy section of the standard, test conditions are outlined, and it does not call for testing at temperatures aside from 90ºF with no door openings, which is estimated to mimic the behavior at 70° F with door openings [16].

According to the standard, the test setup consists of strategically fixing weighted temperature-measuring devices, such as thermocouples, within the refrigerator and freezer compartments. Additional thermocouples are placed outside the unit for ambient temperature verification. The energy data is to be collected by watt-hour meters, voltmeters, micrometers, or their equivalents [17]. Specific settings for various aspects of the test unit are given, such as crispers and ice makers.

Steady state within the compartments is determined by performing two 2-hour tests with a 3-hour intermittence. If the average internal temperatures do not change at a rate more than 0.042 °F per hour, steady state is said to be achieved. It is only after this that the actual energy consumption test may be performed [18]. For non-automatic defrost units, the test period should be at least three hours long and contain at least two compressor cycles. For units with automatic defrost, two test periods must be evaluated: regular compressor cycling (like the non-automatic units) and a defrost cycle. Finally, formulas for computing the energy consumption per day are given, which can easily converted to per year [19].

# 3. BACKGROUND

The main focus of this project was the evaluation of experimental data. Nevertheless, understanding the foundational theory from thermodynamics and heat transfer was of importance. Furthermore, AHAM HRF-1-2008 provides several equations for extrapolating the test data to determine the annual energy consumption.

## 3.1 Underlying Theory

A refrigeration unit uses a simple, closed vapor-compression cycle with a low-boiling refrigerant, such as R-134a, to provide a cooling effect within a thermally insulated cabinet.

With known thermal resistance values for the walls, a theoretical, conductive heat gain into the cabinet could be calculated using Fourier's law. By assuming only conductive heat transfer and using the First Law of Thermodynamics, this heat gain would be equivalent to the heat absorbed by the evaporator coil. If the unit's coefficient of performance (COP) is also known, the minimum required power input to the compressor can be established using the following equation:

$$COP = \frac{\dot{Q}_L}{\dot{W}_{comp,in}} \tag{1}$$

where $\dot{Q}_L$is the heat absorbed by the evaporator and $\dot{W}_{comp,in}$is the compressor power [20].

If, however, the COP is unknown and cannot be obtained, determining the work input requires a more thorough analysis. Two important variables are the maximum and minimum operating pressures, which are typically published in the unit's specifications. Assuming the ideal case of an isentropic compressor and isenthalpic expansion device, the enthalpies before and after the evaporator coil can be established with thermodynamic tables. (This also requires some assumptions regarding the liquid/vapor quality of the fluid.) The following equation shows the relationship between these enthalpies and the minimum compressor power.

$$\dot{W}_{comp,in} = \dot{m}(h_{after} - h_{before}) \tag{2}$$

Again, $\dot{W}_{comp,in}$ refers to the input power, $h_{after}$ is the enthalpy just after the evaporator coil, $h_{before}$ is the enthalpy just before the evaporator coil, and $\dot{m}$ is the mass flow rate of the refrigerant [20]. The mass flow rate is not commonly published, so the manufacturer would have to be contacted.

Either mathematical method would result in a minimum power input under many idealistic assumptions, including a simple vapor-compression cycle without additional ventilation fans or thermostat control modules. Thus, the models would not give accurate energy requirements, rather a baseline estimate. Additionally, neither model would be capable of accurately reflecting the effects of external temperature since the COP in Equation (1) would have come from the design conditions and temperature is not even included in Equation (2).

### 3.2 Calculations from Empirical Data

Once the data from experimental tests has been collected, HRF-1-2008 specifies how to calculate the daily energy consumption. The equations vary between the types of refrigeration units and defrost settings and can be used to further generate the annual consumption and associated cost. The price of electricity utilized by EnergyGuide (a 2007 national average) at 10.65 ¢/kWh was used for this project for the dorm-size and standard-size units [21]. Since the chest freezers purchased were newer models, their EnergyGuide label used an electric rate of 12 ¢/kWh, so this was used for calculations associated with those units [22].

EnergyGuide labels report the energy consumption of a unit at average refrigerator and freezer temperatures of 39°F and 0°F, respectively. To accomplish such a specific setting, the standard requires that two energy tests be performed: the first at the median temperature control setting and the second at the highest or lowest control setting, whichever will bound the design temperatures. For example, if the median setting yielded an internal temperature of 45°F, the second test would be performed at the coldest setting. A weighted average of the energy use based on the internal temperatures would then be performed. For the purpose of this project and related time and budget considerations, experimental tests were performed primarily at the median temperature control setting only.

### *3.2.1 Non-Automatic Units*

The tested dorm-size models and chest freezers fall under the category of non-automatic units because they do not have a built in defrost heater but must be manually defrosted. Per section 5.8.2.1.1 of the standard, the daily energy use in kWh/day can be determined by Equation (3).

$$ET = \frac{EP * 1440 * K}{T} \tag{3}$$

$ET$ is the test cycle energy (kWh/day), $EP$ is the test period energy (kWh), $1440$ is a conversion factor (min/day), $K$ is a correction factor related to unit type (0.7 for chest freezers, 0.85 for wine chillers and upright freezers, and 1 for all other units), and $T$ is the time of the test period (min).

To manipulate the test cycle energy into an annual consumption and annual cost, the following equations can be used:

$$EY = ET * 365 \tag{4}$$

$$C = EY * 0.1065 \tag{5}$$

where $EY$ is the annual energy use (kWh/year), $365$ is a conversion factor (days/year), $C$ is the yearly operating cost ($/year), and $0.1065$ is a conversion factor ($/kWh). The conversion used in the chest freezer cost analyses was 0.12 ($/kWh).

### *3.2.2 Long-Time Automatic Defrost Units*

The tested standard-size models fall under the category of long-time automatic defrost, and such units can be classified by viewing an energy versus time plot. The regular compressor cycles, a defrost heater cycle, and a compressor recovery cycle can be seen, as depicted in Figure 1.

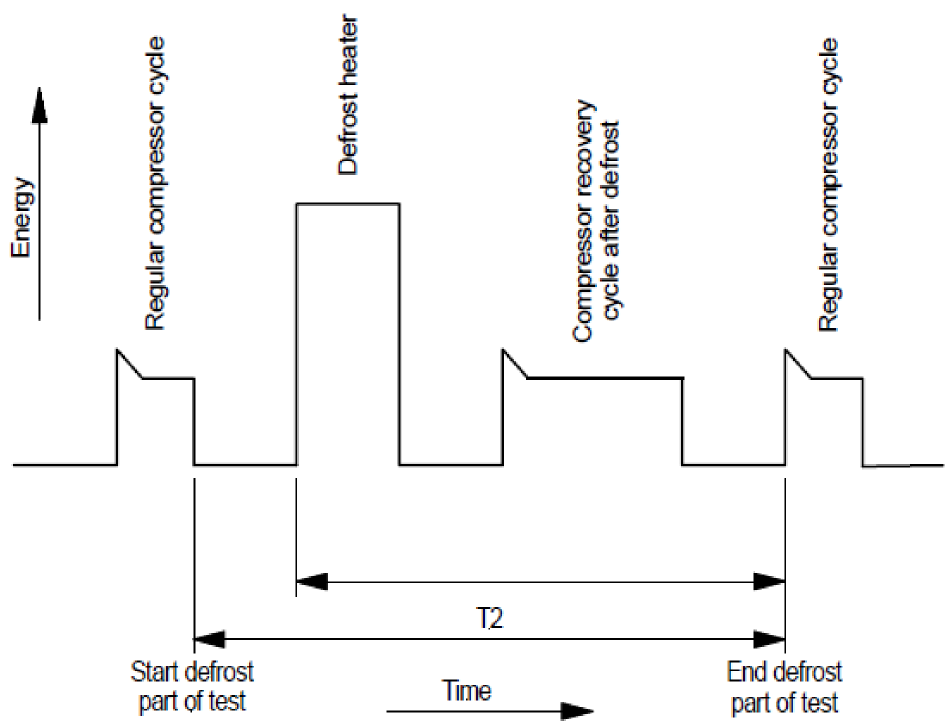


***Figure 1. Energy versus time graph for long-time automatic defrost unit [23]***

For the energy calculations, the test cycle is composed of two parts: the regular compressor cycles (referred to as part 1) and the complete defrost cycle (referred to as part 2). Equation (6) is the formula for computing daily use for such units.

$$ET = \left(1440 * K * \frac{EP1}{T1}\right) + \left(\left(EP2 - \left(EP1 * \frac{T2}{T1}\right)\right) * K * \frac{12}{CT}\right) \tag{6}$$

The synonymous symbols that are used in Equations (3)-(5) represent the same quantities in Equation (6). In addition, $EP1$ is the test period energy for part 1 (kWh), $EP2$ is the test period energy for part 2 (kWh), $T1$ is the time of part 1's test period (min), $T2$ is the time of part 2's test period (min), $12$ is a conversion factor to account for a 50% compressor run time (hr/day), and $CT$ is the time required to complete a defrost cycle (hr). $EP1$ and $EP2$ are calculated by summing the energy use in the respective test period. Finally, Equations (4) and (5) are still applicable for calculating the annual energy use and cost of long-time automatic defrost units.

The test period requirements set forth by the standard were discussed in greater detail in the Review of Literature, but it is important to note that if the long-time automatic defrost units do not experience a defrost cycle in the test period during a certain test, the energy and cost calculations are performed as if they are non-automatic defrost units.

# 4. METHODOLOGY

Experimental tests were conducted on refrigerating units of three different classifications: miniature/dorm-size refrigerator-freezers, standard-size refrigerator-freezers, and chest freezers. These were chosen as a representative of the most commonly used household refrigerating appliances, and two identical units of each classification were tested at the same time to provide a means of internal comparison. The test conditions and set-up were guided by HRF-1-2008, but complete compliance with the standard was not a necessity given the nature of research.

During the experimental tests, the data needed for the calculations presented in the previous chapter was collected. Additionally, data pertaining to areas of interest outside the scope of HRF-1-2008 was collected for analysis.

## 4.1 Test Unit Specifications

The specifications and other information for each unit tested are detailed in Table 1.

*Table 1. Specifications for each test unit type*

| *Unit Type* | *Published Energy Use (kWh/yr)* | *Published Cost ($/yr)* | *Total Capacity ($ft^3$)* |
|---|---|---|---|
| Dorm-Size | 420 | 45 | 3.3 |
| Standard-Size | 404 | 43 | 18 |
| Chest Freezer | 222 | 27 | 9.1 |

The published values of annual energy use and cost provided a basis to compare with the results of the tests performed at the conditions specified by HRF-1-2008. Scatter plots showing typical, commercially available units of each category and the chosen test units is available in the appendix.

### 4.2 Instrumentation

The standard provided a general guideline for selecting the instrumentation based on measurement type and uncertainty constraints. While the temperature measurements did not directly affect the energy consumption calculations, they were necessary to determine if steady-state had been accomplished, the bounds for interpolating to find the energy requirements at the desired internal temperatures (for tests at different internal temperature settings), and the ambient temperature. Additionally, measuring the energy consumption directly can be problematic given the nature of AC circuits with apparent power, reactive power, and true power, so special consideration had to be given in selecting the equipment.

#### *4.2.1 Temperature*

The temperature-measuring devices of choice for the internal compartments, mechanical components, and ambient temperatures near the unit were T-type thermocouples because of their accuracy (±1°C or ±1.8°F), low cost, and easy maintenance.

Per the standard, cylindrical brass weights of 1.125” nominal height and diameter were used on the thermocouples suspended within the refrigerator compartments of the standard and dorm-size units and the freezer compartments of the standard units and chest freezers. A thermally conductive epoxy was used for fixing the thermocouples to the brass weights and other mechanical components, e.g. the compressor outlet.

For the dorm-size units, however, the brass weights were not used for the freezer compartment. Instead, frozen bags of a water and sawdust mixture were used as the thermal storage as defined in the standard. While the sawdust packages were also supposed to be used with the chest freezers, they were not utilized due to the required quantity (75% internal volume). Instead, silica beads were placed in the bottom of the freezers to serve as a desiccant and remove the water vapor that could potentially freeze and increase the need for a defrost cycle. Thus, the weighted thermocouples were used for thermal stability.

Before testing, the thermocouples were calibrated in house by comparing the measured values to an absolute which was determined by using a professionally calibrated, 4 wire RTD. Three references temperatures (nominally 32°F, 75°F, and 120°F) were accomplished with the use of an ice bath and a dry furnace. The instantaneous readings from each thermocouple and the RTD were compared such that linear coefficients were established and implemented into the data reduction process. These coefficients were also key parameters for the individual thermocouple uncertainty values.

Dry bulb and wet bulb temperatures were measured with 3-wire RTDs at a common location within the psychometric chamber. These RTDs were connected to the computer that controls the temperature within the chamber and did not go into any calculations or appear in any plots.

#### *4.2.2 Power*

The power measurements were the lifeblood of the entire project. Two WattsOn® Universal Power Transducers coupled with an ETnet (Ethernet gateway) from Elkor Technologies allowed for the digital collection of single-phase current, voltage, and power factor sampled at a rate of 0.1 Hz, or 1 sample every 10 seconds.

HRF-1-2008 specifies a power supply of 115 ± 1 V at 60 Hz. To step down the supply from a standard outlet at a nominal 120 V, a variable voltage transducer was incorporated into the wiring. Unfortunately, the power quality coming from the local power plant fluctuates beyond the ± 1 V, but this deviation from the standard was considered acceptable as residential homes would receive similar fluctuations.

Because the power transducers were purchased new specifically for this project, additional calibration was not necessary, as the manufacturer specifications were sufficient.

## 4.3 Uncertainty

There are two main factors to consider in quantifying the uncertainty of a single measurement: the bias error and the precision error. The bias error is most closely related to the accuracy given by the manufacturer but can also incorporate errors associated with converting a signal from analog to digital, transmitting the signals, and performing a regression. The precision error is a means of quantifying the statistical repeatability of a measurement.

### *4.3.1 Uncertainty of Temperature Measurements*

Since the temperature measurements during the test periods were not at the same, uniform temperature at all times (as would be the case in an ice bath), the precision error was not considered given that the statistical approach on a fluctuating temperature would result in unrealistically high errors. The uncertainty of the thermocouples, thus, was simply the bias error, or uncertainty from the calibration. This value can also incorporate the mediums between the measurement and the recording device, such as the thermocouple modules and DAQ. However, since the measurements were not taken at temperatures close to the limits of the range and were not necessary for energy consumption calculations, these extra sources of error were considered insignificant.

As mentioned, a linear regression was performed during the calibration of the thermocouples, and corrective coefficients were established. The regressions followed the formula given in the following:

$$T_{actual} = m * T_{measured} + b \tag{7}$$

$T_{actual}$ is the corrected temperature, $m$ is the slope of the linear regression, $T_{measured}$ is the temperature as read by the thermocouple, and $b$ is the y-intercept of the linear regression. Using the Kline-McClintock method for the propagation of uncertainty (Equations (8) and (9)), the resulting uncertainty of each temperature measurement came out to be the slope of the linear regression times the manufacturer specified accuracy, as given in Equation (10).

$$U_{measurement} = \sqrt{\left(\frac{\partial(T_{actual})}{\partial(T_{measured})} U_{thermocouple}\right)^2} \tag{8}$$

$$\frac{\partial(T_{actual})}{\partial(T_{measured})} = m \tag{9}$$

$$U_{measurement} = m * U_{thermocouple} \tag{10}$$

In the previous equations, $U_{measurement}$ is the uncertainty of the temperature measurement and $U_{thermocouple}$ is the manufacturer-specified uncertainty of the thermocouple. From this point forward, all symbols with a capital *U* and a subscript represent the uncertainty of the variable in the subscript.

The worst case of all the thermocouples, both for Unit A and Unit B had an uncertainty of ±1.9°F, and this particular thermocouple was used to measure the temperature of a mechanical component. The worst case of the thermocouples used in the freezer or refrigerator compartments was ±1.8°F. The coefficients and resulting uncertainty for each thermocouple used can be found in the appendix.

### *4.3.2 Uncertainty of Power Measurements*

The power measurement uncertainty was similar to that of the thermocouples. The precision error was ignored since the power was continuously cycling, and the errors from extra equipment were not considered. The bias error was not a result from calibration, but it was taken from the manufacturer's accuracy values given in Table 2.

***Table 2. Manufacturer-specified accuracy for WattsOn® Power Transducers [24]***

| *Parameter* | *Accuracy* |
|---|---|
| Voltage | 0.5% |
| Current | 0.2% |
| Power Factor | 0.5% |

To consider the worst case scenario, the highest voltage reading during all tests was 118.8 V, and the uncertainty was then ±0.594 V. The highest current was 3.609 A, with the resulting uncertainty of ±0.007 A. Finally the maximum power factor was 1, giving an uncertainty of ±0.005. The propagation of these uncertainties in the power calculations was considered during the energy and cost calculations in the following subsection.

#### *4.3.3 Uncertainty of Energy and Cost Calculations*

To determine the uncertainty of the annual energy consumption and annual operating cost, the relationship between voltage $(V)$, current $(I)$, power factor $(PF)$, and time had to be known, and it is given by Equation (11).

$$E = V * I * PF * \Delta t \tag{11}$$

The $\Delta t$ in Equation (11) is the small increment of time between measurements, which was 10 s, and $E$ was the energy consumed during that time period. The summation of these individual energy values (in kWh) is the energy consumption during the test period, or $EP$, from Equation (3).

Using Kline-McClintock again, the uncertainty of a single energy calculation was determined by the following set of equations, assuming there is no uncertainty in the time measurement.

$$U_E = \sqrt{\left(\frac{\partial(E)}{\partial(V)} U_V\right)^2 + \left(\frac{\partial(E)}{\partial(I)} U_I\right)^2 + \left(\frac{\partial(E)}{\partial(PF)} U_{PF}\right)^2} \tag{12}$$

$$\frac{\partial(E)}{\partial(V)} = I * PF * \Delta t \tag{13}$$

$$\frac{\partial(E)}{\partial(I)} = V * PF * \Delta t \tag{14}$$

$$\frac{\partial(E)}{\partial(PF)} = V * I * \Delta t \tag{15}$$

$$U_E = \sqrt{((I * PF * \Delta t)U_V)^2 + ((V * PF * \Delta t)U_I)^2 + ((V * I * \Delta t)U_{PF})^2} \tag{16}$$

Because the accuracy of the voltage, current, and power factor readings are given as percentages, the uncertainty of the energy consumed varied at each data point. The propagation of the energy uncertainty into the annual energy use and cost analysis depended on the type of unit. The dorm-size units and chest freezers were analyzed differently from the standard-size units since they did not experience defrost cycles. The equations used in this calculation come from the relationships given by Equations (3)-(5) and are detailed in the following:

$$EP = \sum_{test\ period} E \tag{17}$$

$$U_{EP} = \sqrt{\sum_{test\ period} (U_E)^2} \tag{18}$$

$$U_{ET} = \sqrt{\left(\frac{\partial(ET)}{\partial(EP)} U_{EP}\right)^2} \tag{19}$$

$$\frac{\partial(ET)}{\partial(EP)} = \frac{1440 * K}{T} \tag{20}$$

$$U_{ET} = \frac{1440 * K}{T} U_{EP} \tag{21}$$

$$U_{EY} = \sqrt{\left(\frac{\partial(EY)}{\partial(ET)} U_{ET}\right)^2} \tag{22}$$

$$\frac{\partial(EY)}{\partial(ET)} = 365 \tag{23}$$

$$U_{EY} = \sqrt{(365 * U_{ET})^2} \tag{24}$$

$$U_C = \sqrt{\left(\frac{\partial(C)}{\partial(EY)} U_{EY}\right)^2} \tag{25}$$

$$\frac{\partial(C)}{\partial(EY)} = 0.1065 \tag{26}$$

$$U_C = \sqrt{(.1065 * U_{EY})^2} \tag{27}$$

The analysis of the standard-size units was the same except for Equations (19) through (21). The following set of equations was used for these units when a defrost cycle occurred.

$$U_{ET} = \sqrt{\left(\frac{\partial(ET)}{\partial(EP1)} U_{EP1}\right)^2 + \left(\frac{\partial(ET)}{\partial(EP2)} U_{EP2}\right)^2} \tag{28}$$

$$\frac{\partial(ET)}{\partial(EP1)} = \frac{1440 * K}{T_1} - \frac{12 * T_2 * K}{T_1 * CT} \tag{29}$$

$$\frac{\partial(ET)}{\partial(EP2)} = \frac{12 * K}{CT} \tag{30}$$

$$U_{ET} = \sqrt{\left(\left(\frac{1440 * K}{T_1} - \frac{12 * T_2 * K}{T_1 * CT}\right) U_{EP1}\right)^2 + \left(\left(\frac{12 * K}{CT}\right) U_{EP2}\right)^2} \tag{31}$$

However, the worst cases for each type of unit are given in Table 3.

***Table 3. Annual energy consumption and cost uncertainty values for the worst case scenario of each type of unit***

| ***Unit Type*** | ***Energy Uncertainty (kWh/yr)*** | ***Cost Uncertainty ($/yr)*** |
|---|---|---|
| Dorm-Size | ± 1.38 | ± 0.15 |
| Standard-Size | ± 0.15 | ± 0.02 |
| Chest Freezer | ± 0.13 | ± 0.02 |

# 5. TEST SET-UP

The test set-up generally followed the requirements of HRF-1-2008. Though certain aspects of the set-up were different for each type of unit, there were also several similarities. For example, the standard calls for the use of a support platform if the temperature of the floor of the chamber is not within 3°F of the desired ambient temperature. Given that the floor of the psychometric chamber is composed of uninsulated concrete, it was assumed that floor temperature would not meet the temperature constraints, and two platforms of wood were constructed such that each unit would have at least 12” of clearance on the sides and front. Figure 2 is a picture of one platform.

***Figure 2. Photo of support platform***

### 5.1 Temperature Measurements

Figures 5-1 and 5-2 (pages 17-19) of the standard show the general locations for thermocouple placement within the insulated compartments. In addition to these, four thermocouples were fixed to the geometric center of the top, left, and right walls at an orthogonal distance of 12” (top) or 10” (sides), based on the standard’s requirements. The remaining thermocouples were strategically placed on areas of interest, such as the compressor inlet and outlet. These extraneous measurements varied slightly by unit type and will be detailed in following subsections.

For data collection, two National Instruments thermocouple modules (NI 9213) were connected to a compact DAQ (NI cDAQ 9174) that was connected to a computer. A simple LabVIEW program was developed to record the temperature measurements and write them to a text file that could later be opened in Microsoft Excel for reduction. Figure 3 and Figure 4 show the NI modules and DAQ and LabView block diagram, respectively.


***Figure 3. Photo of the NI thermocouple modules and compact DAQ for temperature measurements***

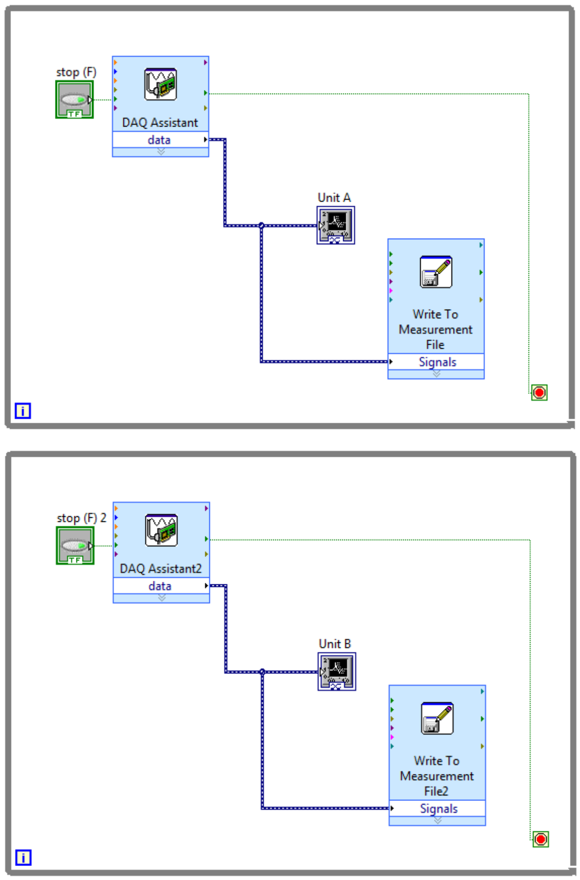


***Figure 4. LabVIEW block diagram for thermocouple data collection and recording***

### *5.1.1 Dorm-Size Units*

The dorm-size units had two separate cabinets for the freezer and refrigerator. Therefore, it was necessary to measure the temperatures within both cabinets, whereas if the freezer had just been a small (<0.5 ft$^3$) compartment within the refrigerating cabinet, freezer temperature measurements would not have been needed. As mentioned in Section 4.2.1 , thermal storage within the freezer was accomplished by means of frozen water and sawdust mixture bags. The bags were plastic, zipper-lock storage bags, and the mixture weight was between 8.16 and 10.88 oz. The bags were stacked within the main compartment in a wire frame for stability and in the door shelves. The total number of bags was 26. Three thermocouples were inserted into the geometric center of three different bags and stacked such that they were in the locations given by Figure 5.

In the refrigerator cabinet, three brass-weighted thermocouples were hung at various heights along the centerline for the width and depth. The other thermocouples were installed at the compressor surface, compressor inlet, compressor outlet, touching an inside wall, touching the adjacent outside wall, and 1’ away from the wall, as shown in Figure 5 and Figure 6.

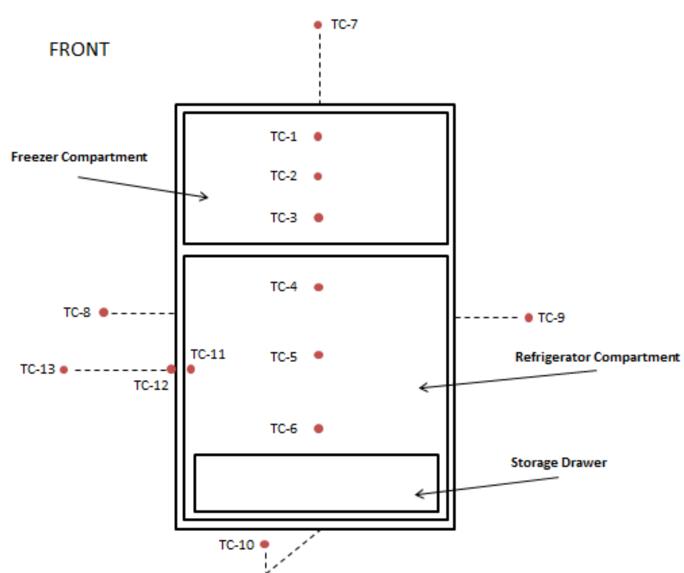


*Figure 5. Schematic of thermocouple placement for dorm-size units (front)*

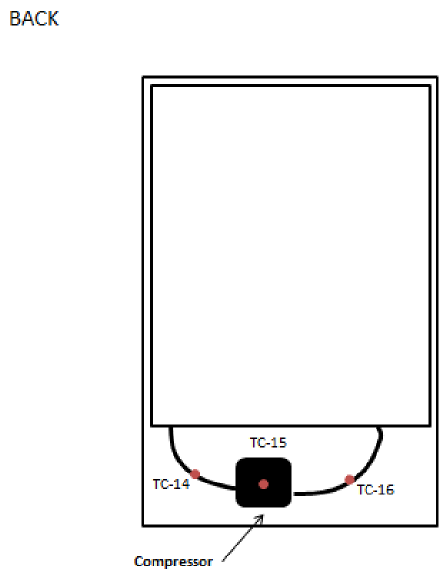


*Figure 6. Schematic of thermocouple placement for dorm-size units (back)*

A photo of an actual unit is given in Figure 7.


*Figure 7. Photo of instrumented dorm-size test unit*

### *5.1.2 Standard-Size Units*

The standard-size units had top-mounted freezer compartments with a width of 30”. Being automatic defrost, all thermocouples within the freezer and refrigerator were weighted. The locations of the thermocouples in the freezer varied slightly from that given in the standard. These units were donated and already contained instrumentation (which was later replaced with the same thermocouples used for the other tests), so those previously designated locations were kept. The only deviation was the instead of all three being located at various heights along the vertical in the geometric center, the top and bottom were offset approximately 3” from the back and front walls, respectively.

The remaining thermocouples not in use for the ambient measurements were placed on the compressor inlet, compressor outlet, evaporative inlet, evaporator outlet, condenser outlet, and touching an external wall. These are shown in Figure 8 and Figure 9.

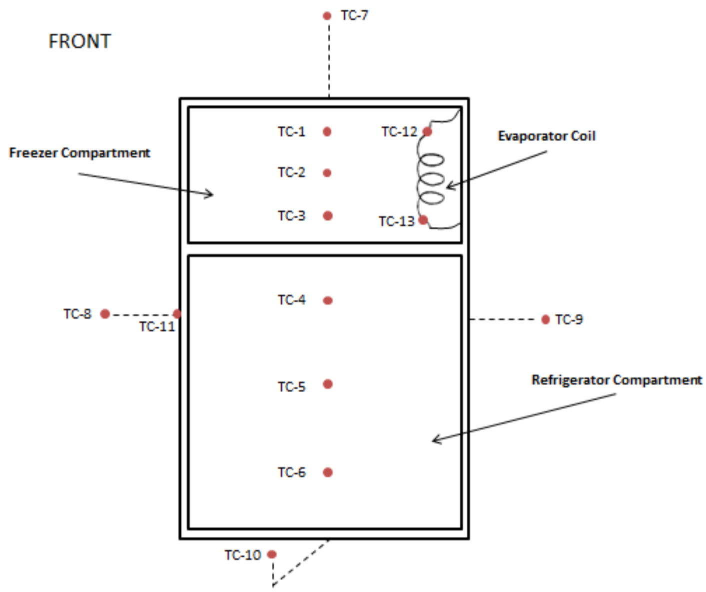


***Figure 8. Schematic of thermocouple placement for standard-size units (front)***

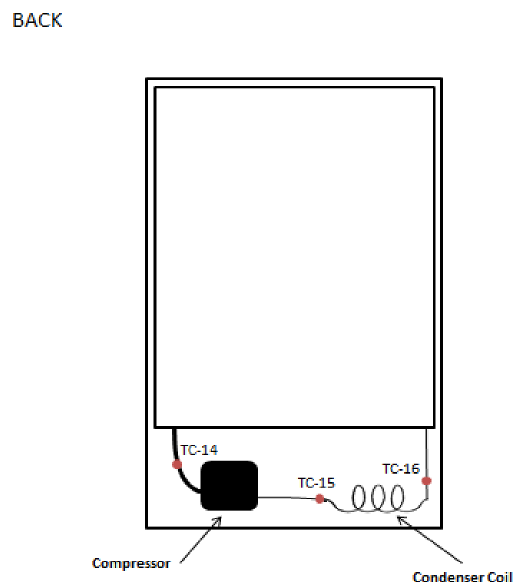


***Figure 9. Schematic of thermocouple placement for standard-size units (back)***

Figure 10 is a photo of an actual test unit.

***Figure 10. Photo of instrumented standard-size test unit***

### *5.1.3 Chest Freezer Units*

The chest freezers were composed of a single cabinet and required 5 internal freezer measurements. As mentioned previously, the standard called for the use of thermal storage packages. However, weighted thermocouples were used in conjunction with dehumidifying silica beads. Three of the thermocouples were placed at various heights along the vertical in the geometric center. Another was fixed equidistantly between the left side and center at a depth of $1\frac{1}{4}$" while the remaining thermocouple was fixed equidistantly between the center and the right side at a depth of $30\frac{1}{4}$".

The remaining thermocouples, aside from those designated for ambient conditions, were fixed to the internal wall, adjacent external wall, compressor inlet, and compressor outlet. All of these can be seen in the following schematics (Figure 11and Figure 12):

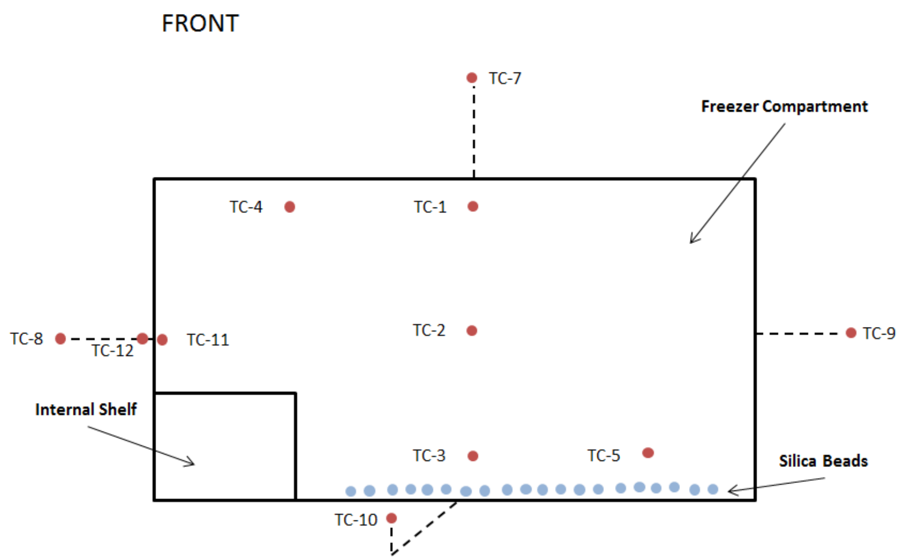


***Figure 11. Schematic of thermocouple placement for chest freezers (front)***

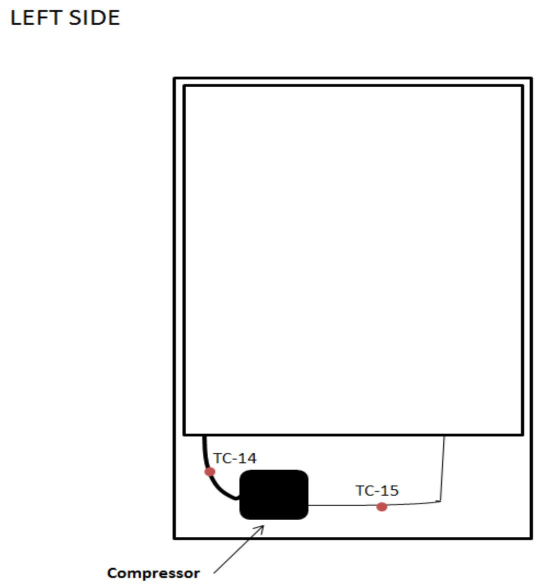


***Figure 12. Schematic of thermocouple placement for chest freezers (left side)***

Figure 13 is a photo of an actual test unit.

***Figure 13. Photo of instrumented chest freezer test unit***

## 5.2 Power Measurements

All three types of units and both test units were connected to the same grid for the power measurements. The schematic in Figure 14 shows the components and wiring to make the automatic data collection possible. While only one WattsOn® transducer is depicted, the second was connected synonymously from the same DC voltage supply. A real photo of the wiring is in Figure 15.

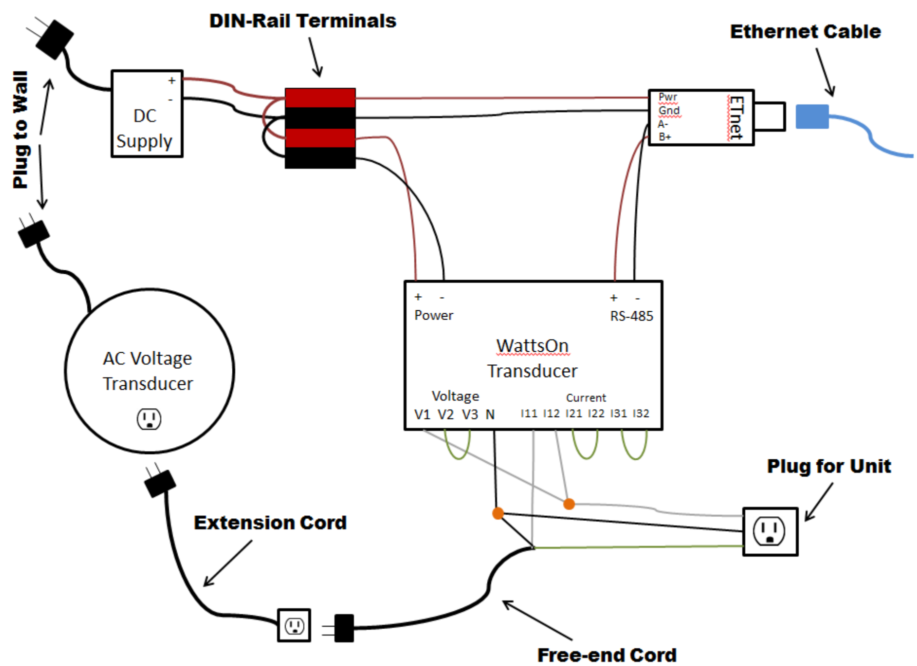


*Figure 14. Schematic of wiring for power measurements*

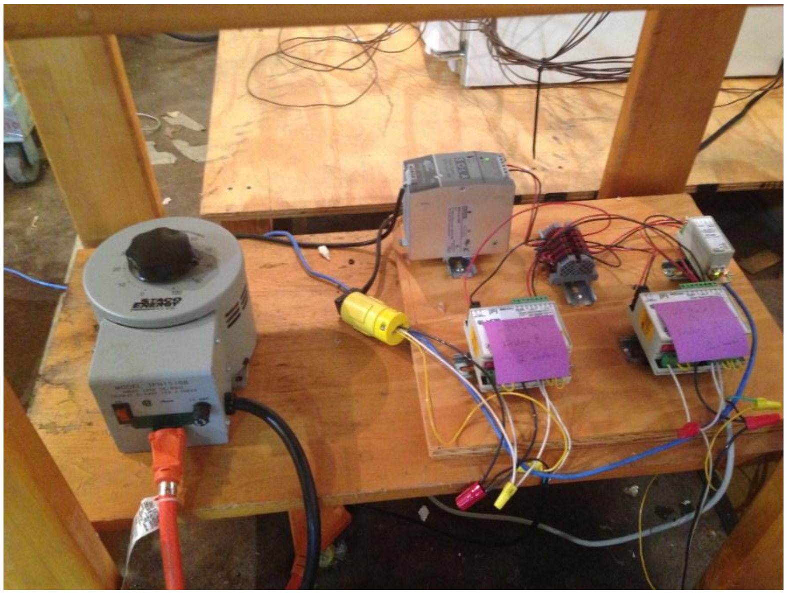

*Figure 15. Photo of electrical components and wiring for power measurements*

The Ethernet cable was connected to the computer with the Elkor Technologies data software. A sample of the interface is shown in Figure 16. Though many quantities were available, only the voltage, current, and power factor were recorded.

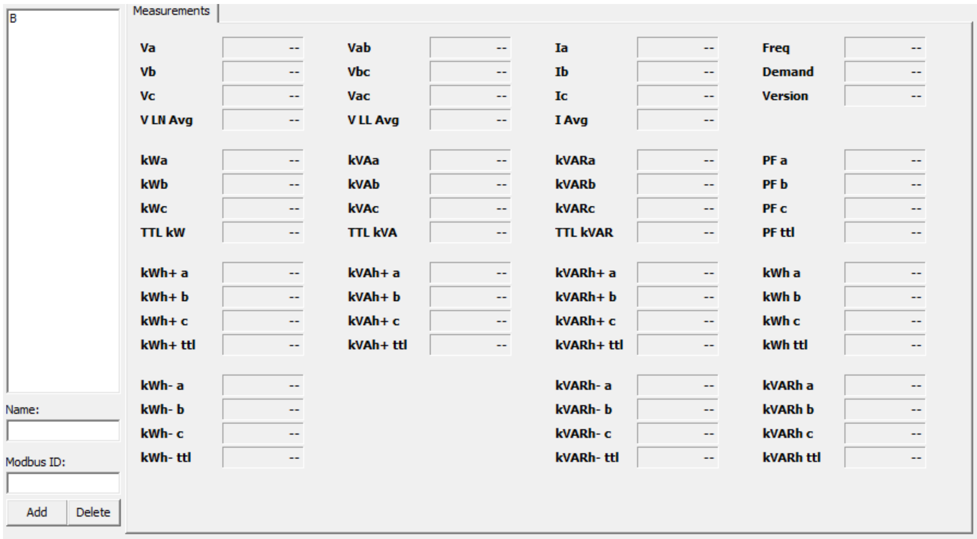


***Figure 16. Sample of Elkor Technologies software interface for power measurements and recording***

## 5.3 Psychometric Chamber

The psychometric chamber is a complex system in and of itself. For simplicity and brevity, in-depth details of the control system's computer code, PID controller constants, and specifications will not be given as the program was in use before the beginning of this project. In general, the program receives dry-bulb and wet-bulb temperature readings from the RTDs and sends voltage signals to the heaters or cooling water valve to bring the chamber to the desired temperature. Should the humidity need to be regulated as well, other valves can be controlled to introduce water vapor into the chamber. The user defines a blower speed and pump speed (if cooling). The cooling water, a mix of water and ethylene glycol, comes from an external chiller and flows through a cooling coil to absorb heat from the circulating air. A sample of the interface is given in Figure 17.

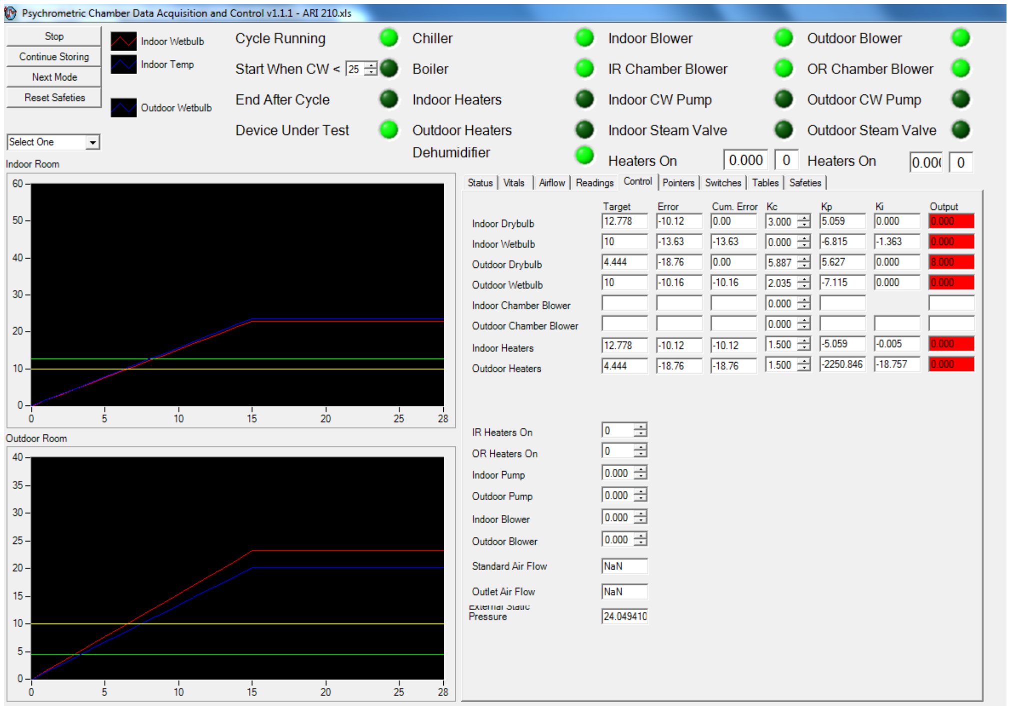


***Figure 17. Sample of psychometric room interface for temperature control***

During the tests above 70°F, the heaters were initiated. Typically three of the four heaters were used, and the supplied voltage was higher for the warmer tests. The blower was kept at 80% full speed to prevent the heaters from overheating and provide a means of thermal distribution. The units were shielded from the blower's jet stream by a solid, impingement board at the duct outlet. The units were also not in the direct radiation area of the heaters.

For the tests 70°F and under, the heaters were disengaged, and the chiller was used. Again, the blower was kept around 80%, and so was the cooling water pump. A bypass valve provided the means of temperature control such that when more cooling was needed, the valve was closed to allow the cooling water to flow through the cooling coil. When less cooling was needed, the valve was opened to allow the flow to bypass the cooling coil.

# 6. RESULTS FOR DORM-SIZE UNITS

The general trend of all three types of units was that energy consumption increases with unconditioned space temperature, and the dorm-size units exhibited a quadratic or cubic trend. The subsequent sections detail the results for the temperature profiles and energy consumption during the test with an unconditioned space temperature of 90°F and a comparison with the other temperature settings. The complete collection of generated graphs and raw data can be found in the appendices.

Because of the large size of the psychometric chamber, thermal uniformity at finite locations is not easily achieved and was not perfectly exhibited in the experimental tests. Additionally, the standard calls for no more than ±1°F deviations from the nominal unconditioned space temperature. However, the control system of the psychometric chamber does not employ such strict bounds. Thus, the unconditioned space temperatures may have varied more from the nominal value. However, since a general trend was the ultimate objective and the two test units could be compared for reasonableness, these temperature excursions were deemed acceptable for the sake of research. Additionally, the standard requires that the test period covers at least two compressor cycles. However, the compressor was not as active at the lower external temperatures, and some tests did not, in fact, have two cycles.

The dorm-size units appeared to be the most sensitive to the external environment. Because of their relatively low cost, this was expected since the insulation and control system may not be as sophisticated as that of a larger unit.

## 6.1 Temperature

Though the standard calls for a particularly time consuming determination of steady state, a visual inspection of the internal temperatures shows that the units were in fact steady, and though the unconditioned space temperatures fluctuated, the effects on the internal were not immediately obvious. The internal refrigerator and freezer temperatures of the units were higher than the recommended temperatures of 39°F and 0°F, respectively. There were also minor differences in the freezer temperatures between the two test units. Figure 18 and Figure 19 show the internal temperatures during the test period of Unit A and Unit B.

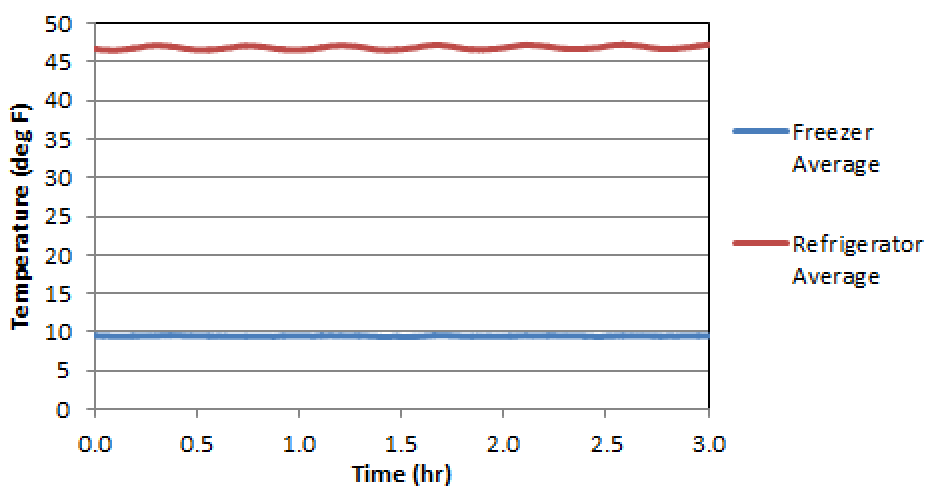


***Figure 18. Internal temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit A***

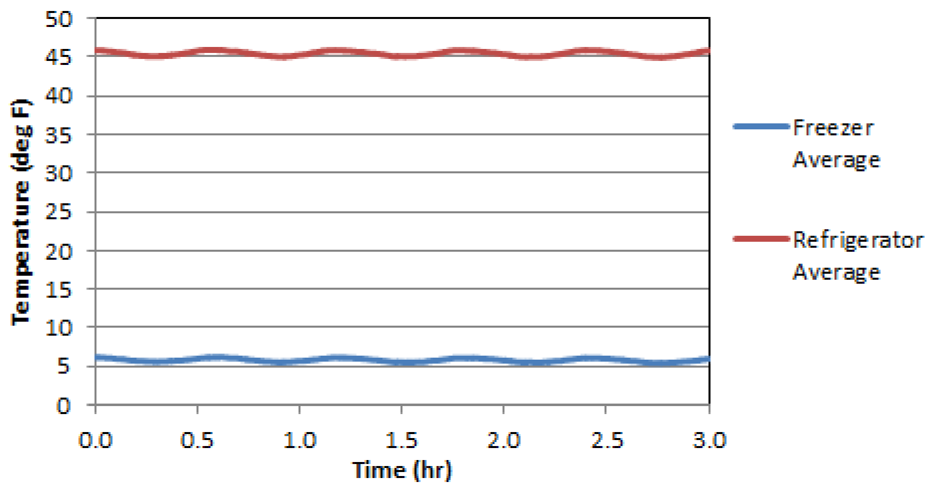


***Figure 19. Internal temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit B***

In addition to the average refrigerator and freezer temperatures, plots (Figure 20-Figure 23) showing the individual readings were generated. These can provide more insight into how thermally uniform the respective chamber is.

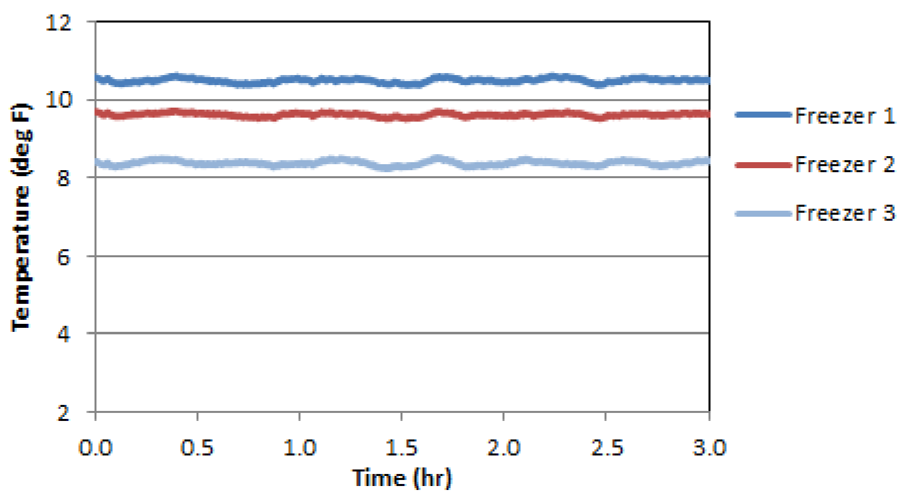


***Figure 20. Individual freezer temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit A***

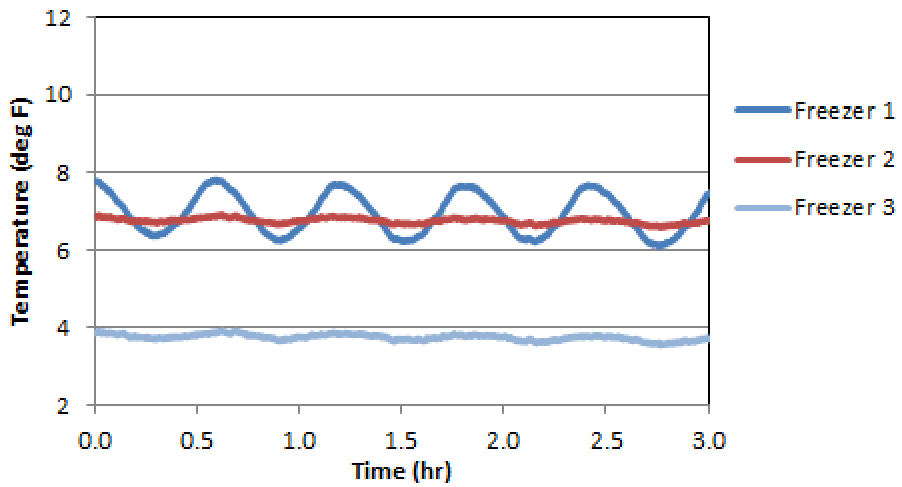


*Figure 21. Individual freezer temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit B*

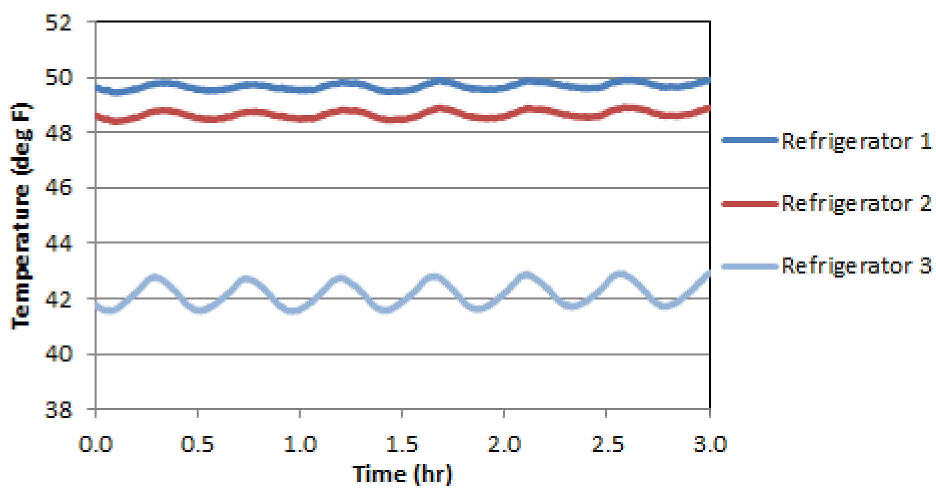


*Figure 22. Individual refrigerator temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit A*

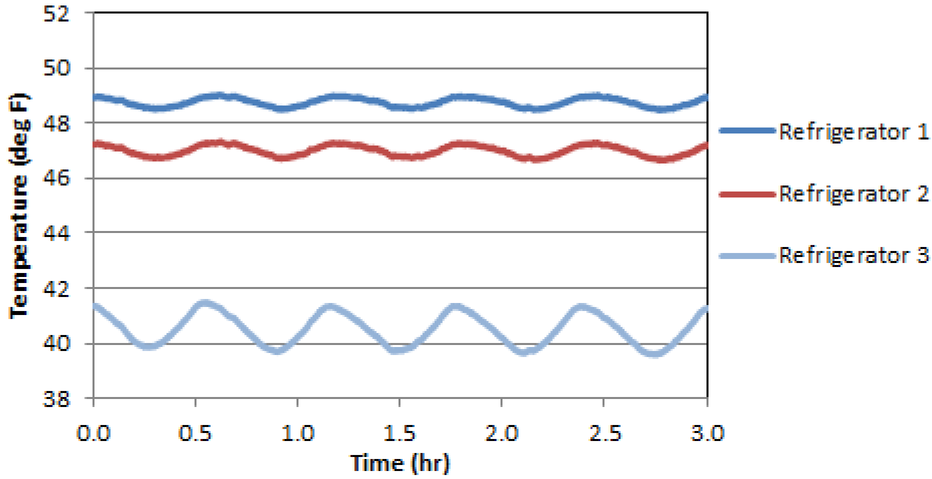


***Figure 23. Individual refrigerator temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit B***

The subtle discrepancies between the differing internal temperatures may have been derived from the differences in the unconditioned space temperature. As mentioned, the psychometric chamber is significantly large, and thermal uniformity was not achieved. The cost and energy consumption comparisons will validate the insignificance of the discrepancy. The next two figures (Figure 24 and Figure 25) depict the unconditioned space temperatures for these units.

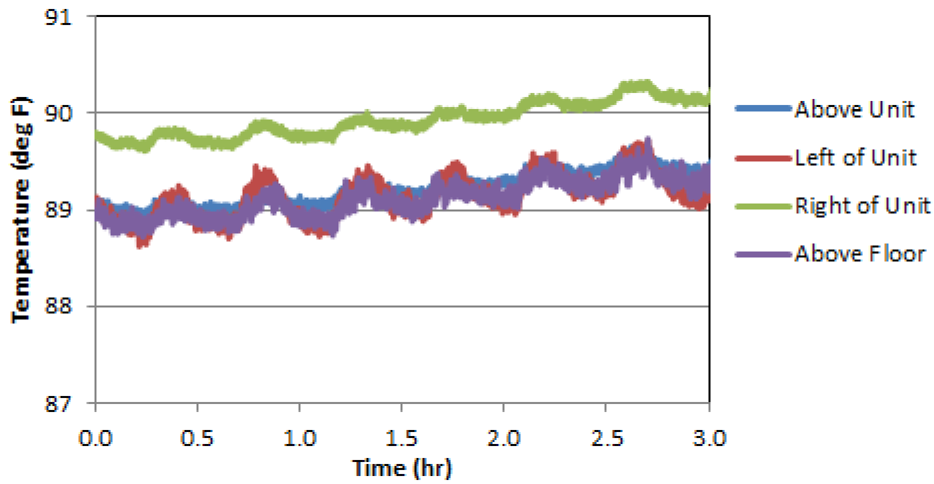


***Figure 24. Unconditioned space temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit A***

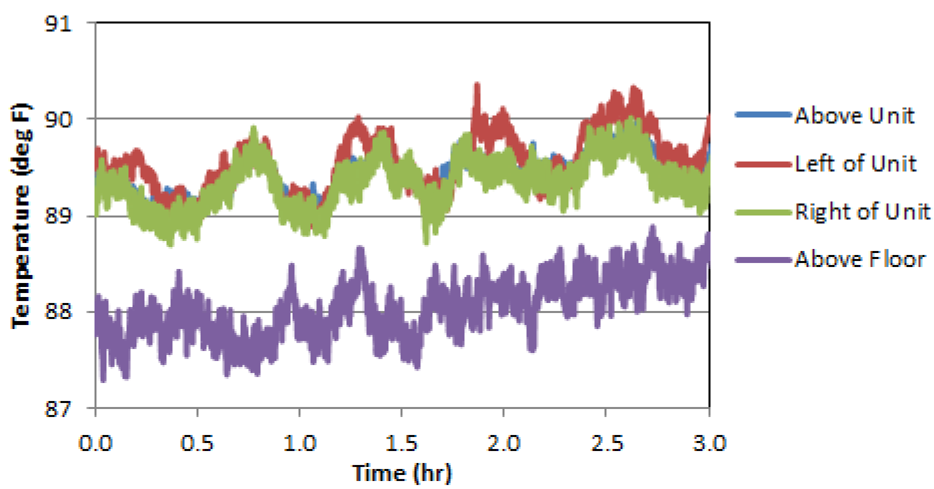


***Figure 25. Unconditioned space temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit B***

Data was also collected on an internal wall, the adjacent location on the external wall, and 1’ away from the unit over the same area. It is interesting that the external wall (touching) temperature cycles with the compressor, and it can reach significantly high temperatures. These results are given in Figure 26 and Figure 27.

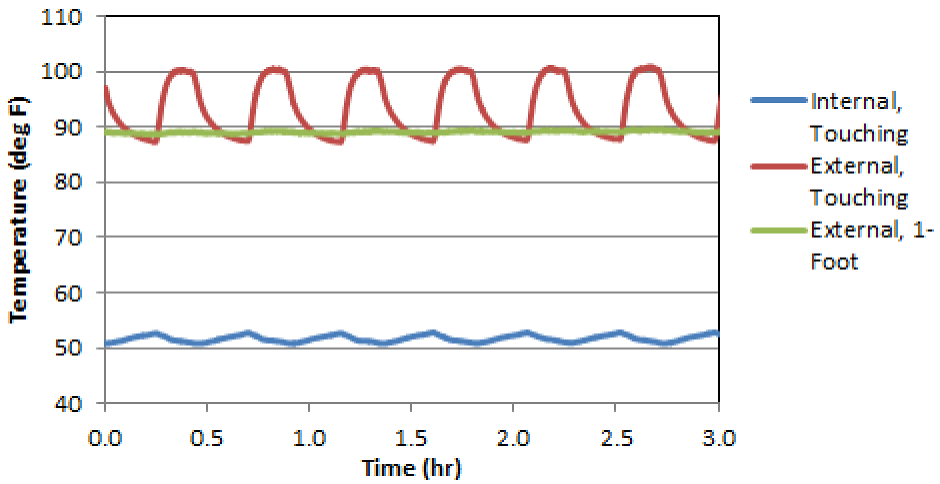


***Figure 26. Wall temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit A***

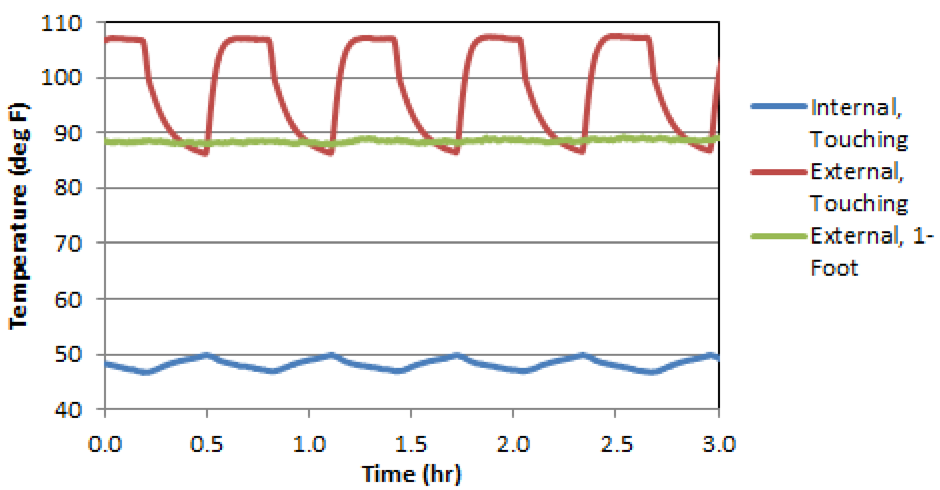


***Figure 27. Wall temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit B***

Finally, the temperatures of the reachable mechanical equipment (only the compressor for the dorm-size units) are given in Figure 28 and Figure 29.

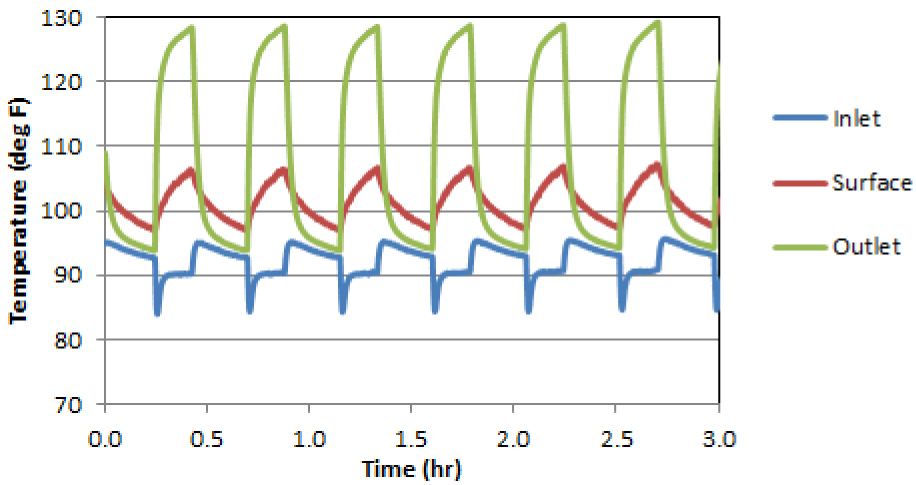


***Figure 28. Compressor temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit A***

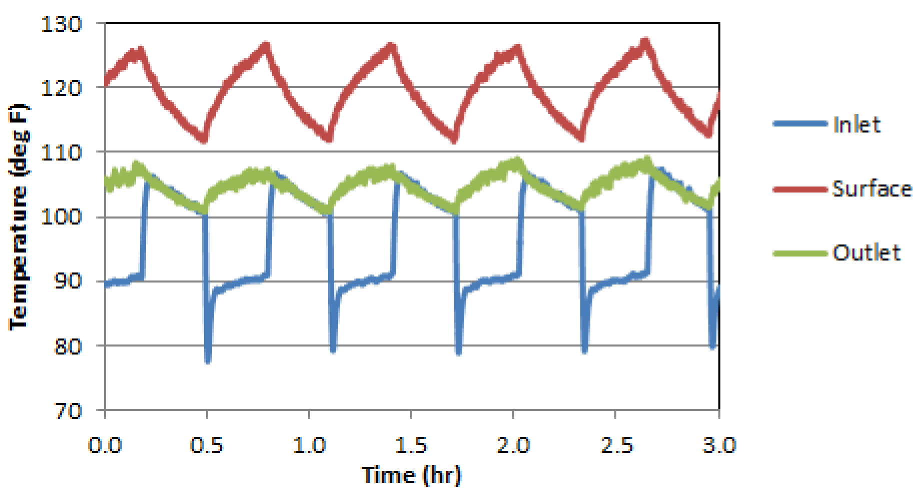


***Figure 29. Compressor temperatures versus time during the test period at 90°F and median thermostat setting for dorm-size Unit B***

## 6.2 Energy Consumption

Graphs of the power use over of the test period were generated. The standard called for at least 2 compressor cycles in the test period of no less than 3 hours. A sample of the plots is given in the following two figures (Figure 30 and Figure 31).

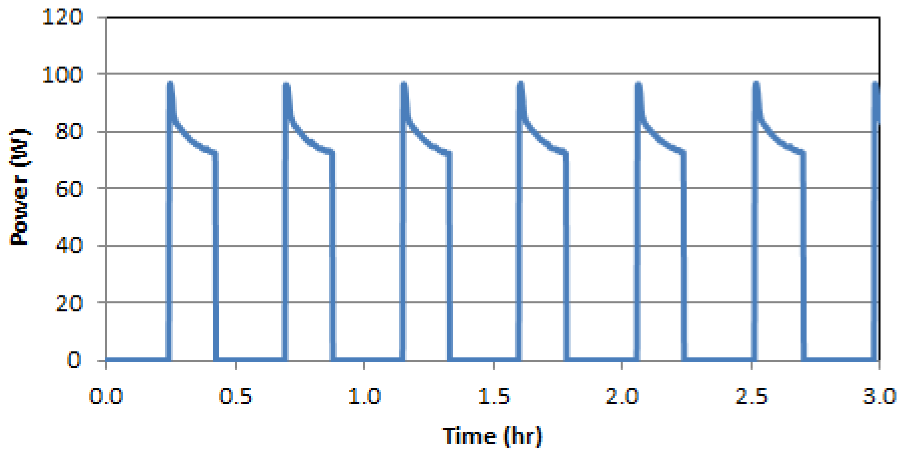


***Figure 30. Power versus time during the test period at 90°Fand median thermostat setting for dorm-size Unit A***

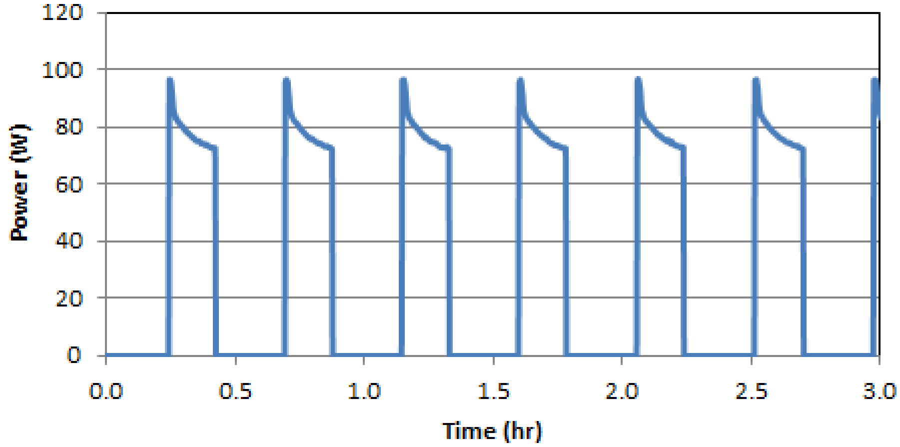


***Figure 31. Power versus time during the test period at 90°Fand median thermostat setting for dorm-size Unit B***

While the above plots are helpful to see the compressor cycles and verify that the units behave similarly, they do not provide any inherently useful information. A more useful quantity is how much energy is consumed annually and the associated cost. These values for the dorm-size units at 90°F and the median thermostat are given in Table 4. Again, the cost was determined by assuming an electricity rate of $0.1065/kWh.

***Table 4. Energy consumption and annual cost at 90°F and median thermostat setting for dorm-size units***

Unit A

| | | |
|---|---|---|
| EP | 0.093 | kwh |
| T | 184 | min |
| K | 1 | |
| ET | 0.731 | kWh/day |
| EY | 266.8 | kWh/yr |
| Cost | $ 28.41 | |

Unit B

| | | |
|---|---|---|
| EP | 0.094 | kwh |
| T | 184 | min |
| K | 1 | |
| ET | 0.736 | kWh/day |
| EY | 268.5 | kWh/yr |
| Cost | $ 28.59 | |

Comparing Unit A to Unit B, the results were within 1% of each other. The other means of determining if the data was valid was comparing the experimental energy consumption and annual cost to the published values. For a better comparison, a test was performed at the *coldest* thermostat setting (still at 90°F externally). The results of that test are in Table 5.

***Table 5. Energy consumption and annual cost at 90°F and coldest thermostat setting for dorm-size units***

Unit A

| | | |
|---|---|---|
| EP | 0.198 | kwh |
| T | 185 | min |
| K | 1 | |
| ET | 1.548 | kWh/day |
| EY | 565.2 | kWh/yr |
| Cost | $ 60.19 | |

Unit B

| | | |
|---|---|---|
| EP | 0.195 | kwh |
| T | 185 | min |
| K | 1 | |
| ET | 1.521 | kWh/day |
| EY | 555.2 | kWh/yr |
| Cost | $ 59.13 | |

After linear interpolation (or averaging) between the median and coldest settings, the experimental costs for Unit A and B came out to $44.30 and $43.86, respectively.

The annual kWh/yr were 416 and 412. The manufacturer publishes values of $45 and 420 kWh/yr, so the experimental data was within a reasonable margin for comparison.

### 6.3 Comparisons

The previous plots and values were specifically for the dorm-size unit at 90°F. Figure 32 and Figure 33 show the values at the other experimental temperatures for easy comparison and to determine the trend.

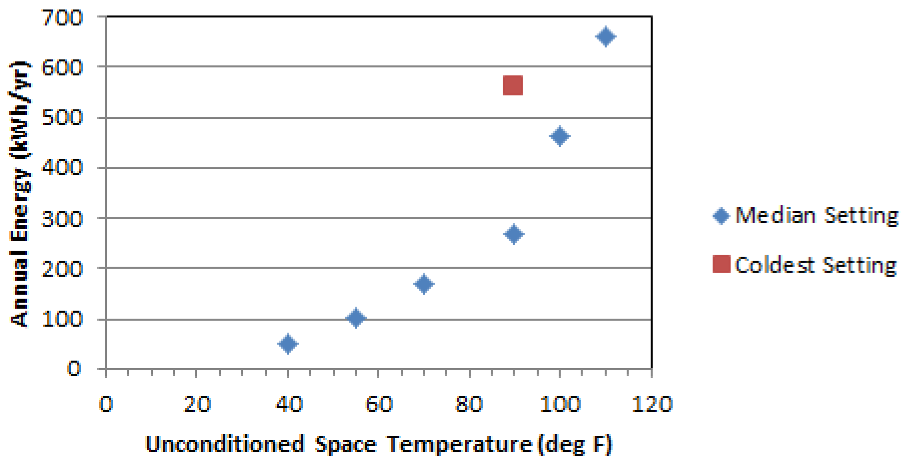


*Figure 32. Average annual energy use versus unconditioned space temperature for dorm-size units*

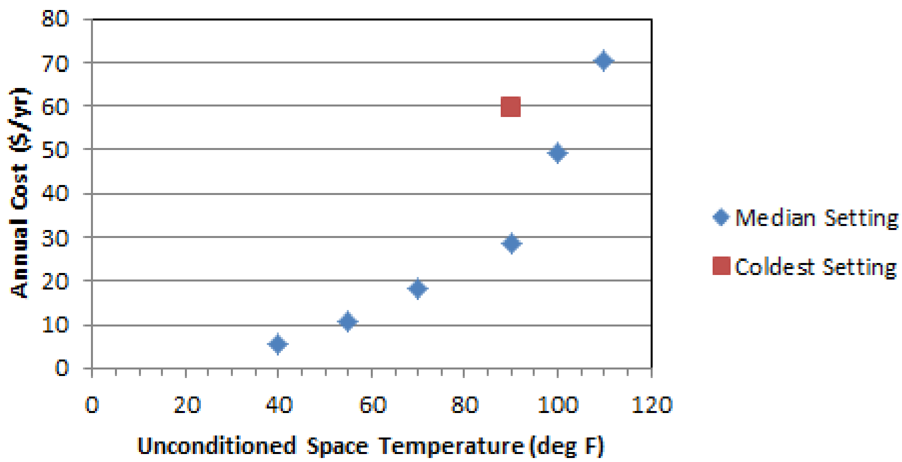


***Figure 33. Average annual cost versus unconditioned space temperature for dorm-size units***

It can be seen that the annual energy use and cost plots have the exact same trend, just a different scale and unit. It is interesting to see the difference in energy consumption and cost from the median thermostat setting to the coldest. While some households may choose the median, others may choose the coldest to ensure their food does not prematurely spoil. If it is assumed that the difference in cost from the median to coldest setting at 90°F (about $31) is the same for all unconditioned space temperatures, the following plot (Figure 34) can be used to predict costs at the coldest setting.

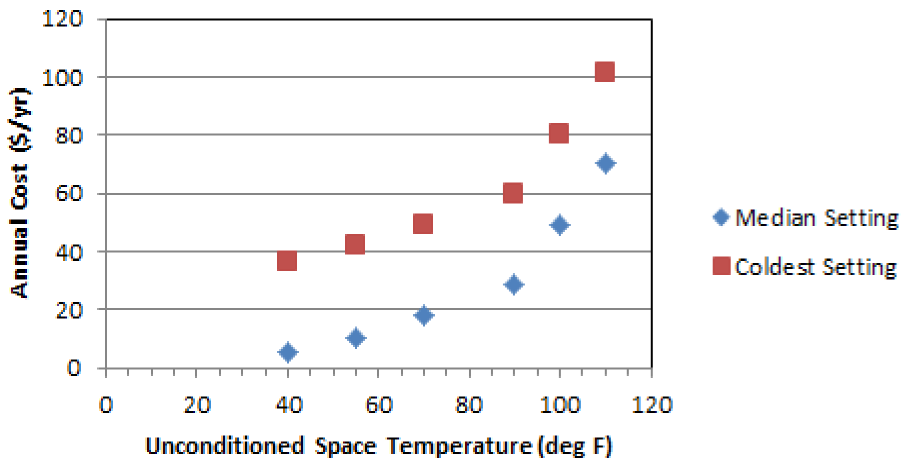


***Figure 34. Average annual cost at median setting and predicted annual cost at coldest thermostat setting versus unconditioned space temperature for dorm-size units***

Additionally, the unconditioned space temperature may extend beyond the range tested. For example, a refrigerator in a garage in the Middle East could see temperatures higher than 110°F and a refrigerator in a garage in Canada could see temperatures lower than 40°F. To predict the behavior outside the tested range, a regression was applied to the data taken at the median thermostat setting. Three regressions were performed in Microsoft Excel: linear, quadratic, and cubic. The metric used for comparison is the $R^2$ value which is a measure of goodness-of-fit (the closer to 1 the better). The following three plots (Figure 35-Figure 37) show the trend lines and equations.

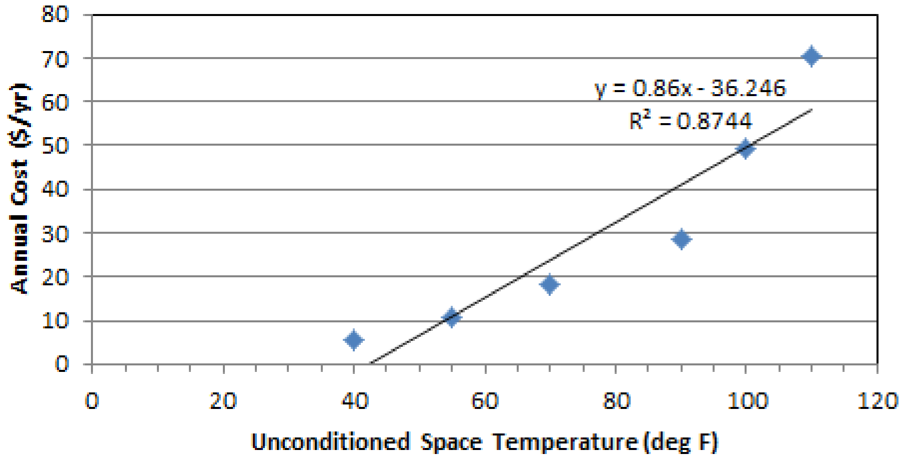


*Figure 35. Linear regression for average annual cost versus unconditioned space temperature at median thermostat setting for dorm-size units*

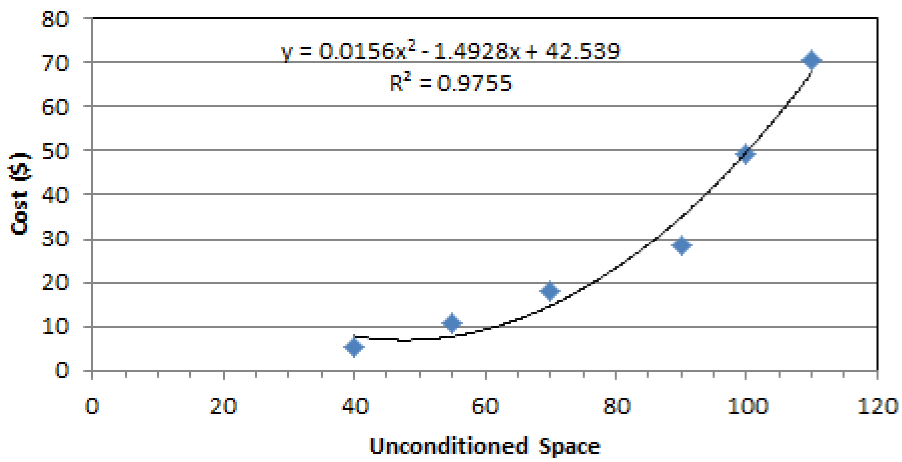


*Figure 36. Quadratic regression for average annual cost versus unconditioned space temperature at median thermostat setting for dorm-size units*

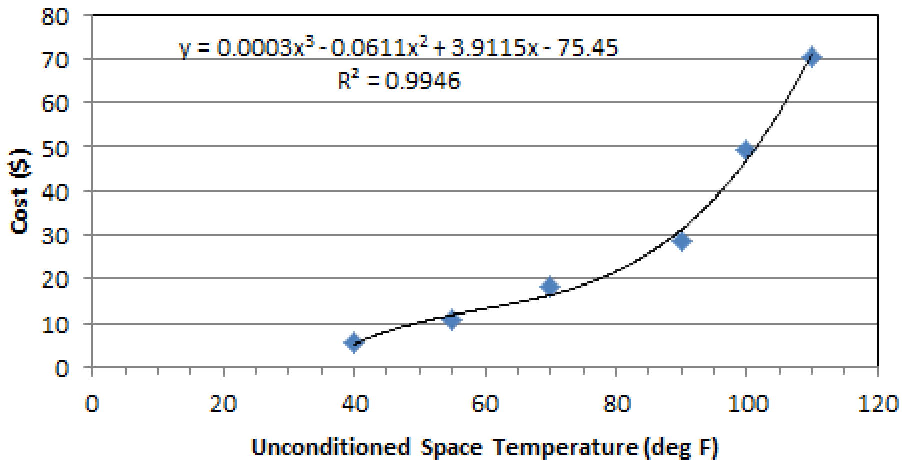


***Figure 37. Cubic regression for average annual cost versus unconditioned space temperature at median thermostat setting for dorm-size units***

It is obvious that the cubic regression is the best fit since the $R^2$ value is closest to 1 at 0.9946. However, more data points at intermediate points would be necessary to properly rule out a quadratic fit. The linear fit is not nearly as strong as the other two.

Another interesting phenomenon to consider is the effect the unconditioned space temperature has on the internal temperature. While it may be intuitive to think the hotter it is externally, the hotter the internal temperature will be, the opposite behavior within the freezer cabinet is actually shown by the data, presented in Figure 38. The refrigerator temperature, however, does increase with the increasing unconditioned space temperature.

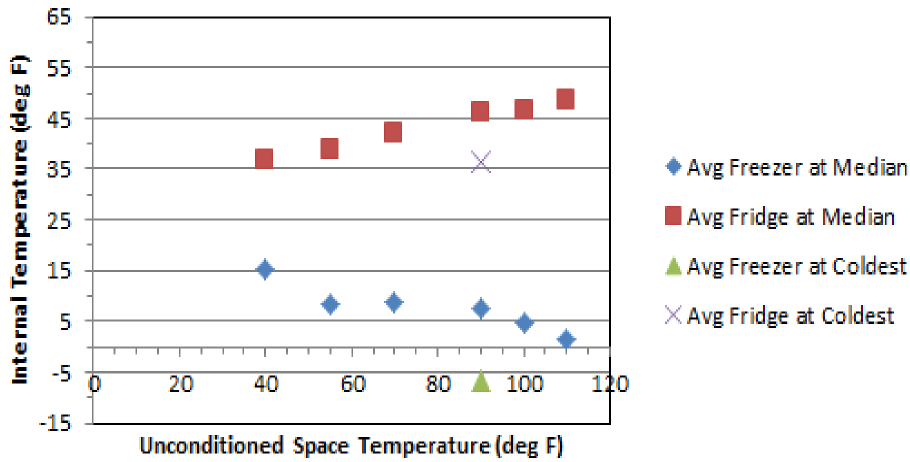


*Figure 38. Internal temperature versus unconditioned space temperature at the median and coldest thermostat settings for dorm-size units*

# 7. RESULTS FOR STANDARD-SIZE UNITS

The standard-size units' internal control system was more sophisticated than that of the dorm-size units, and they exhibited long-time automatic defrost cycles. In order to capture such defrost cycles in addition to regular compressor cycling, data was collected for a longer period of time, typically between 15 and 25 hours. Thus, in the subsequent sections, plots of the total test will contain solid and dashed black lines to distinguish what time frames were considered in the energy consumption and cost analysis. Interesting behavior occurred at the lower temperatures and further research is needed to more accurately determine the behavior in this region.

Unless otherwise mentioned, the sample of data presented comes from the 90°F test at the median thermostat setting. The other tests have similarly formatted tables and graphs in Appendix D.

## 7.1 Temperature

The temperature measurements over the total test served as the most obvious way to verify steady-state, both internally and externally, during the two test periods. While no manual calculation was performed, steady state was verified by visual inspection.

As with the dorm-size units, temperature excursions beyond HRF-1-2008's requirements existed. Because these units have additional fans for the condenser coil and compressor, they have about a 3" gap between the floor and the bottom of the actual refrigerator chamber for ventilation. This gap is covered by a plastic grill in the front, and the thermocouple just above the floor experienced higher temperatures from the exhaust. There were also minor differences in the internal temperatures between the two test units. Figure 39 and Figure 40 show the internal temperatures during the total test of Unit A and Unit B.

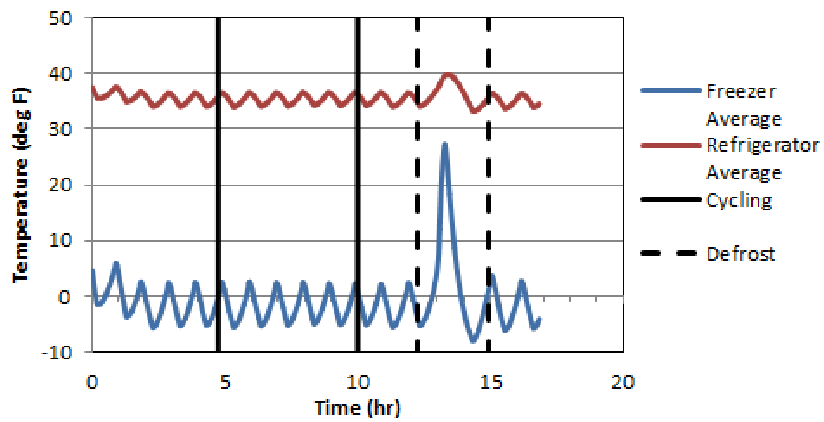


***Figure 39. Internal temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit A***

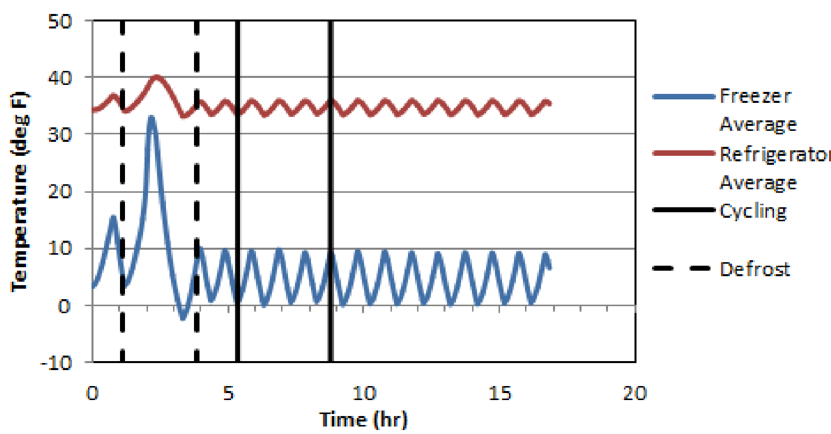


***Figure 40. Internal temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit B***

For a better understanding of how the temperature behaved during the defrost cycle and regular cycles, the following four plots (Figure 41-Figure 44) were generated as a “zoomed in” view of such.

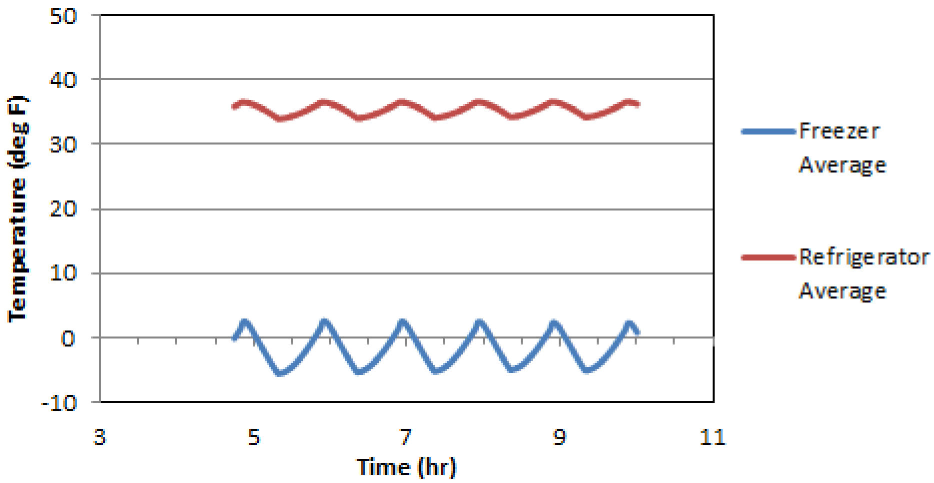


***Figure 41. Internal temperatures versus time during regular compressor cycling at 90°F and median thermostat setting for standard-size Unit A***

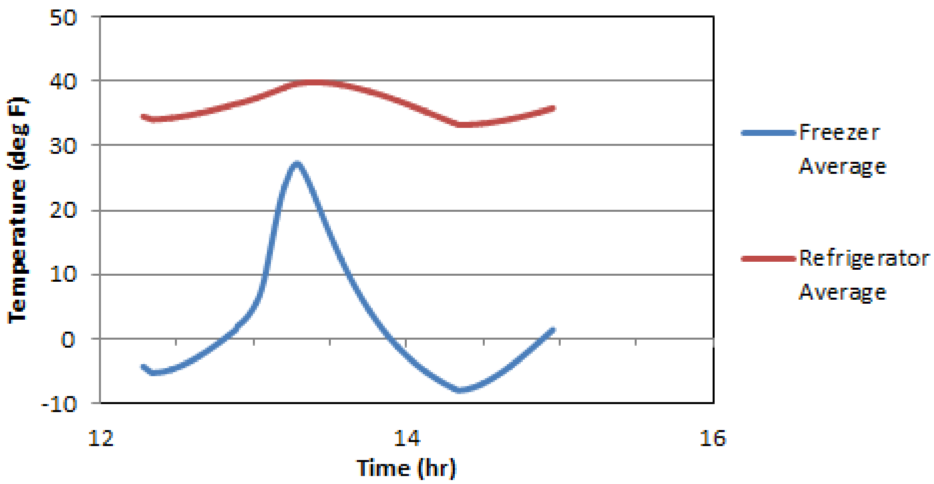


***Figure 42. Internal temperatures versus time during the defrost cycle at 90°F and median thermostat setting for standard-size Unit A***

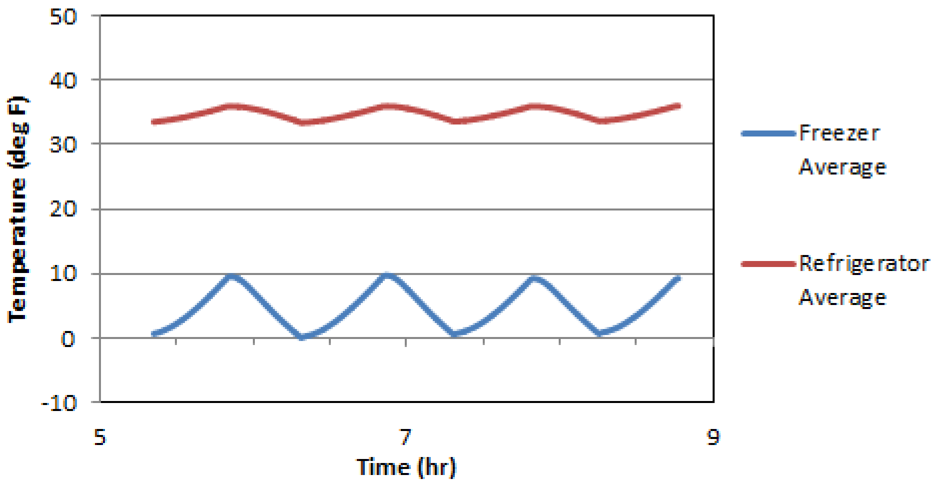


*Figure 43. Internal temperatures versus time during regular compressor cycling at 90°F and median thermostat setting for standard-size Unit B*

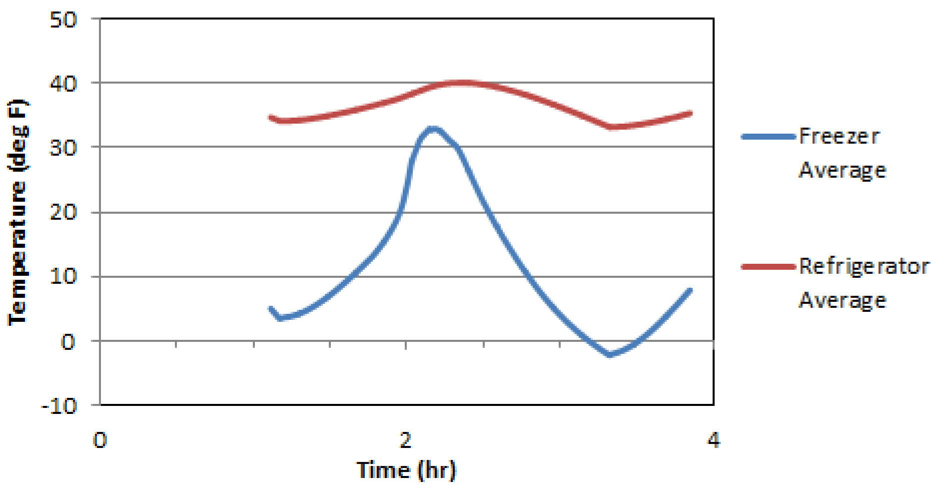


*Figure 44. Internal temperatures versus time during the defrost cycle at 90°F and median thermostat setting for standard-size Unit B*

The individual temperature readings (not the average) for both the refrigerator and freezer compartments were also plotted over the total test, regular compressor cycles, and defrost cycle. Figure 45 through Figure 50 depict these measurements.

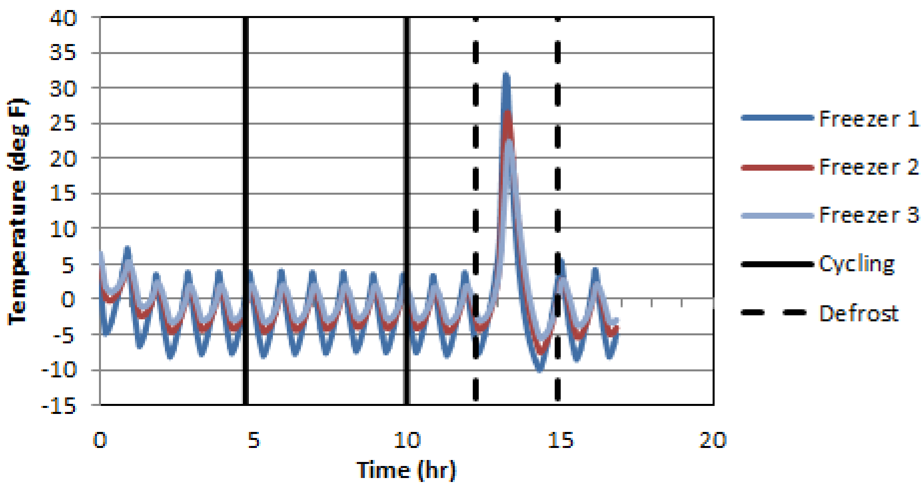


***Figure 45. Individual freezer temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit A***

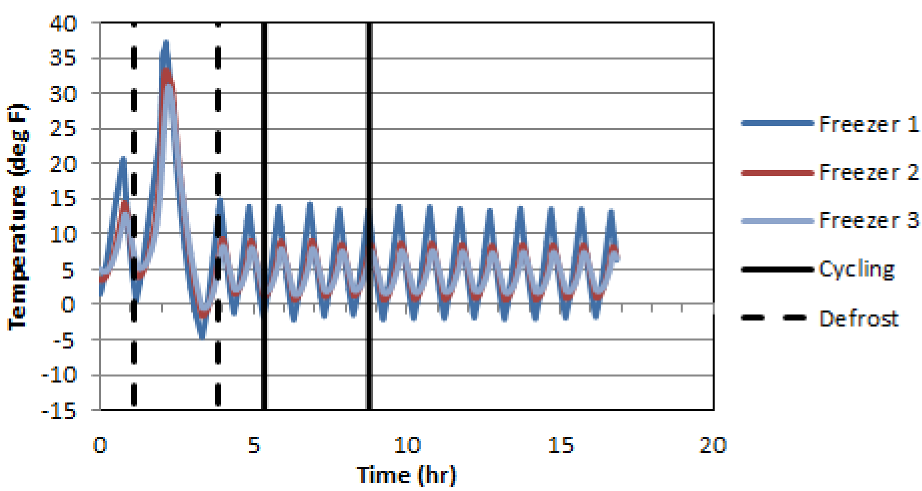


***Figure 46. Individual freezer temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit B***

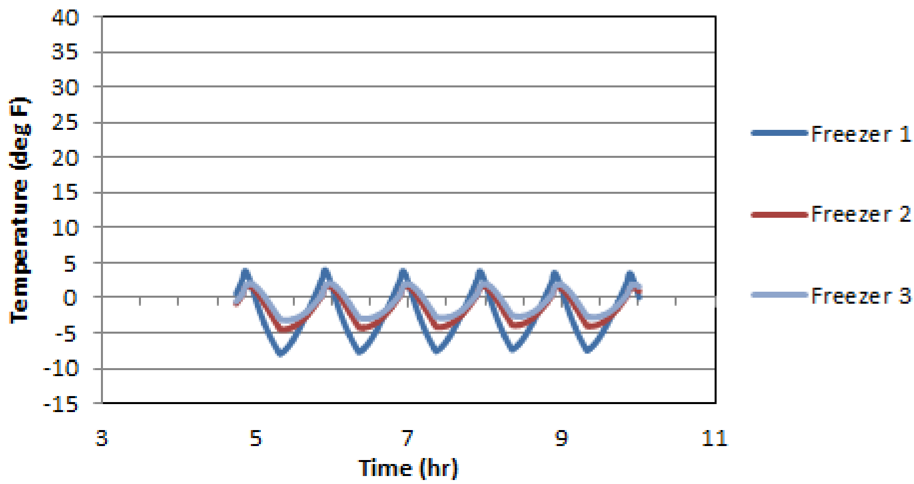


***Figure 47. Individual freezer temperatures versus time during the regular compressor cycling at 90°F and median thermostat setting for standard-size Unit A***

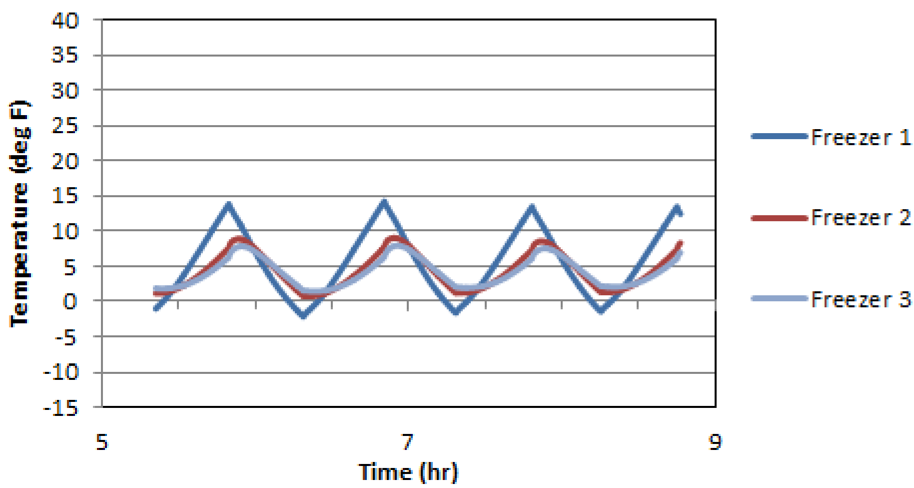


***Figure 48. Individual freezer temperatures versus time during the regular compressor cycling at 90°F and median thermostat setting for standard-size Unit B***

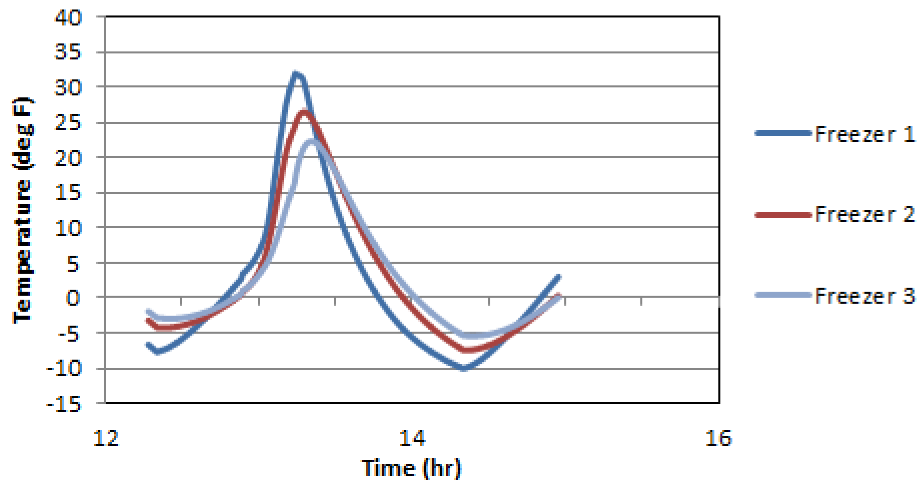


***Figure 49. Individual freezer temperatures versus time during the defrost cycle at 90°F and median thermostat setting for standard-size Unit A***

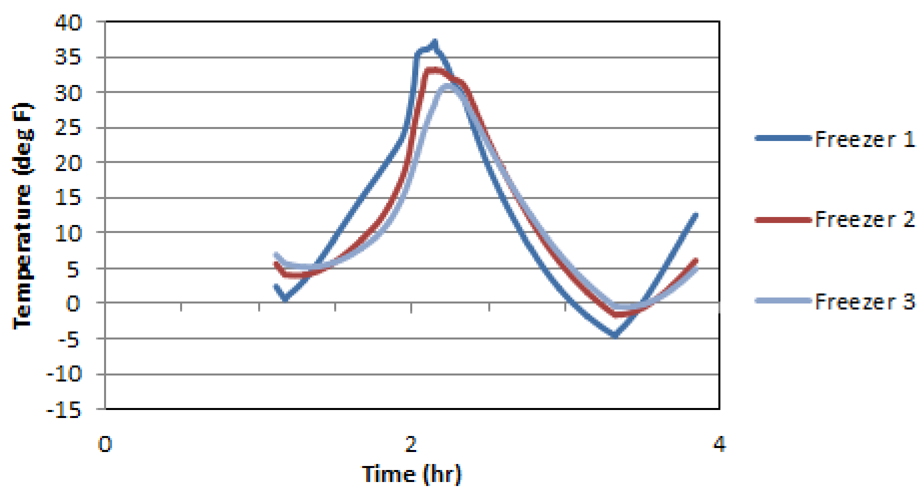


***Figure 50. Individual freezer temperatures versus time during the defrost cycle at 90°F and median thermostat setting for standard-size Unit B***

As with the dorm-size units, the subtle discrepancy between the internal temperatures may have been a result of the slight differences in the unconditioned space temperature or even the slight differences in the thermostat settings since the knobs did not have the median as a preset locked position. The next two plots (Figure 51 and Figure 52) depict the unconditioned space temperatures over the total test for these units.

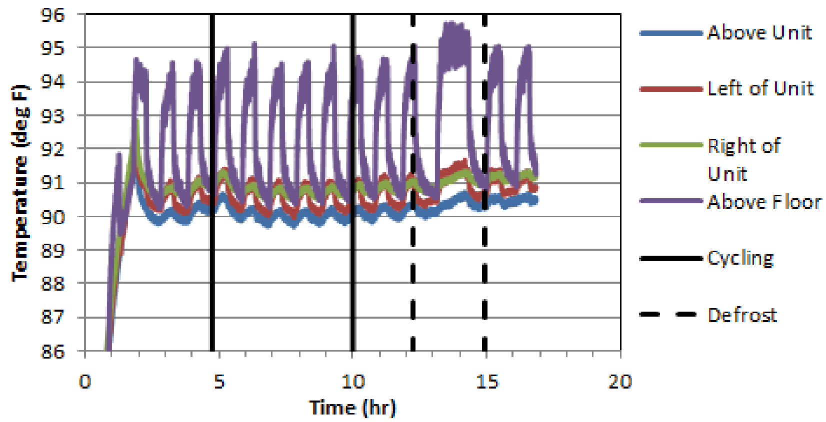


***Figure 51. Unconditioned space temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit A***

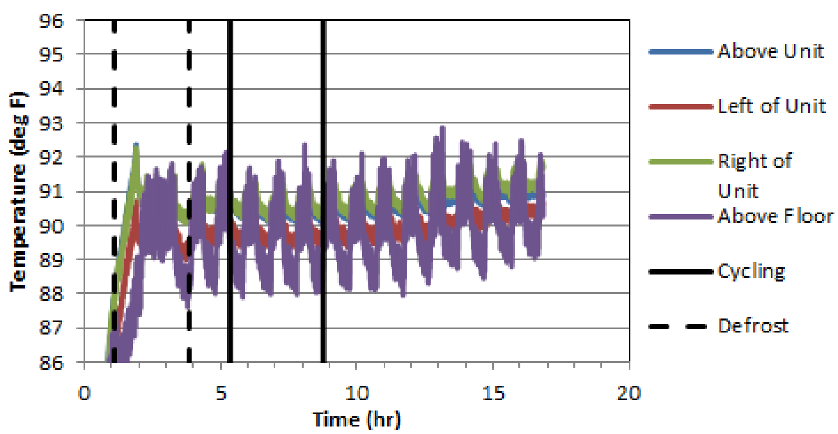


***Figure 52. Unconditioned space temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit** B*

While it was not very obvious in Figure 40, it can be seen in Figure 52 that the unconditioned space temperature was not steady during the defrost cycle. This will be addressed in later sections. As mentioned, the temperature just above the floor in front of the unit experienced the greatest range in sync with the cycling of the compressor, and Unit A appeared to be more affected than Unit B.

Since more mechanical components were available for analysis, data was not collected at the same wall locations as with the dorm-size units. Instead, only the external wall temperature was taken since it exhibited the most interesting behavior in the dorm-size test. These results are given in Figure 26 and Figure 54.

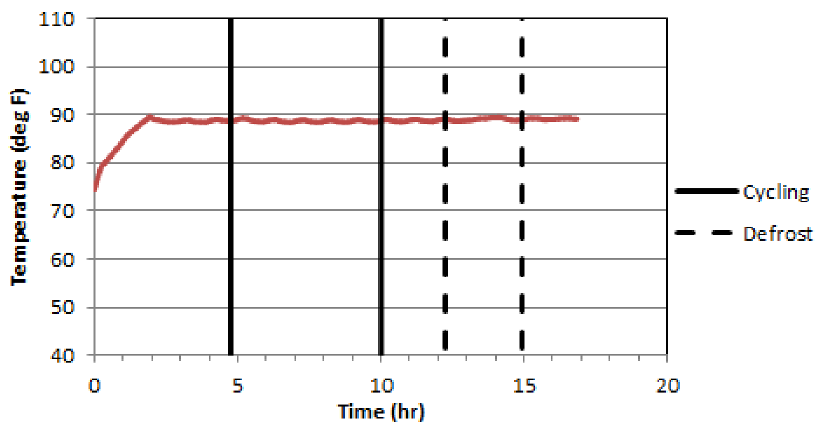


***Figure 53. Wall temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit A***

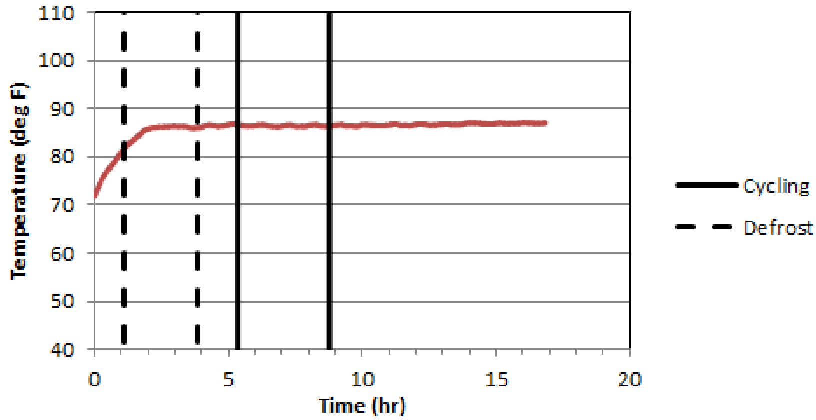


***Figure 54. Wall temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit B***

Finally, the temperatures of the mechanical components are given in the Figure 55 and Figure 56. The locations included the evaporator inlet, evaporator outlet, compressor inlet, compressor outlet, and condenser outlet.

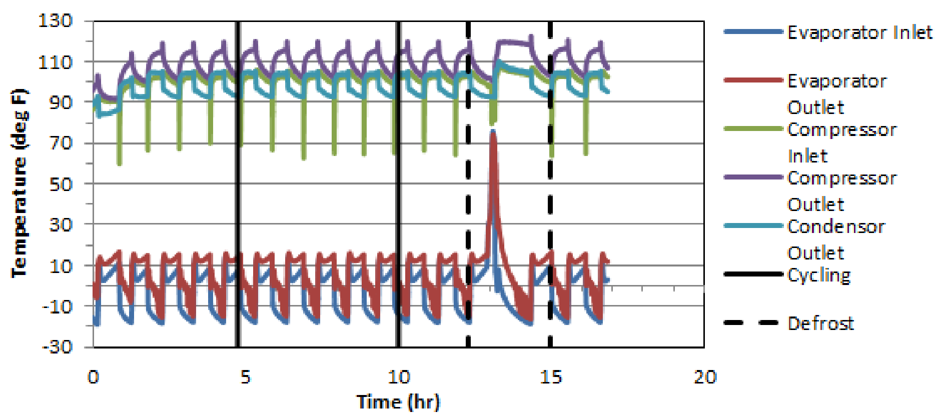


***Figure 55. Component temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit A***

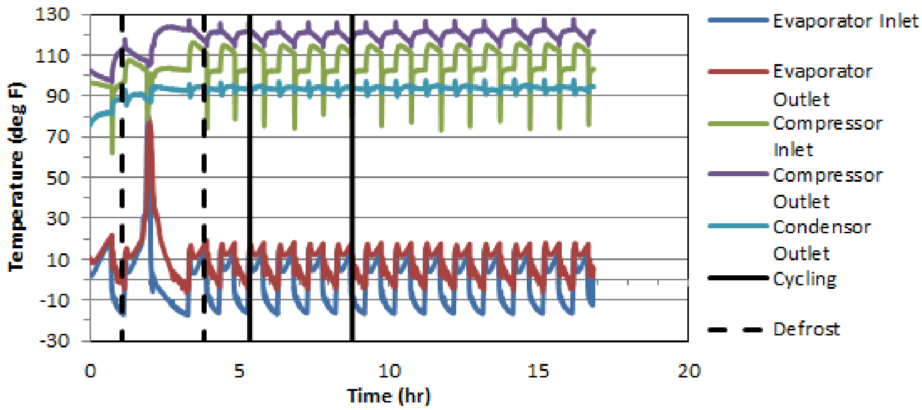


***Figure 56. Component temperatures versus time during the total test at 90°F and median thermostat setting for standard-size Unit B***

## 7.2 Energy Consumption

Graphs of the power use over of the total test, regular cycles, and defrost cycle were generated. The long-time automatic defrost cycles, as originally depicted in Figure 1, can easily be seen in Figure 57 and Figure 58. Solid and dashed black lines, again, distinguish the two sections of the final test period. Figure 59-Figure 62 plot the "zoomed-in" view of the energy use for the two types of cycles.

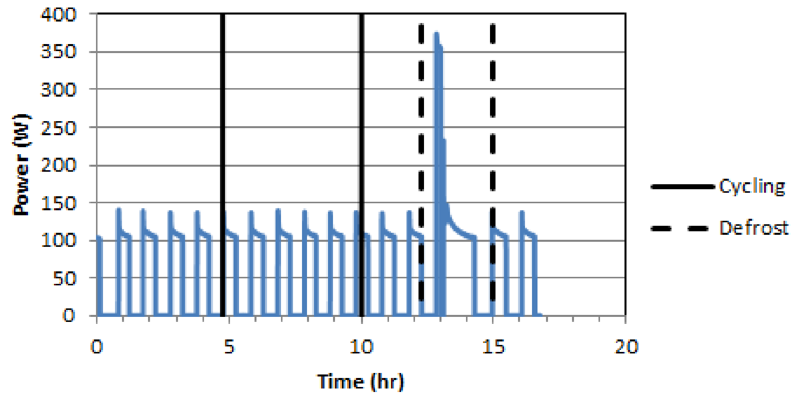


*Figure 57. Power versus time during the total test at 90°Fand median thermostat setting for standard-size Unit A*

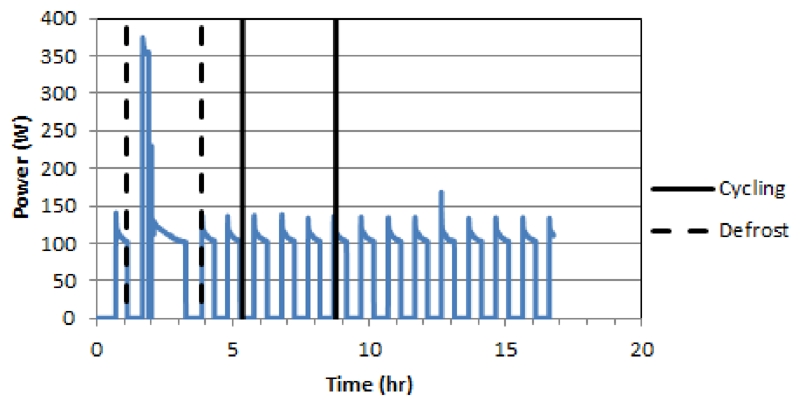


*Figure 58. Power versus time during the total test at 90°Fand median thermostat setting for standard-size Unit B*

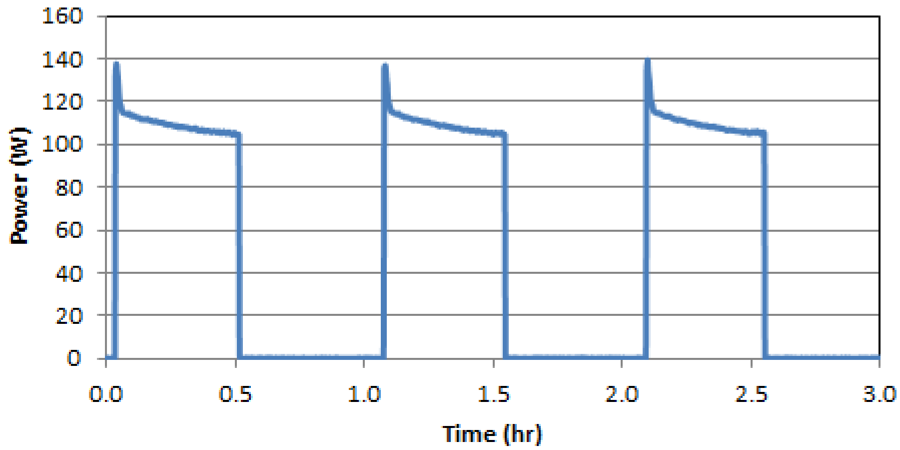


*Figure 59. Power versus time during the regular compressor cycling at 90°Fand median thermostat setting for standard-size Unit A*

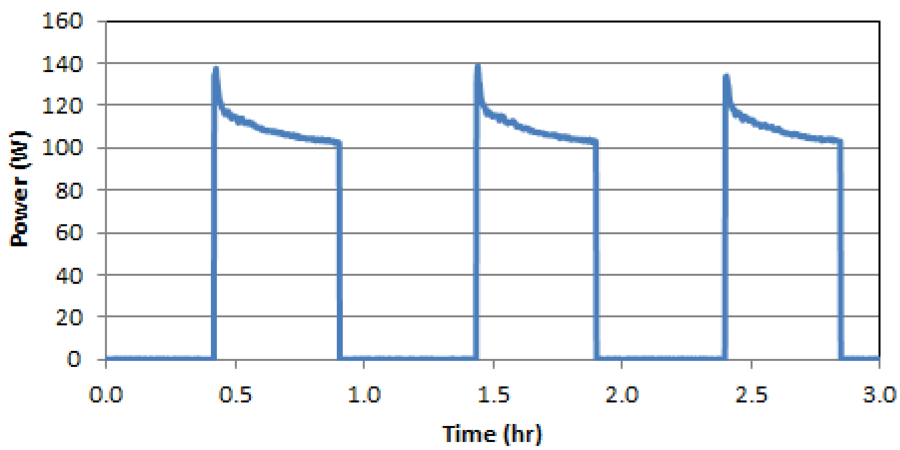


*Figure 60. Power versus time during the regular compressor cycling at 90°Fand median thermostat setting for standard-size Unit B*

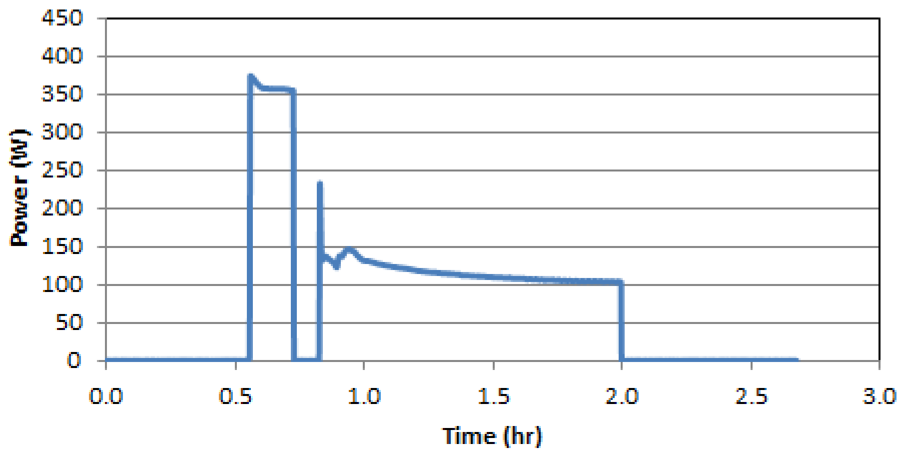


*Figure 61. Power versus time during the defrost cycle at 90°Fand median thermostat setting for standard-size Unit A*

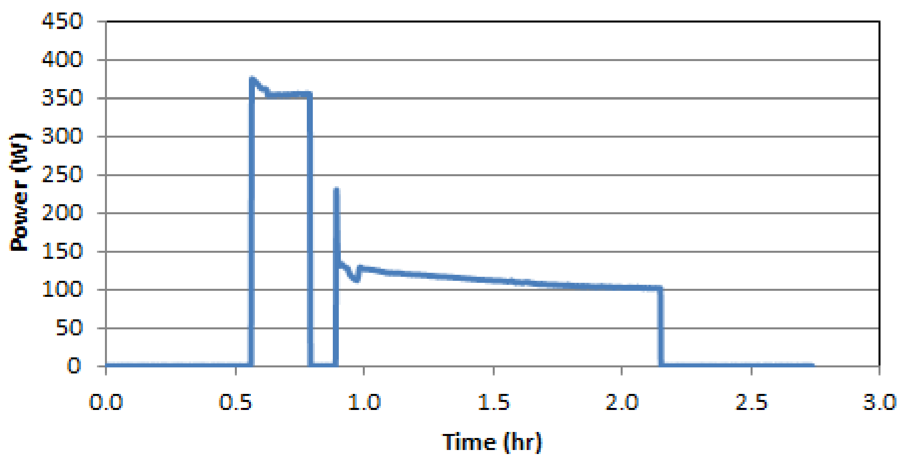


*Figure 62. Power versus time during the defrost cycle at 90°Fand median thermostat setting for standard-size Unit B*

Again, these plots are helpful to see the compressor cycles and verify that the units behave similarly; they do not provide any inherently useful information. The annual energy consumption and cost for the standard-size units at 90°F and the median thermostat are given in Table 6 (electric rate of $0.1065/kWh).

***Table 6. Energy consumption and annual cost at 90°F and median thermostat setting for standard-size units***

Unit A

| | | |
|---|---|---|
| EP1 | 0.278 | kwh |
| T1 | 316 | min |
| EP2 | 0.197 | kwh |
| T2 | 161 | min |
| K | 1 | |
| CT | 2.7 | hours |
| ET | 1.517 | kWh/day |
| EY | 553.6 | kWh/year |
| Cost | $ 58.96 | |

Unit B

| | | |
|---|---|---|
| EP1 | 0.163 | kwh |
| T1 | 206 | min |
| EP2 | 0.224 | kwh |
| T2 | 164 | min |
| K | 1 | |
| CT | 2.7 | hours |
| ET | 1.560 | kWh/day |
| EY | 569.3 | kWh/year |
| Cost | $ 60.63 | |

Comparing Unit A to Unit B, the results were within 3% of each other. These values, specifically EP2, show that the unsteady unconditioned space temperature during the defrost cycle of Unit B had little effect on the overall energy consumption. To compare the results to the manufacturer's published information, a test was performed at the *coldest* thermostat setting (still at 90°F externally).

Interestingly, Unit B did not experience a defrost cycle during the nearly 18-hour long test. As detailed in the Methodology section, when one unit experienced a defrost cycle and the other did not, the unit without the defrost cycle was treated as a non-automatic defrost unit for energy and cost calculations. However, this led to a significant discrepancy in energy consumption and cost between Unit A and Unit B. To reconcile this discrepancy, the defrost values from Unit A were “borrowed” to compute additional energy and cost values for Unit B. For additional comparison, the average cost between the two units, as is, was computed. Table 7 contains these results.

***Table 7. Energy consumption and annual cost at 90°F and coldest thermostat setting for standard-size units***

Unit A

| | | |
|---|---|---|
| EP1 | 0.477 | kwh |
| T1 | 444 | min |
| EP2 | 0.282 | kwh |
| T2 | 253 | min |
| K | 1 | |
| CT | 4.2 | hours |
| ET | 1.575 | kWh/day |
| EY | 574.8 | kWh/year |
| Cost | $ 61.21 | |

Unit B

*(As Is, No Defrost)*

| | | |
|---|---|---|
| EP1 | 0.523 | kwh |
| T1 | 480 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 1.570 | kWh/day |
| EY | 572.9 | kWh/year |
| Cost | $ 61.01 | |

*(Borrowed Defrost)*

| | | |
|---|---|---|
| EP1 | 0.523 | kwh |
| T1 | 480 | min |
| EP2 | 0.282 | kwh |
| T2 | 253 | min |
| K | 1 | |
| CT | 4.2 | hours |
| ET | 1.585 | kWh/day |
| EY | 578.7 | kWh/year |
| Cost | $ 61.63 | |

*(Averaged)*

| | | |
|---|---|---|
| EY A | 574.8 | kWh/year |
| Cost A | $ 61.21 | |
| EY B | 572.9 | kWh/year |
| Cost B | $ 61.01 | |
| Avg EY | 573.85 | kWh/year |
| Avg Cost | $ 61.11 | |

It can be seen that all of the results in Table 7 are within 1% of each other, regardless of the method. Thus, the comparison of the experimental data and published data was possible. After averaging between the median and coldest thermostat settings (the borrowed defrost was used for Unit B), the experimental costs for Unit A and B came out to $60.09 and $61.13, respectively. The annual kWh/yr were 564 and 574. The manufacturer publishes values of $43 and 404 kWh/yr, which is significantly lower than the experimental values.

One possible explanation for such a large difference is that the average internal temperatures for Unit A at the median thermostat setting were actually slightly lower than the required, so the second test should have been performed at the warmest thermostat setting. However, the average freezer temperatures for Unit B were higher than 0°F, and that test had to be performed at the coldest setting. Even so, it is not likely that performing a test at the warmest setting would impact the result that greatly since there is only a $0.40 difference between the median and coldest settings. The other potential reason is that the manufacturer’s testing methods for this particular model number were insufficient. These units were donated by the manufacturer and are not commercially available. Nevertheless, the general trend (and overall object of this project) should still be valid.

### 7.3 Comparisons

From the three methods of handling the data from tests in which one unit defrosts and the other does not, it was necessary to choose a method that best represents the physical system. A comparison of the tests in which both units experienced a defrost cycle was performed. It was found that the greatest percentage difference between the defrost cycle energy (EP2) and time (T2) for both test units was 18%. While this percentage seems high, the two values that had the greatest influence were 0.148 and 0.178 kWh, which is a difference of just 0.03 kWh. Therefore, it was decided that the method of “borrowing a defrost cycle” from the other unit was most effective in predicting the behavior under given conditions. This method was employed for the tests at unconditioned space temperatures of 33°F, 90°F (coldest setting), and 100°F.

Synonymously to the dorm-size units, the previous plots and values were specifically for the standard-size units at 90°F. The following plots show the values at the other experimental temperatures. Again, it is important to note that the energy and cost values in these plots reflect “borrowed defrost cycles” where needed, but plots of the “as tested” and averaged values can be found in the appendices.

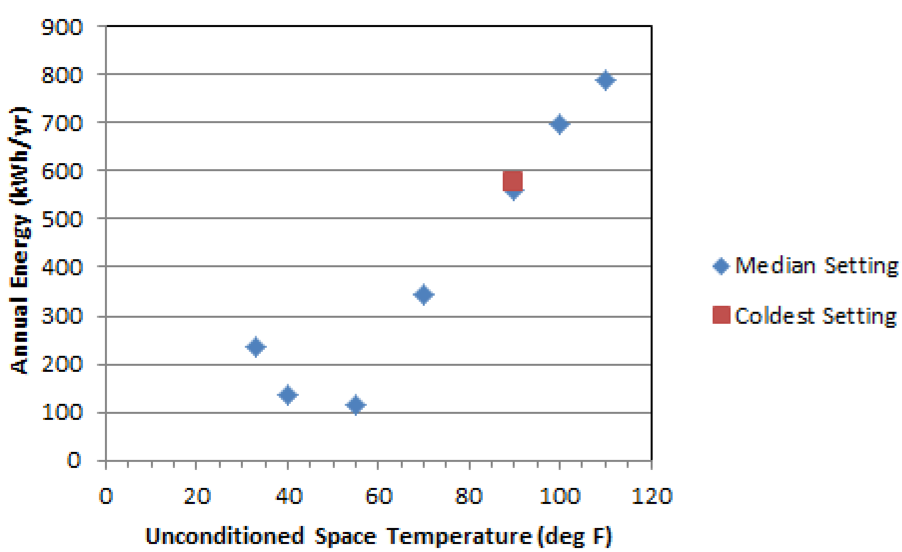


***Figure 63. Average annual energy use versus unconditioned space temperature for standard-size units***

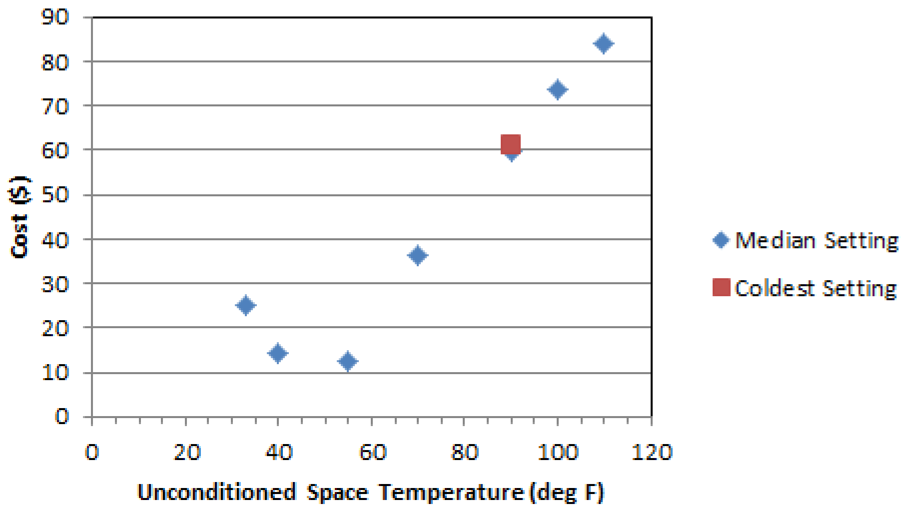


***Figure 64. Average annual cost versus unconditioned space temperature for standard-size units***

The first thing to take away from Figure 63 and Figure 64 is that the difference in energy consumption and cost from the median thermostat setting to the coldest is not very large, which was quantified in Section 7.2. In fact, it is almost insignificant given the uncertainty margins. Therefore, a prediction of costs at the other temperatures would not provide much new information.

Additionally, the trend appears to be primarily linear at temperatures above 55°F, and becomes more nonlinear at the lower temperatures. Linear, quadratic, and cubic regressions were applied to the entire data set taken at the median thermostat setting. The following three plots (Figure 65-Figure 67) show the trend lines, equations, and $R^2$ values.

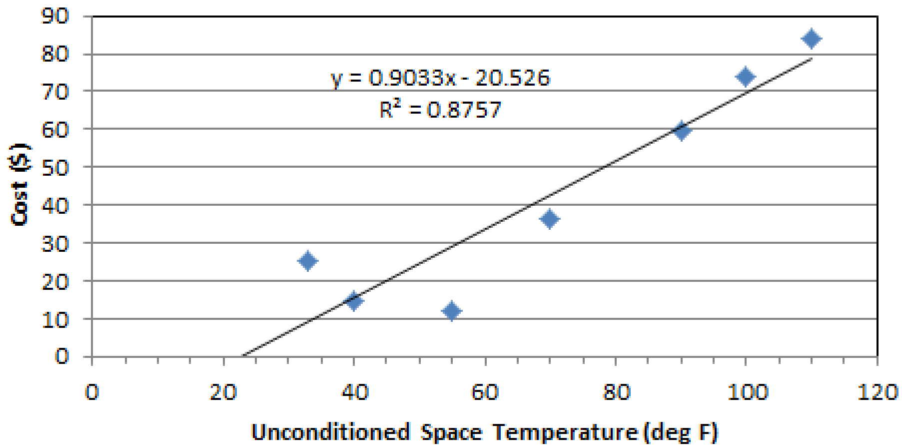


*Figure 65. Linear regression for average annual cost versus unconditioned space temperature at median thermostat setting for standard-size units*

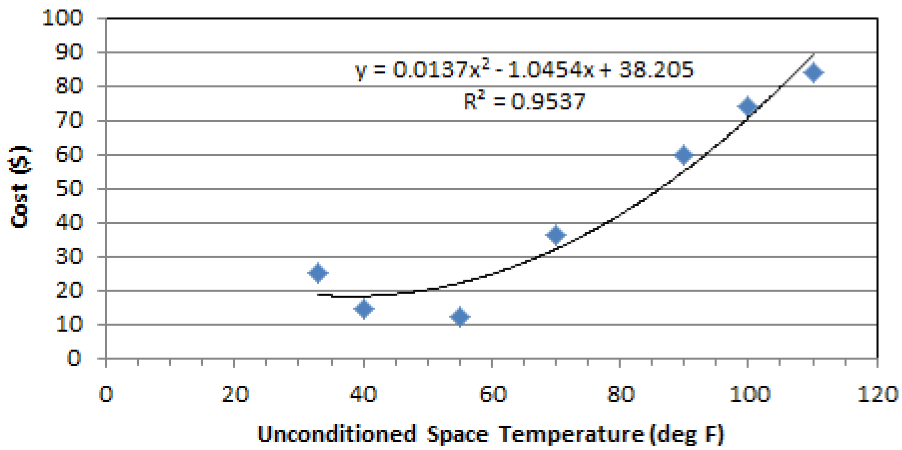


*Figure 66. Quadratic regression for average annual cost versus unconditioned space temperature at median thermostat setting for standard-size units*

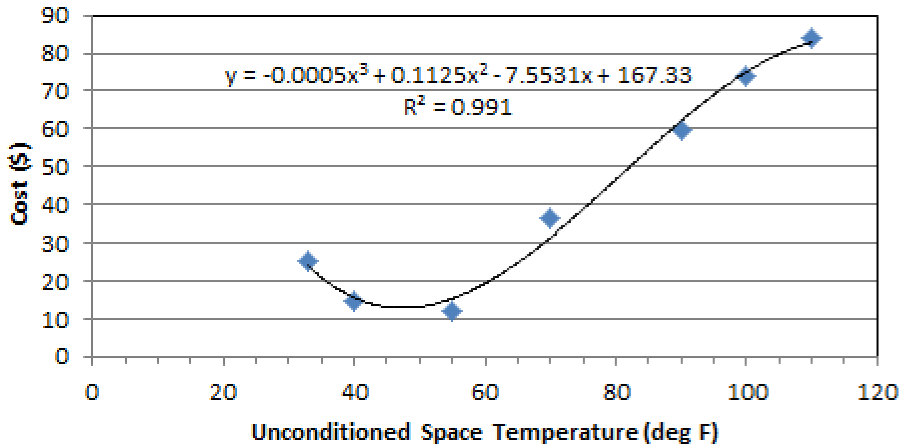


***Figure 67. Cubic regression for average annual cost versus unconditioned space temperature at median thermostat setting for standard-size units***

An analysis was also conducted for the higher temperatures and lower temperatures separately. As mentioned, the higher temperatures, by visual inspection, were linear, and thus, that regression was applied. A quadratic regression was applied to the lower temperatures. These are given in Figure 68 and Figure 69.

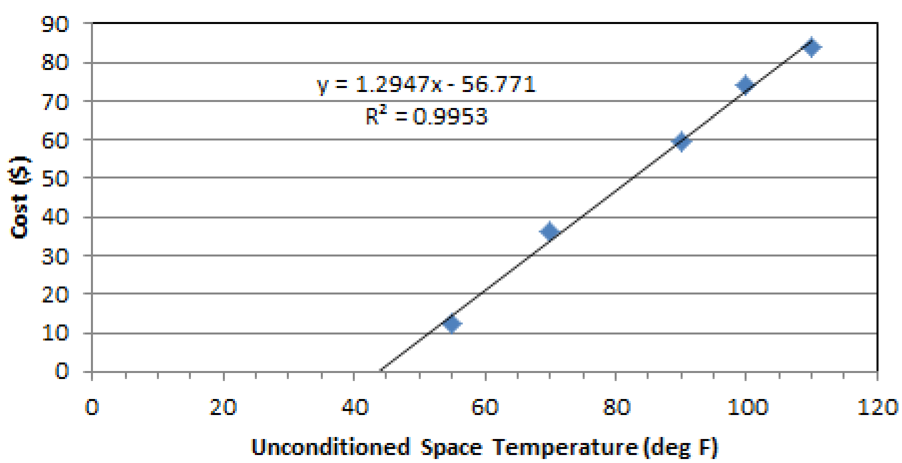


***Figure 68. Linear regression for average annual cost versus unconditioned space temperature 55°F and above at median thermostat setting for standard-size units***

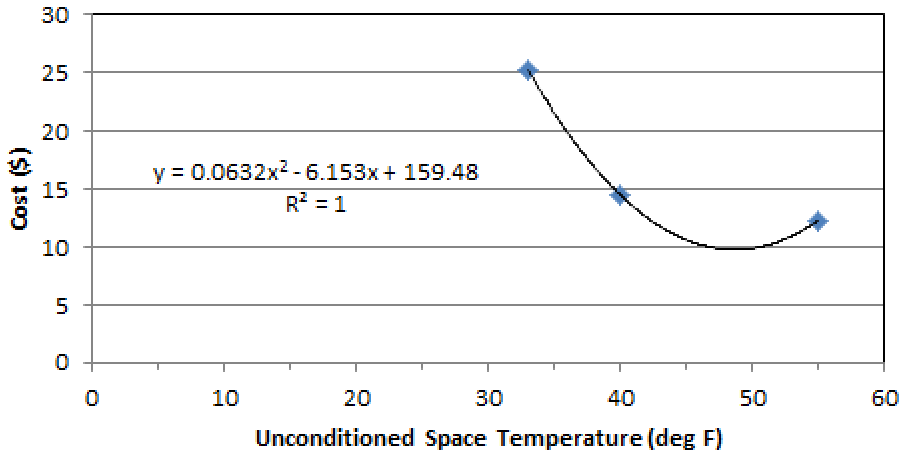


***Figure 69. Quadratic regression for average annual cost versus unconditioned space temperature 55°F and below at median thermostat setting for standard-size units***

Again, the cubic regression seems to be the best fit when looking at all of the data points together. However, if the data points are split into the two sections (55+ and 55-), a linear regression for the upper end is even stronger than the cubic regression. The quadratic regression on the lower end may be deceptively as strong ($R^2$=1) since there are only three data points which is the minimum requirement for a quadratic fit. More tests are necessary to validate this regression.

While the dorm-size units showed consistently warmer refrigerator temperatures with increasing unconditioned space temperatures, the standard-size units exhibited more unpredictable behavior. Figure 70 contains the internal temperatures over the test temperature range.

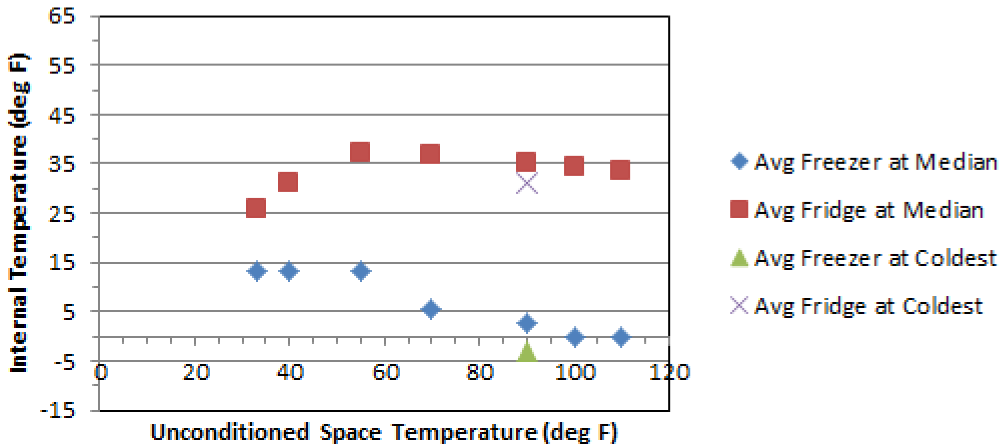


*Figure 70. Internal temperature versus unconditioned space temperature at the median and coldest thermostat settings for standard-size units*

# 8. RESULTS FOR CHEST FREEZERS

As with the other units, the overall trend observed with the chest freezers was that energy consumption increases with unconditioned space temperature. The chest freezers fell under the category of non-automatic defrost units, and therefore, the test period and data reduction process was much more simplistic than that of the standard-size units. The results for the temperature profiles and energy consumption during the total test time and test period at an unconditioned space temperature of 90°F are given in the following subsections, and a comparison with the other temperature settings will be given. Again, the complete collection of generated graphs and raw data can be found in the appendices.

## 8.1 Temperature

Visual inspection of the internal temperatures shows that the units were in fact steady, and though the unconditioned space temperatures fluctuated, the effects on the internal were not immediately obvious. At the median thermostat setting, the internal freezer temperatures of the units were higher than the recommended temperature of 0°F. Minor differences in freezer temperatures existed between the two test units. Figure 71 and Figure 72 show the average internal temperature during the total test of Unit A and Unit B.

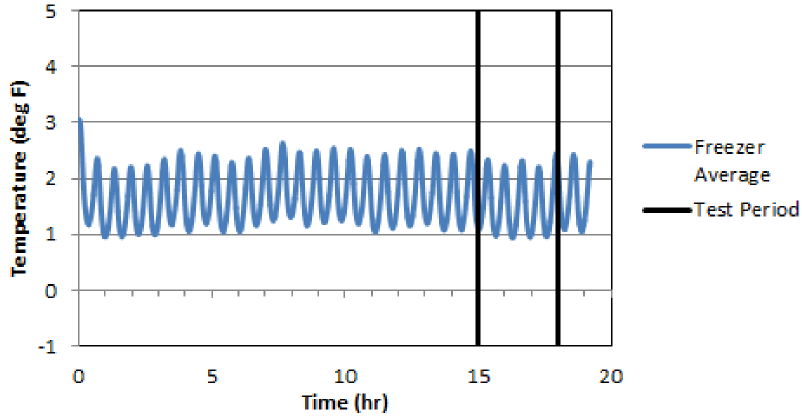


***Figure 71. Internal temperatures versus time during the total test at 90°F and median thermostat setting for chest freezer Unit A***

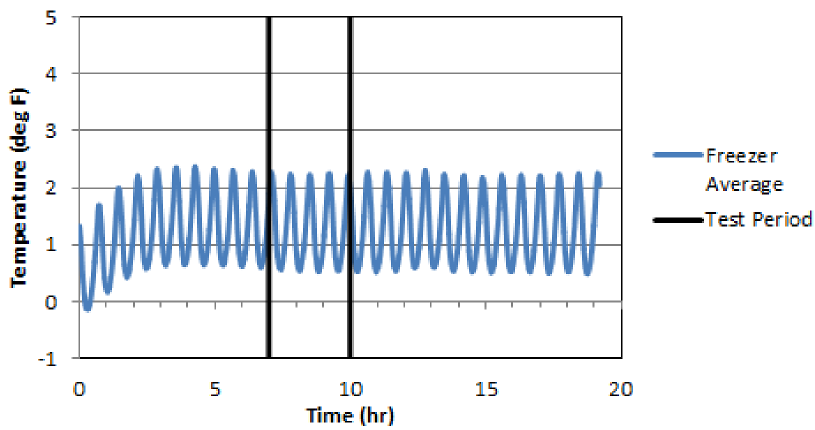


***Figure 72. Internal temperatures versus time during the total test at 90°F and median thermostat setting for chest freezer Unit B***

In addition to the average freezer temperatures, plots showing the individual readings were generated for the total test and test period. These are given in the following (Figure 73 through Figure 76):

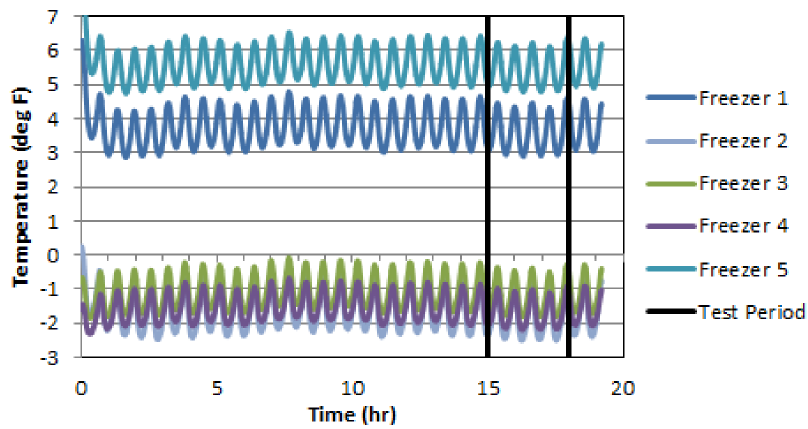


*Figure 73. Individual freezer temperatures versus time during the total test at 90°F and median thermostat setting for chest freezer Unit A*

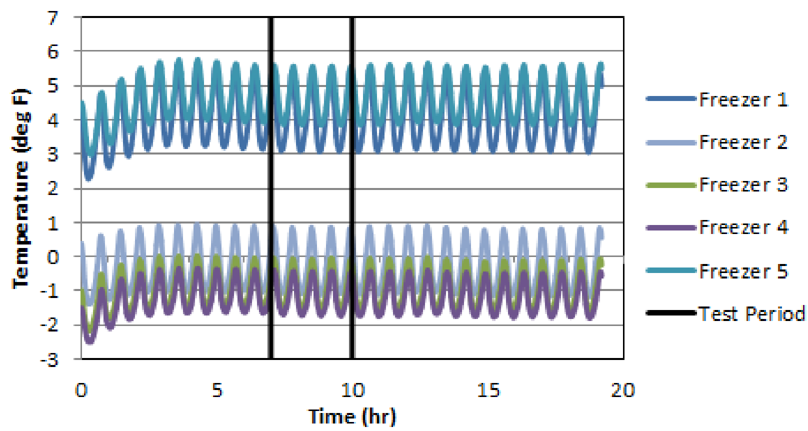


*Figure 74. Individual freezer temperatures versus time during the total test at 90°F and median thermostat setting for chest freezer Unit B*

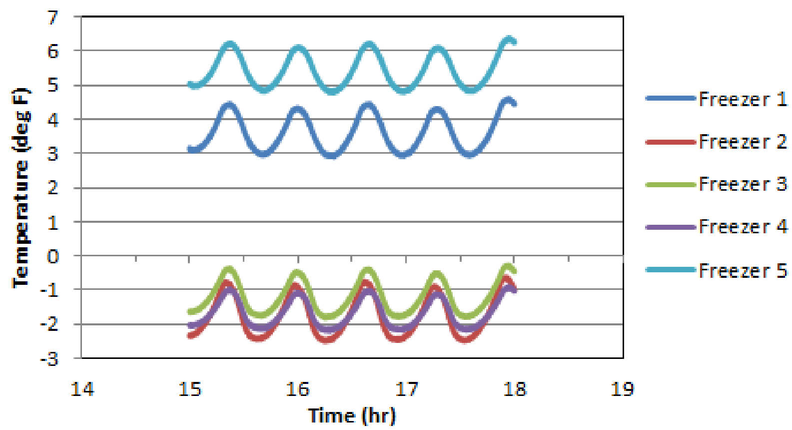


*Figure 75. Individual freezer temperatures versus time during the test period at 90°F and median thermostat setting for chest freezer Unit A*

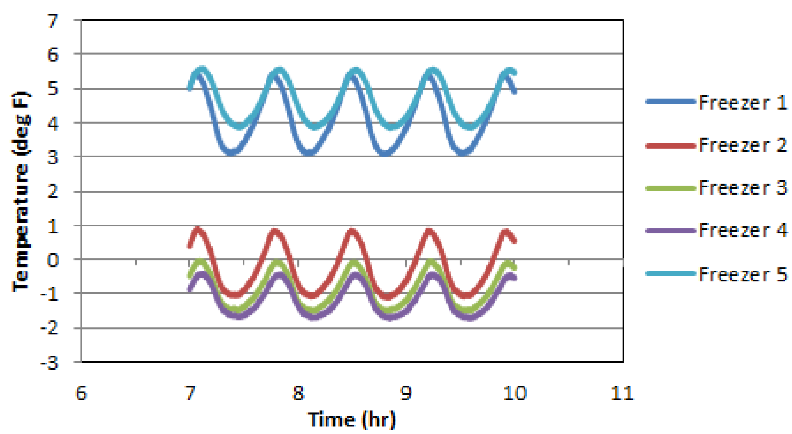


*Figure 76. Individual freezer temperatures versus time during the test period at 90°F and median thermostat setting for chest freezer Unit B*

The differences in internal temperature between Unit A and Unit B were even small than the differences seen in the dorm-size and standard-size units. While part of the reason could be slight differences in thermostat setting or physical system differences, it could partly be due to the varying external temperature from Unit A to

Unit B. Figure 77 and Figure 78 depict the unconditioned space temperatures for these units for the entire test time.

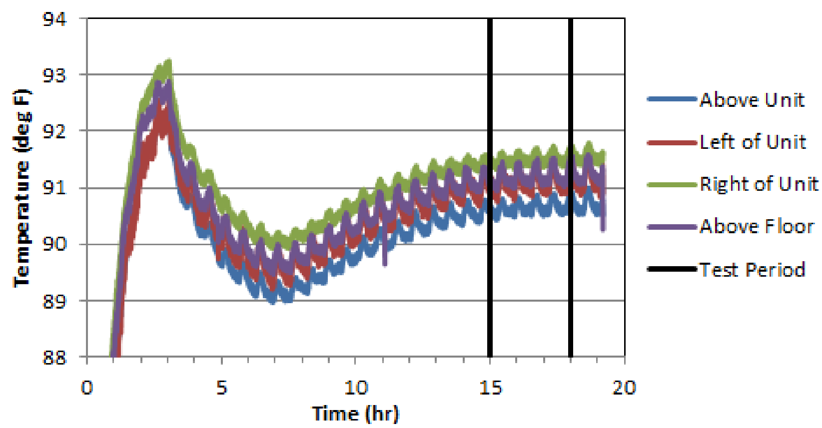


***Figure 77. Unconditioned space temperatures versus time during the total test at 90°F and median thermostat setting for chest freezer Unit A***

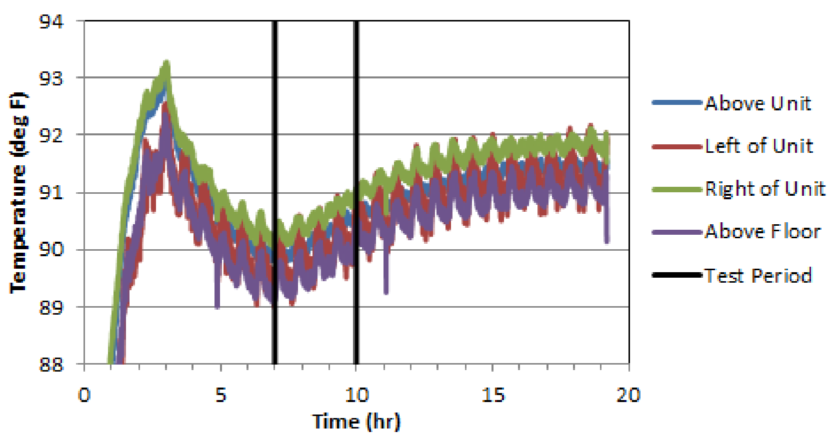


***Figure 78. Unconditioned space temperatures versus time during the total test at 90°F and median thermostat setting for chest freezer Unit A***

Similar to the dorm-size units, temperature data was collected on an internal wall and touching the adjacent, external location. These results are given in Figure 79 and

Figure 80. Interestingly, both the internal and external wall temperatures appear to cycle with the compressor.

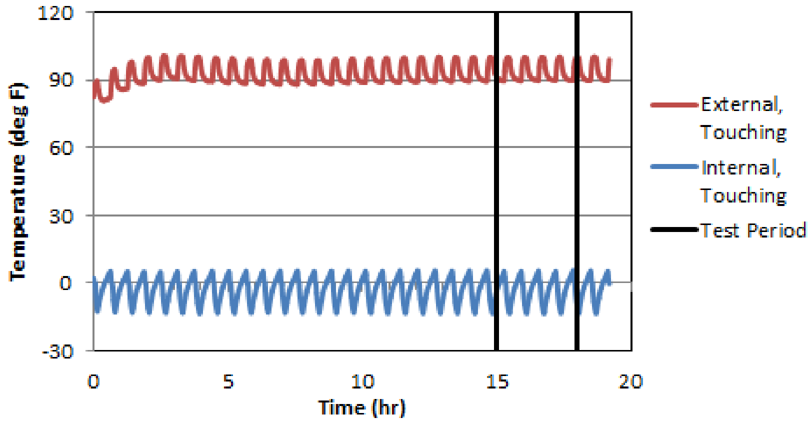


***Figure 79. Wall temperatures versus time during the test period at 90°F and median thermostat setting for chest freezer Unit A***

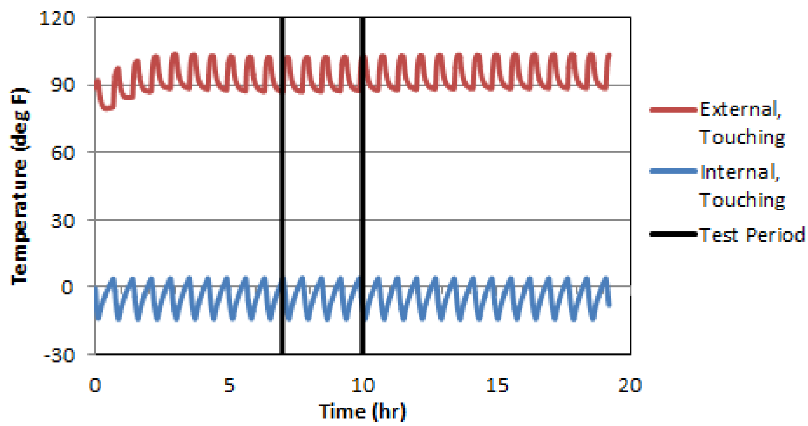


***Figure 80. Wall temperatures versus time during the test period at 90°F and median thermostat setting for chest freezer Unit B***

Finally, the temperatures of the reachable mechanical equipment (only the compressor for these units) are given in Figure 81 and Figure 82.

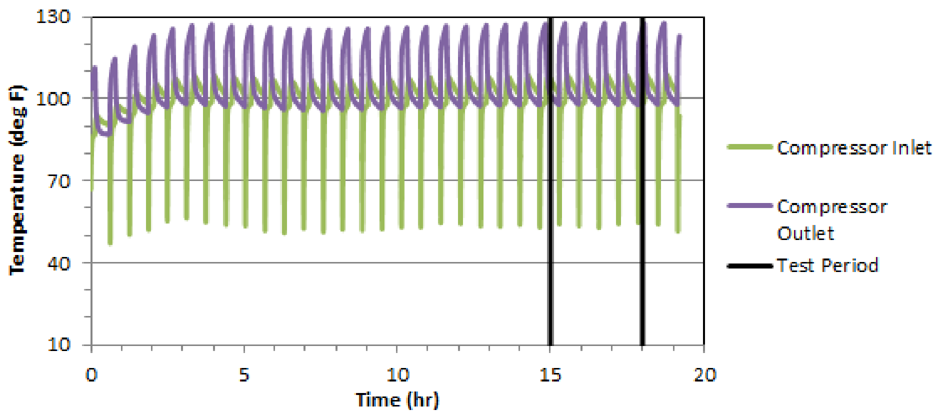


*Figure 81. Compressor temperatures versus time during the test period at 90°F and median thermostat setting for chest freezer Unit A*

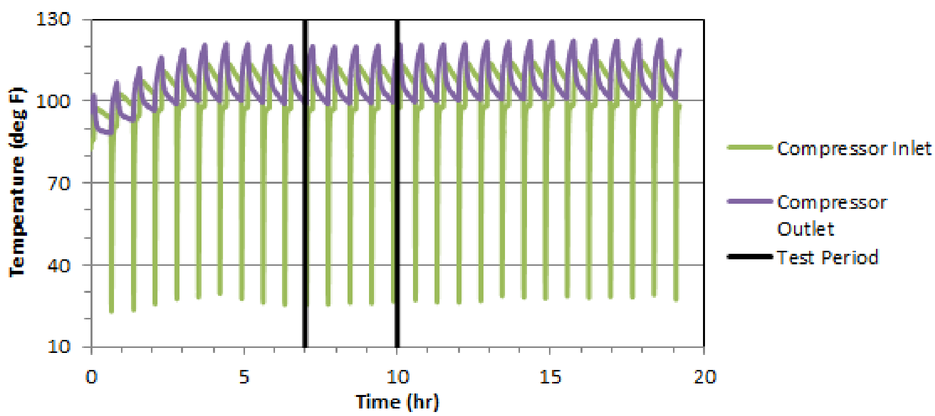


*Figure 82. Compressor temperatures versus time during the test period at 90°F and median thermostat setting for chest freezer Unit B*

## 8.2 Energy Consumption

Graphs of the power use over the total test and test period were generated. These are given in Figure 83 through Figure 86.

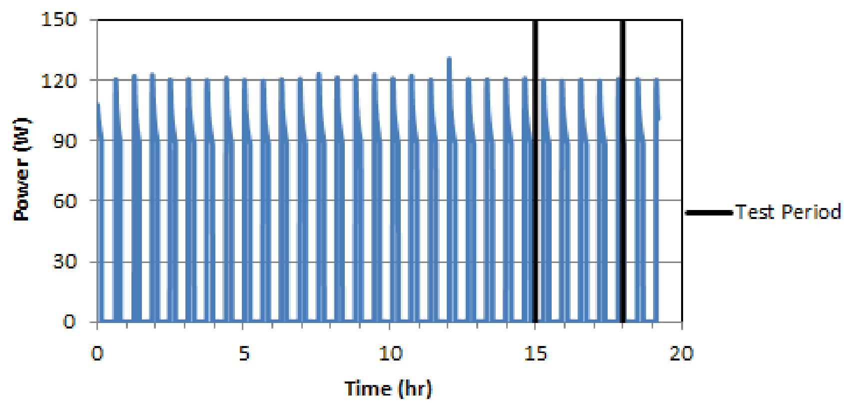


*Figure 83. Power versus time during the total test at 90°F and median thermostat setting for chest freezer Unit A*

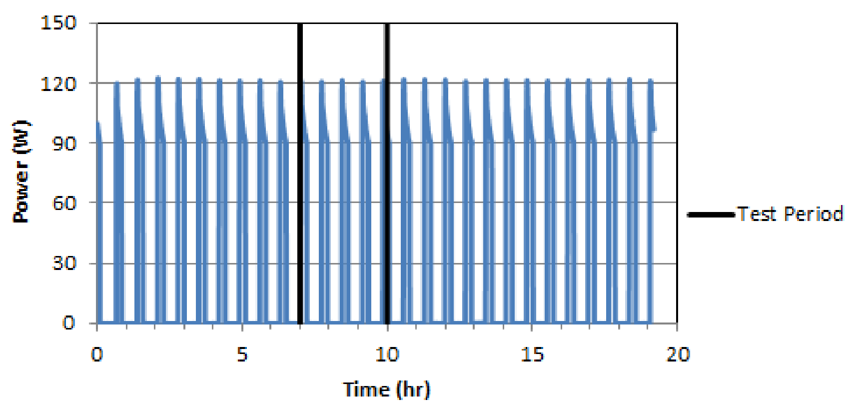


*Figure 84. Power versus time during the total test at 90°F and median thermostat setting for chest freezer Unit B*

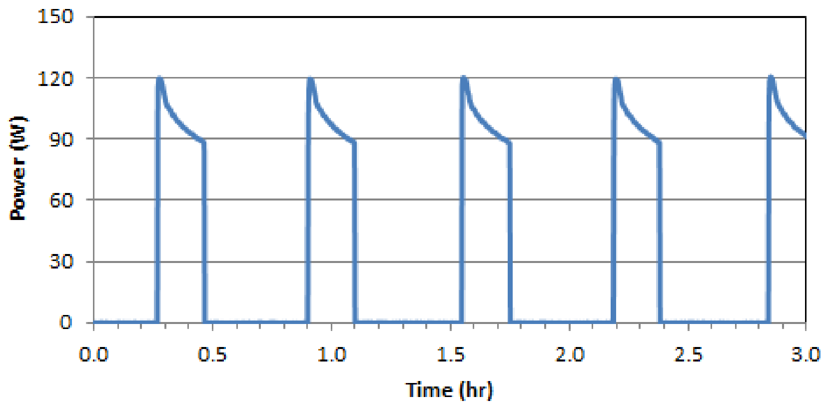


***Figure 85. Power versus time during the test period at 90°F and median thermostat setting for chest freezer Unit A***

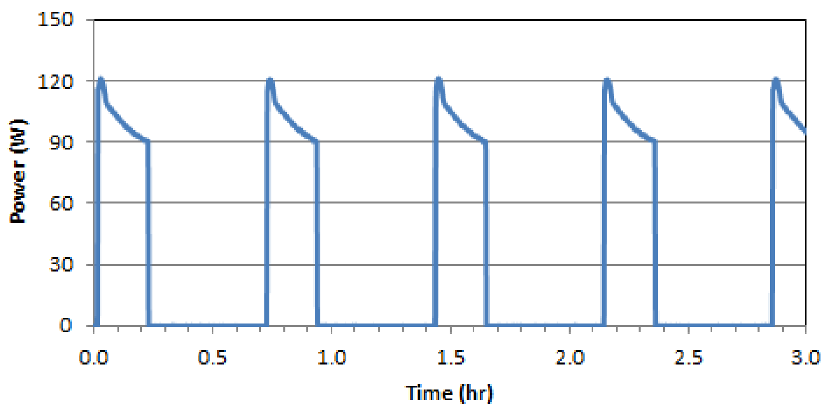


***Figure 86. Power versus time during the test period at 90°F and median thermostat setting for chest freezer Unit B***

The annual energy consumption and associated costs were tabulated and given in Table 8. Again, it should be mentioned that the cost was determined by assuming an electricity rate of \$0.12/kWh, instead of \$0.1065/kWh as with the other units. This electricity cost was used since it is what the published annual cost was based upon.

***Table 8. Energy consumption and annual cost at 90°F and median thermostat setting for dorm-size units***

Unit A

| | | |
|---|---|---|
| EP | 0.095 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.533 | kWh/day |
| EY | 194.46 | kWh/yr |
| Cost | $ 23.34 | |

Unit B

| | | |
|---|---|---|
| EP | 0.101 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.568 | kWh/day |
| EY | 207.44 | kWh/yr |
| Cost | $ 24.89 | |

Comparing Unit A to Unit B, the results were within 6.6% of each other. This percentage is higher than the dorm-size units, but the monetary difference is only $1.55. For comparing the experimental energy consumption and annual cost to the published values, a test was performed at the *coldest* thermostat setting (still at 90°F externally). The results of that test are in Table 9.

***Table 9. Energy consumption and annual cost at 90°F and coldest thermostat setting for dorm-size units***

Unit A

| | | |
|---|---|---|
| EP | 0.109 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.612 | kWh/day |
| EY | 223.31 | kWh/yr |
| Cost | $ 26.80 | |

Unit B

| | | |
|---|---|---|
| EP | 0.106 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.593 | kWh/day |
| EY | 216.59 | kWh/yr |
| Cost | $ 25.99 | |

After linear interpolation (or averaging) between the median and coldest settings, the experimental costs for Unit A and B came out to $25.07 and $25.44, respectively.

The annual kWh/yr were 209 and 212. The manufacturer publishes values of $27 and 222 kWh/yr, so the experimental data was within a reasonable margin for comparison.

### 8.3 Comparisons

The previous plots and values were specifically for the chest freezer units at 90°F. The following plots (Figure 87 and Figure 88) show the energy and cost values at the other experimental temperatures for easy comparison and to determine the trend.

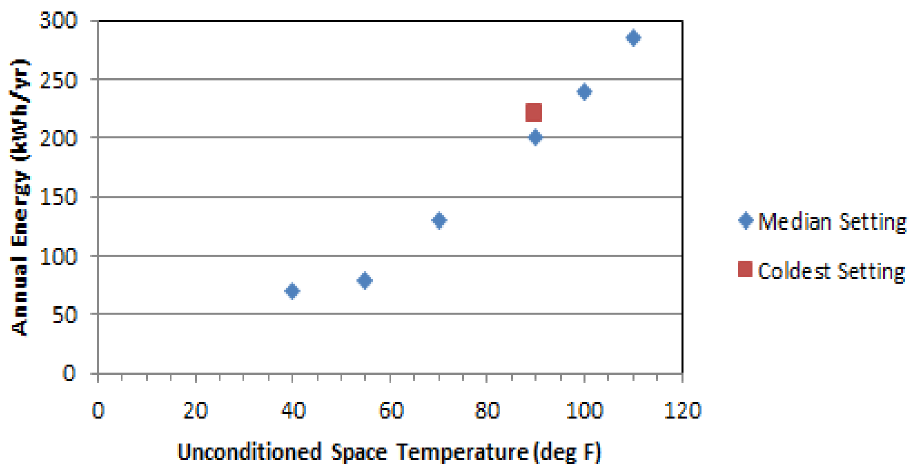


*Figure 87. Average annual energy use versus unconditioned space temperature for chest freezer units*

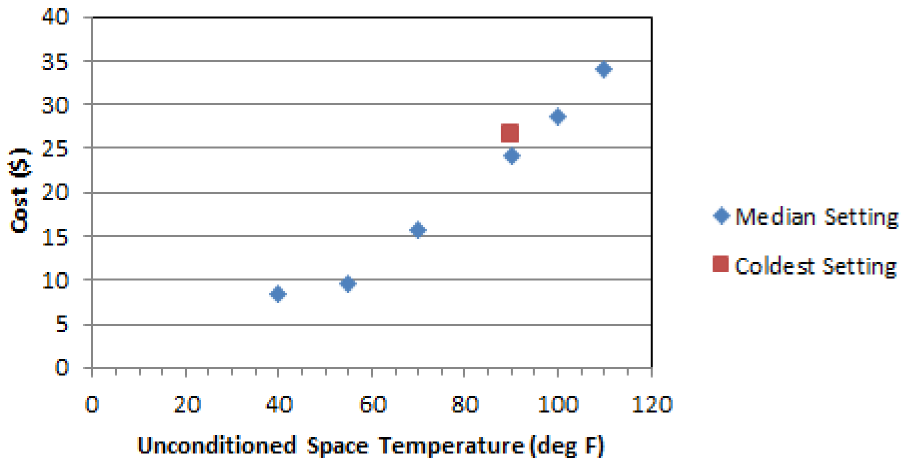


***Figure 88. Average annual cost versus unconditioned space temperature for chest freezer units***

The difference in energy consumption and cost from the median thermostat setting to the coldest is small, only about a $2.50 difference. If it is assumed that the difference in cost from the median to coldest setting at 90°F is the same for all unconditioned space temperatures, the following plot (Figure 89) can be used to predict costs at the coldest setting.

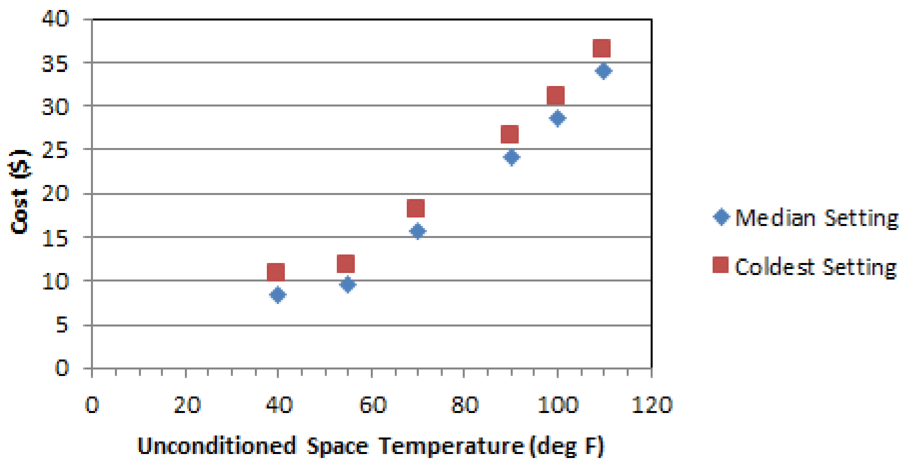


*Figure 89. Average annual cost at median setting and predicted annual cost at coldest thermostat setting versus unconditioned space temperature for chest freezer units*

To predict the behavior outside the tested range, a regression analysis was performed on the data taken at the median thermostat setting. Three regressions were generated in Microsoft Excel: linear, quadratic, and cubic. The following three plots (Figure 90-Figure 92) show the trend lines and equations.

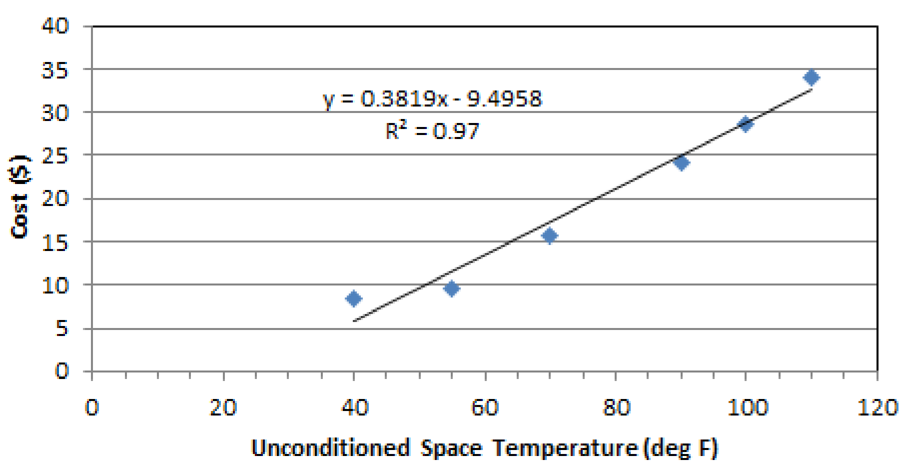


*Figure 90. Linear regression for average annual cost versus unconditioned space temperature at median thermostat setting for chest freezer units*

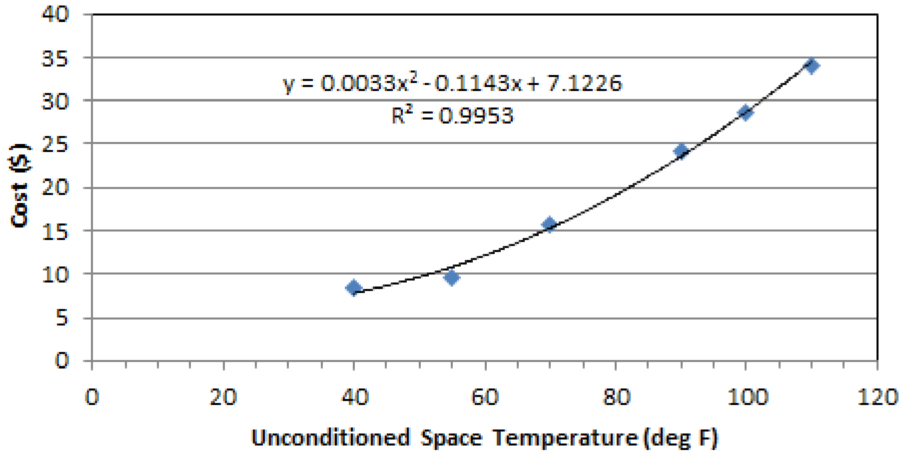


*Figure 91. Quadratic regression for average annual cost versus unconditioned space temperature at median thermostat setting for chest freezer units*

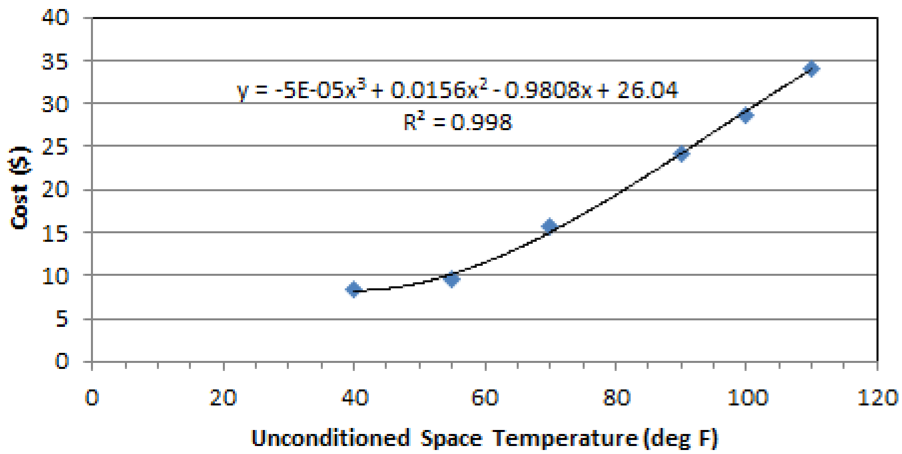


*Figure 92. Cubic regression for average annual cost versus unconditioned space temperature at median thermostat setting for chest freezer units*

The quadratic and cubic regressions are very close in goodness of fit measures. Even so, it does appear that the cubic regression is superior for predicting costs at both unconditioned space temperature extremes.

The effect of the unconditioned space temperature on the internal temperature was of interest. These units followed the most expected trend of the colder the external temperature was, the colder the internal temperature was, but this was only the case at and below 70ºF. Above the 70ºF threshold, the internal temperature actually decreased as the external temperature increased (see Figure 93).

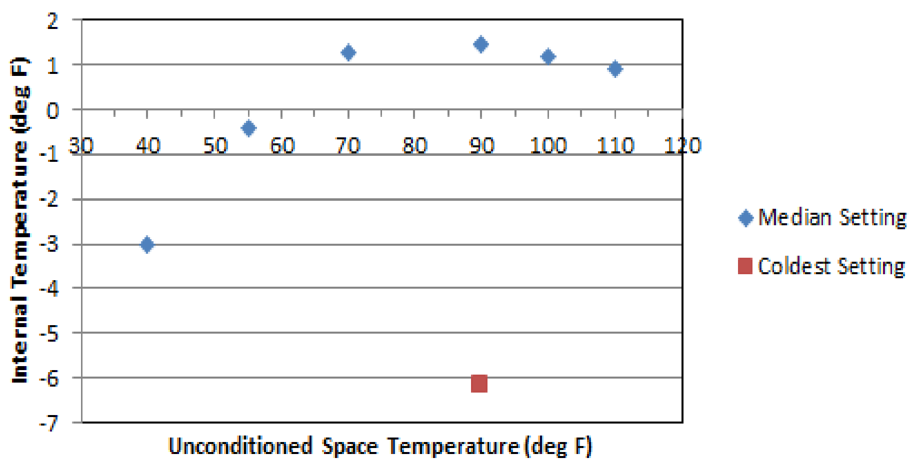


***Figure 93. Internal temperature versus unconditioned space temperature at the median and coldest thermostat settings for chest freezer units***

# 9. CONCLUSIONS

From the plots presented in the Results sections and given in the appendices, it is clear that the energy consumption of the test refrigerators and freezers generally increases with the external temperature. Particularly with units located in garages in warm or hot climates, this can lead to significantly higher electric bills with nearly a doubled energy use by the refrigerator or freezer. Additionally, since the compressor is running more frequently due to the elevated external temperatures, the lifecycle of the unit will likely be reduced compared to a unit kept in a conditioned space.

For units kept in unconditioned spaces colder than a standard kitchen, the energy use appears to be lower until the threshold of the design internal temperature is met in which case there are some unsteady fluctuations likely due to confusion experienced by the controller system. There is possibly an optimal external temperature that reduces the energy consumption without adverse effects on the compressor.

It is recommended that units are not kept in areas that will see temperatures greater than 90ºF as this was the design temperature and basis for the annual energy use. It would also be wise to not store units in areas that will experienced external temperatures lower than 55ºF since that is the temperature that the standard-size units started to see lapses in the control system and where the chest freezers appear to plateau or level off.

# 10. FUTURE WORK

The scope of this project was not all-inclusive of the needed research in the area of refrigerator and freezer energy consumption, and there is still more work to be done. In particular, more tests at the lower temperatures are needed to verify the behavior, specifically with the standard-size units. Tests should be performed at smaller temperature increments, such as 5º increments. Communication with the manufacturer should be established to determine what the design conditions are for the compressor to determine if storing units in colder environments will have a negative impact on the mechanical components.

In addition, tests should be performed on a larger variety of units. Since standard-size units are the most commonly used in residential homes, tests should be done on side-by-side, French door, and bottom-mounted freezer units.

Finally, it would be interesting to see how the newest refrigerant (HFO-1234ze) compares to R-134a in the same units at the same conditions. Perhaps this refrigerant would perform better at the higher external temperatures, but additional research is necessary to establish such claims.

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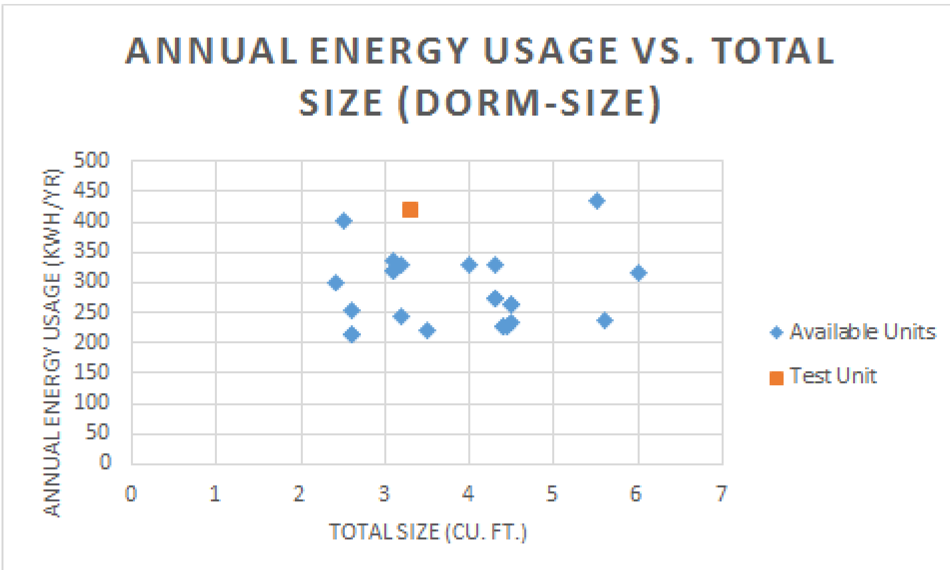
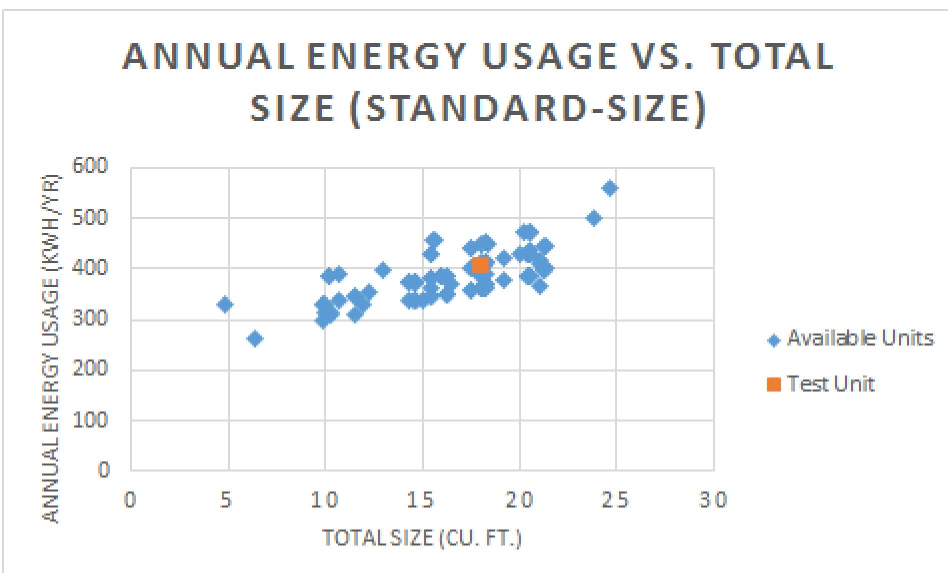
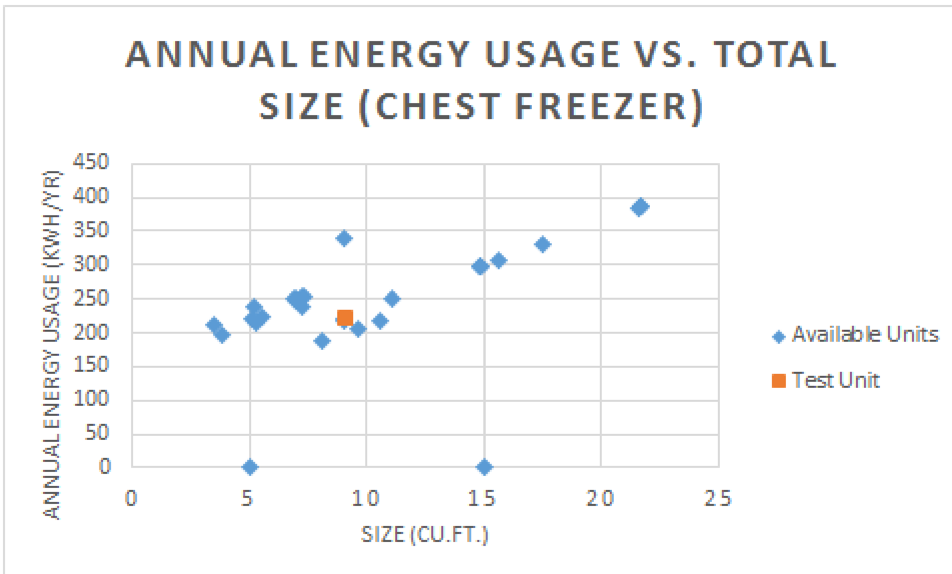
# APPENDIX A: COMPARISON WITH COMMERCIALLY AVAILABLE UNITS



## APPENDIX A: CONTINUED



# APPENDIX B: THERMOCOUPLE CALIBRATION COEFFICIENTS

| Label | Measured Value | Actual Value | | | |
|---|---|---|---|---|---|
| | 32.2971 | 32.3 | | M | 1.0051 |
| A-1 | 77.3164 | 77.6 | | b | -0.1437 |
| | 119.357 | 119.8 | | U | 1.81 |
| | 32.6143 | 32.3 | | M | 1.0098 |
| A-2 | 77.2517 | 77.6 | | b | -0.5617 |
| | 119.2673 | 119.8 | | U | 1.82 |
| | 31.5806 | 32.3 | | M | 1.0052 |
| A-3 | 77.1343 | 77.6 | | b | 0.399 |
| | 118.6166 | 119.8 | | U | 1.81 |
| | 32.0425 | 32.3 | | M | 1.0047 |
| A-4 | 77.0555 | 77.6 | | b | 0.13 |
| | 119.1321 | 119.8 | | U | 1.81 |
| | 31.4483 | 32.3 | | M | 0.999 |
| A-5 | 76.9882 | 77.6 | | b | 0.8211 |
| | 119.0325 | 119.8 | | U | 1.80 |
| | 32.2247 | 32.3 | | M | 1.0082 |
| A-6 | 76.8359 | 77.6 | | b | -0.0839 |
| | 119.018 | 119.8 | | U | 1.81 |
| | 33.9938 | 32.3 | | M | 1.0287 |
| A-7 | 76.863 | 77.6 | | b | -2.2701 |
| | 119.0609 | 119.8 | | U | 1.85 |
| | 31.4941 | 32.3 | | M | 1.0008 |
| A-8 | 76.7958 | 77.6 | | b | 0.7685 |
| | 118.9234 | 119.8 | | U | 1.80 |
| | 31.2773 | 32.3 | | M | 1.0001 |
| A-9 | 76.8442 | 77.6 | | b | 0.9329 |
| | 118.7633 | 119.8 | | U | 1.80 |
| | 32.5378 | 32.3 | | M | 1.0147 |
| A-10 | 76.6032 | 77.6 | | b | -0.5229 |
| | 118.7796 | 119.8 | | U | 1.83 |
| | 31.0091 | 32.3 | | M | 0.9973 |
| A-11 | 76.7566 | 77.6 | | b | 1.2707 |
| | 118.7384 | 119.8 | | U | 1.80 |
| | 31.7588 | 32.3 | | M | 1.0054 |
| A-12 | 76.6777 | 77.6 | | b | 0.415 |
| | 118.7921 | 119.8 | | U | 1.81 |
| | 31.3188 | 32.3 | | M | 1.0018 |
| A-13 | 76.6597 | 77.6 | | b | 0.885 |
| | 118.6584 | 119.8 | | U | 1.80 |
| | 31.2689 | 32.3 | | M | 1.0034 |
| A-14 | 76.6054 | 77.6 | | b | 0.8607 |
| | 118.4629 | 119.8 | | U | 1.81 |
| | 32.6528 | 32.3 | | M | 1.0136 |
| A-15 | 76.7028 | 77.6 | | b | -0.5816 |
| | 118.9899 | 119.8 | | U | 1.82 |
| | 31.4757 | 32.3 | | M | 1.0049 |
| A-16 | 76.6976 | 77.6 | | b | 0.6219 |
| | 118.5422 | 119.8 | | U | 1.81 |

| | | | | | |
|---|---|---|---|---|---|
| | 31.2234 | 32.3 | | M | 0.9646 |
| A-1* | 72.3599 | 72.3 | | b | 2.2855 |
| | 111.9318 | 110.15 | | U | 1.74 |
| | 31.1644 | 32.3 | | M | 0.9688 |
| A-2* | 72.2832 | 72.3 | | b | 2.1629 |
| | 111.5263 | 110.15 | | U | 1.74 |
| | 31.0928 | 32.3 | | M | 0.965 |
| A-3* | 72.2557 | 72.3 | | b | 2.3856 |
| | 111.7681 | 110.15 | | U | 1.74 |

# APPENDIX B: CONTINUED

| Label | Measured Value | Actual Value | | | |
|---|---|---|---|---|---|
| B-1 | 31.8484 | 32.4 | | M | 1.001 |
| | 76.7025 | 77.2 | | b | 0.4879 |
| | 120.1605 | 120.8 | | U | 1.80 |
| B-2 | 31.2486 | 32.4 | | M | 0.9959 |
| | 76.5987 | 77.2 | | b | 1.1593 |
| | 120.0059 | 120.8 | | U | 1.79 |
| B-3 | 31.225 | 32.4 | | M | 0.9953 |
| | 76.5194 | 77.2 | | b | 1.2313 |
| | 120.0427 | 120.8 | | U | 1.79 |
| B-4 | 31.3312 | 32.4 | | M | 0.9993 |
| | 76.4556 | 77.2 | | b | 0.9922 |
| | 119.7848 | 120.8 | | U | 1.80 |
| B-5 | 31.485 | 32.4 | | M | 0.9988 |
| | 76.4772 | 77.2 | | b | 0.9068 |
| | 119.9888 | 120.8 | | U | 1.80 |
| B-6 | 31.7175 | 32.4 | | M | 1.0067 |
| | 76.3636 | 77.2 | | b | 0.4241 |
| | 119.5313 | 120.8 | | U | 1.81 |
| B-7 | 31.816 | 32.4 | | M | 1.0055 |
| | 76.298 | 77.2 | | b | 0.4315 |
| | 119.7297 | 120.8 | | U | 1.81 |
| B-8 | 31.648 | 32.4 | | M | 1.0152 |
| | 76.3038 | 77.2 | | b | 0.0972 |
| | 118.7179 | 120.8 | | U | 1.83 |
| B-9 | 31.7518 | 32.4 | | M | 1.0161 |
| | 76.2056 | 77.2 | | b | 0.0141 |
| | 118.7429 | 120.8 | | U | 1.83 |
| B-10 | 31.2021 | 32.4 | | M | 1.0036 |
| | 76.2047 | 77.2 | | b | 0.9644 |
| | 119.277 | 120.8 | | U | 1.81 |
| B-11 | 32.0142 | 32.4 | | M | 1.0091 |
| | 76.0969 | 77.2 | | b | 0.1975 |
| | 119.6149 | 120.8 | | U | 1.82 |
| B-12 | 32.1843 | 32.4 | | M | 1.0082 |
| | 76.1094 | 77.2 | | b | 0.1221 |
| | 119.8641 | 120.8 | | U | 1.81 |
| B-13 | 33.2795 | 32.4 | | M | 1.0228 |
| | 76.0787 | 77.2 | | b | -1.2964 |
| | 119.6991 | 120.8 | | U | 1.84 |
| B-14 | 34.1875 | 32.4 | | M | 1.0329 |
| | 76.0676 | 77.2 | | b | -2.3905 |
| | 119.7519 | 120.8 | | U | 1.86 |
| B-15 | 33.6868 | 32.4 | | M | 1.0373 |
| | 76.074 | 77.2 | | b | -2.2643 |
| | 118.9066 | 120.8 | | U | 1.87 |
| B-16 | 36.0575 | 32.4 | | M | 1.053 |
| | 76.1459 | 77.2 | | b | -4.6792 |
| | 119.94 | 120.8 | | U | 1.90 |

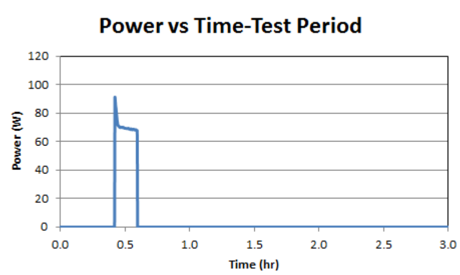
| | | | | | |
|---|---|---|---|---|---|
| B-1* | 31.7222 | 32.3 | | M | 0.9698 |
| | 72.5259 | 72.3 | | b | 1.677 |
| | 112.0013 | 110.15 | | U | 1.75 |
| B-2* | 31.3421 | 32.3 | | M | 0.9657 |
| | 72.4535 | 72.3 | | b | 2.133 |
| | 111.9647 | 110.15 | | U | 1.74 |
| B-3* | 31.6729 | 32.3 | | M | 0.9706 |
| | 72.5254 | 72.3 | | b | 1.6711 |
| | 111.8819 | 110.15 | | U | 1.75 |

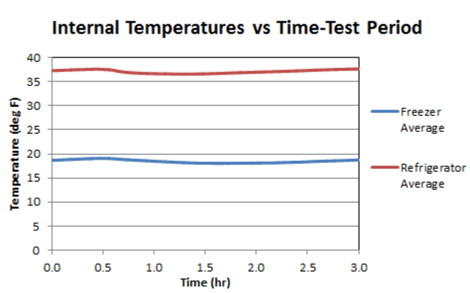
# APPENDIX C: TEMPERATURE AND POWER PLOTS FOR DORM-SIZE UNITS

**Unconditioned Space Temperature: 40°F (median thermostat)**

*Unit A*

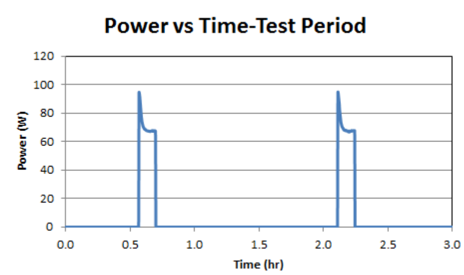
| | | |
|---|---|---|
| EP | 0.017 | kwh |
| T | 188 | min |
| K | 1 | |
| ET | 0.133 | kWh/day |
| EY | 48.4 | kWh/yr |
| Cost | $ 5.15 | |

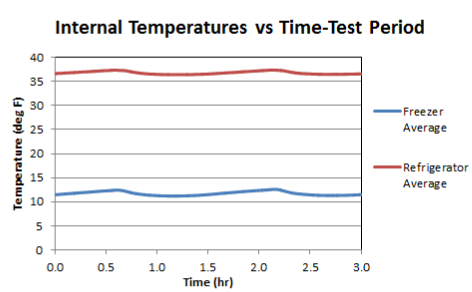



*Unit B*

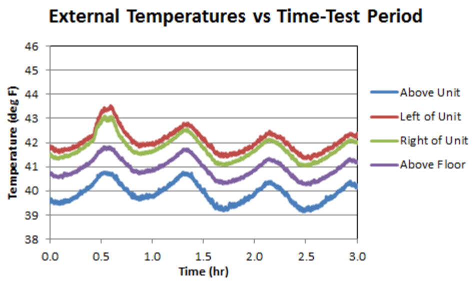
| | | |
|---|---|---|
| EP | 0.019 | kwh |
| T | 188 | min |
| K | 1 | |
| ET | 0.144 | kWh/day |
| EY | 52.7 | kWh/yr |
| Cost | $ 5.61 | |

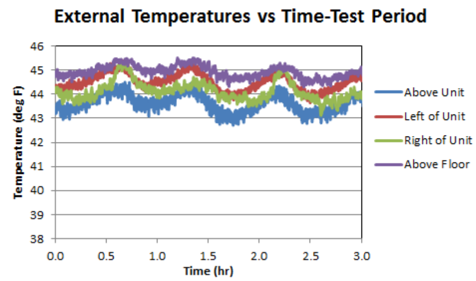


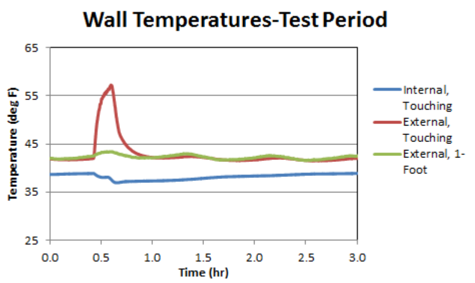



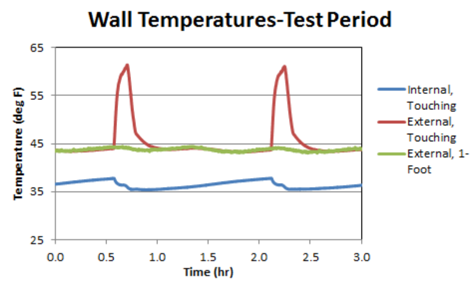
# APPENDIX C: CONTINUED

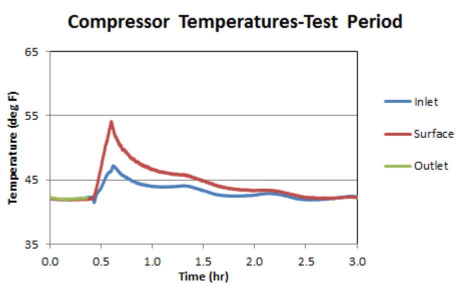
**(40ºF median)**

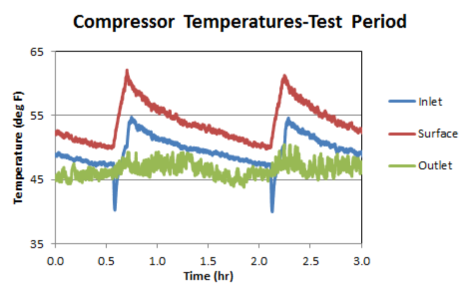


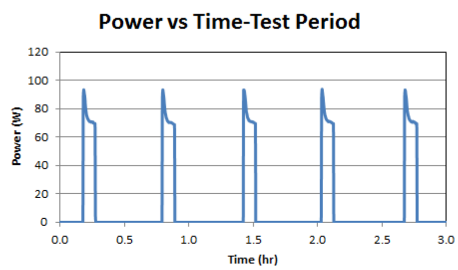



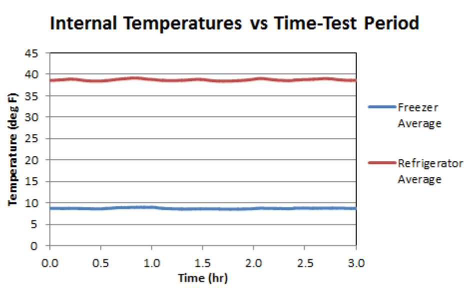
# APPENDIX C: CONTINUED

## Unconditioned Space Temperature: 55°F (median thermostat)

*Unit A*

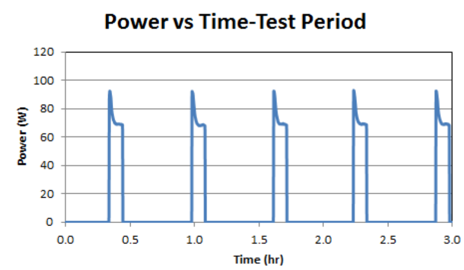
| | | |
|---|---|---|
| EP | 0.036 | kwh |
| T | 192 | min |
| K | 1 | |
| ET | 0.269 | kWh/day |
| EY | 98.3 | kWh/yr |
| Cost | $ 10.47 | |

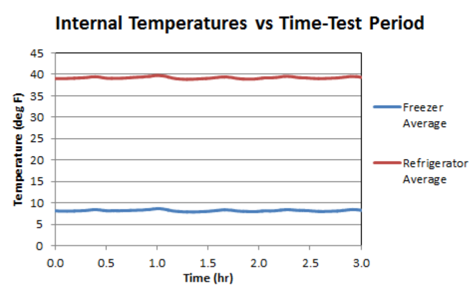



*Unit B*

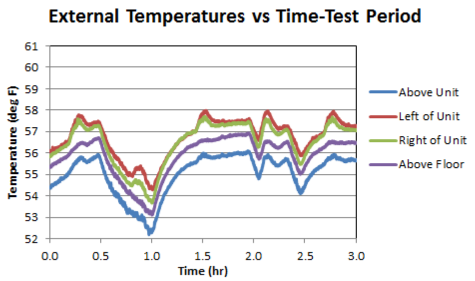
| | | |
|---|---|---|
| EP | 0.038 | kwh |
| T | 192 | min |
| K | 1 | |
| ET | 0.285 | kWh/day |
| EY | 104.1 | kWh/yr |
| Cost | $ 11.09 | |

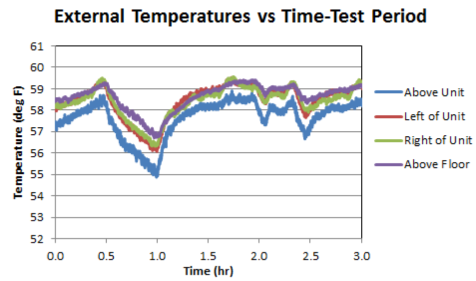


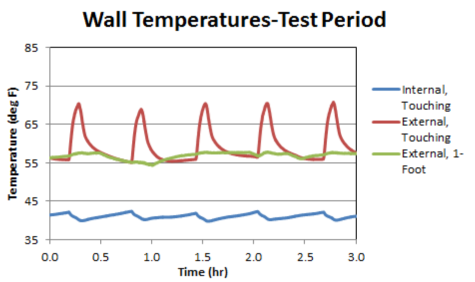



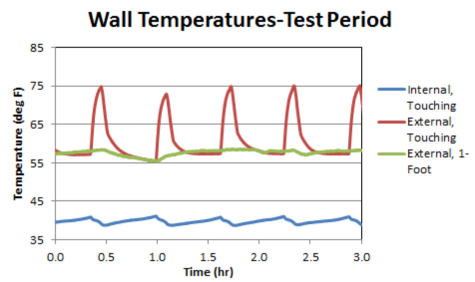
# APPENDIX C: CONTINUED

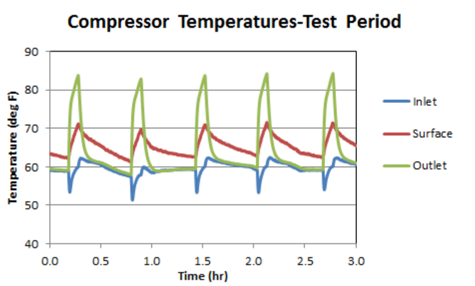
**(55ºF median)**

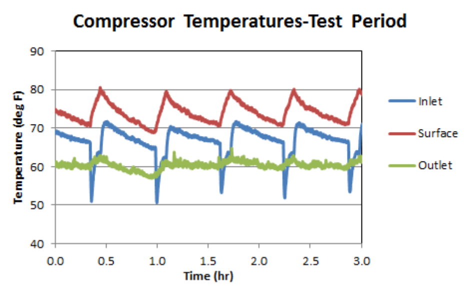


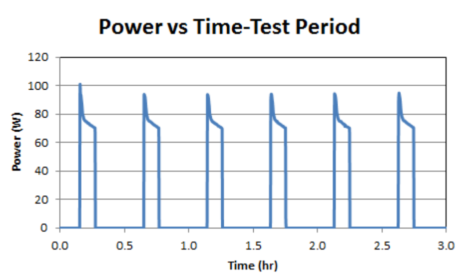



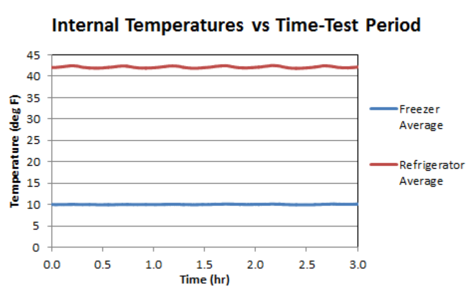
# APPENDIX C: CONTINUED

## Unconditioned Space Temperature: 70°F (median thermostat)

*Unit A*

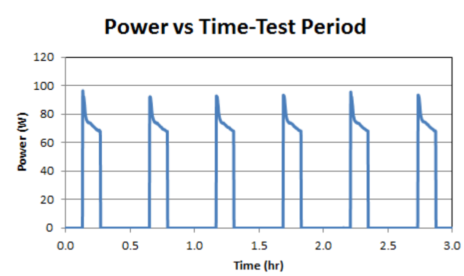
| | | |
|---|---|---|
| EP | 0.063 | kwh |
| T | 199 | min |
| K | 1 | |
| ET | 0.458 | kWh/day |
| EY | 167.2 | kWh/yr |
| Cost | $ 17.81 | |

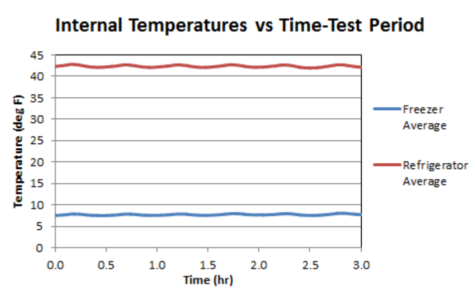


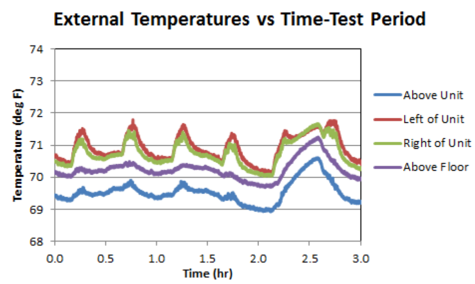

*Unit B*

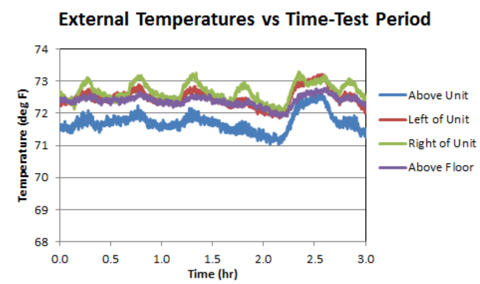
| | | |
|---|---|---|
| EP | 0.066 | kwh |
| T | 199 | min |
| K | 1 | |
| ET | 0.476 | kWh/day |
| EY | 173.9 | kWh/yr |
| Cost | $ 18.52 | |

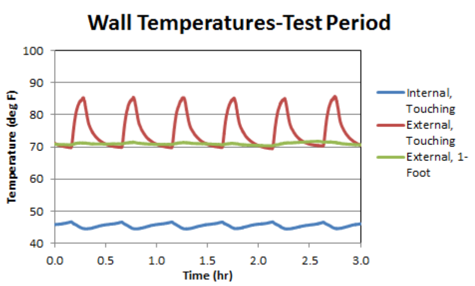


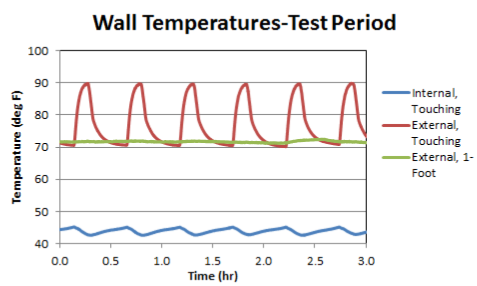



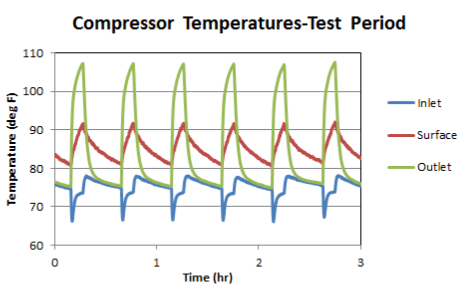
**(70ºF median)**

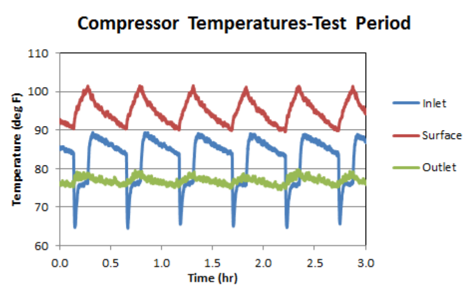

External Temperatures vs Time-Test Period
Temperature (deg F)
Time (hr)
Above Unit
Left of Unit
Right of Unit
Above Floor


External Temperatures vs Time-Test Period
Temperature (deg F)
Time (hr)
Above Unit
Left of Unit
Right of Unit
Above Floor


Wall Temperatures-Test Period
Temperature (deg F)
Time (hr)
Internal, Touching
External, Touching
External, 1-Foot


Wall Temperatures-Test Period
Temperature (deg F)
Time (hr)
Internal, Touching
External, Touching
External, 1-Foot


Compressor Temperatures-Test Period
Temperature (deg F)
Time (hr)
Inlet
Surface
Outlet

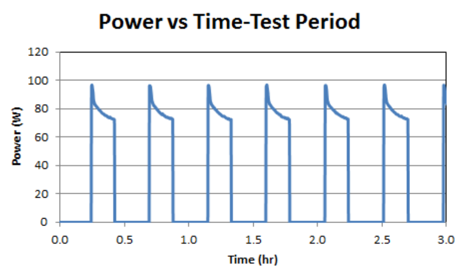

Compressor Temperatures-Test Period
Temperature (deg F)
Time (hr)
Inlet
Surface
Outlet

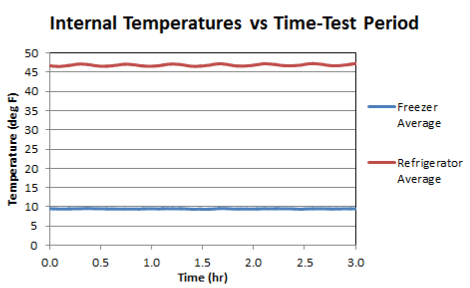
# APPENDIX C: CONTINUED

## Unconditioned Space Temperature: 90°F (median thermostat)

*Unit A*

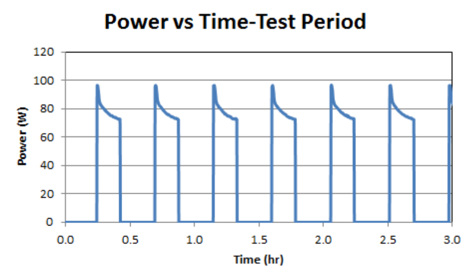
| | | |
|---|---|---|
| EP | 0.093 | kwh |
| T | 184 | min |
| K | 1 | |
| ET | 0.731 | kWh/day |
| EY | 266.8 | kWh/yr |
| Cost | $ 28.41 | |

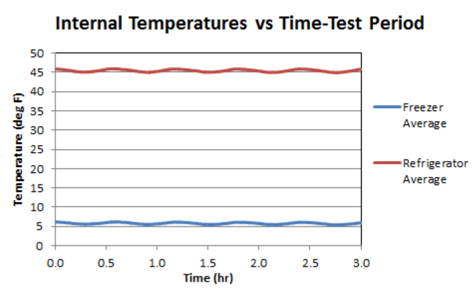



*Unit B*

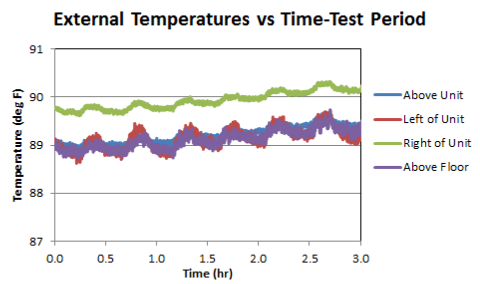
| | | |
|---|---|---|
| EP | 0.094 | kwh |
| T | 184 | min |
| K | 1 | |
| ET | 0.736 | kWh/day |
| EY | 268.5 | kWh/yr |
| Cost | $ 28.59 | |

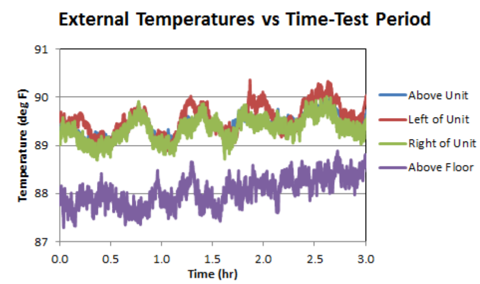


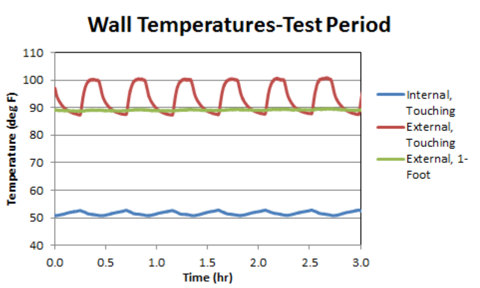



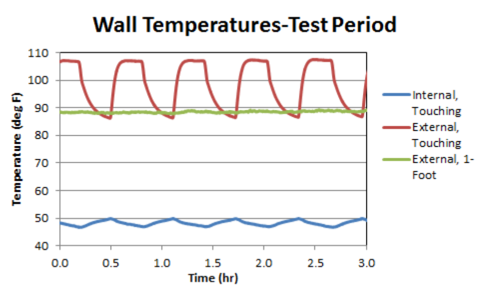
# APPENDIX C: CONTINUED

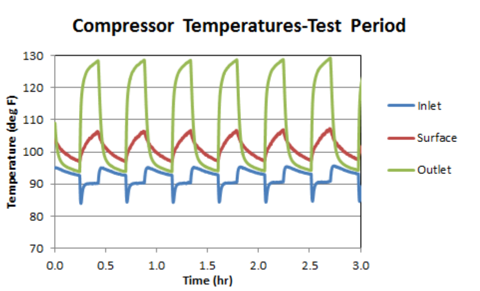
## (90ºF median)

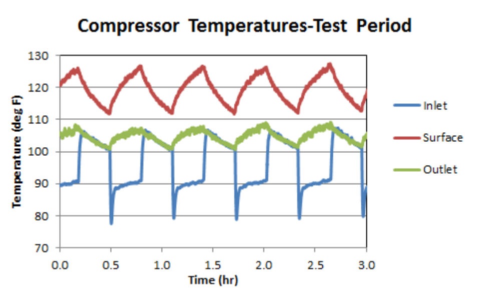


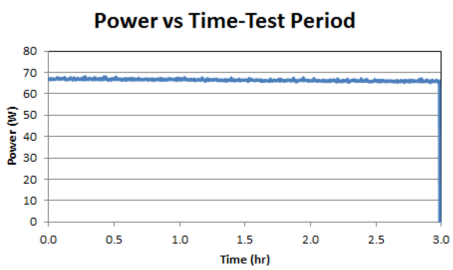



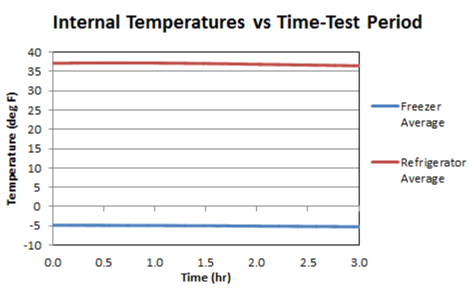
# APPENDIX C: CONTINUED

## Unconditioned Space Temperature: 90ºF (coldest thermostat)

*Unit A*

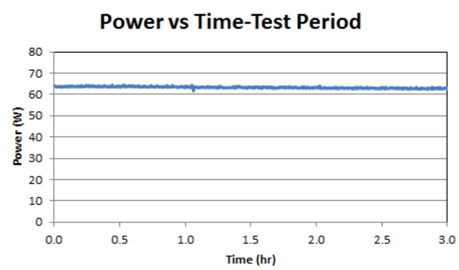
| | | |
|---|---|---|
| EP | 0.198 | kwh |
| T | 185 | min |
| K | 1 | |
| ET | 1.548 | kWh/day |
| EY | 565.2 | kWh/yr |
| Cost | $ 60.19 | |

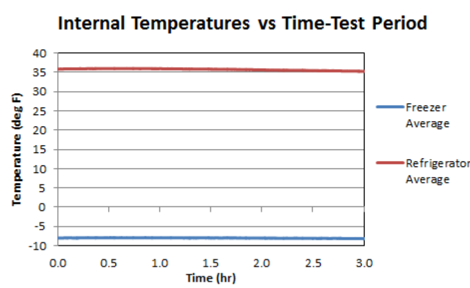



*Unit B*

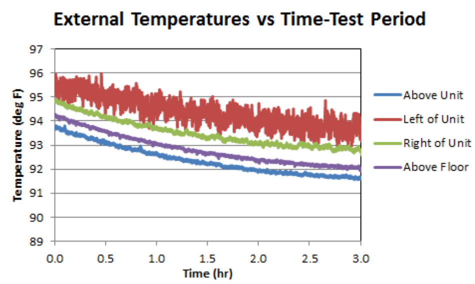
| | | |
|---|---|---|
| EP | 0.195 | kwh |
| T | 185 | min |
| K | 1 | |
| ET | 1.521 | kWh/day |
| EY | 555.2 | kWh/yr |
| Cost | $ 59.13 | |

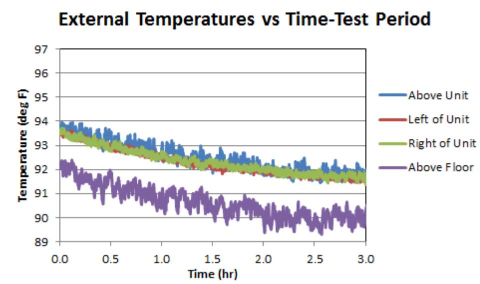


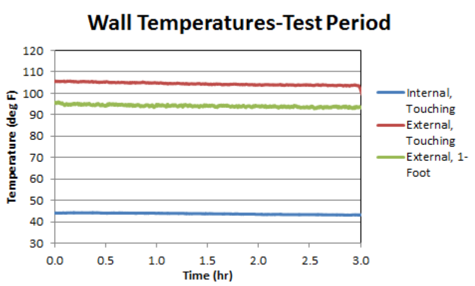



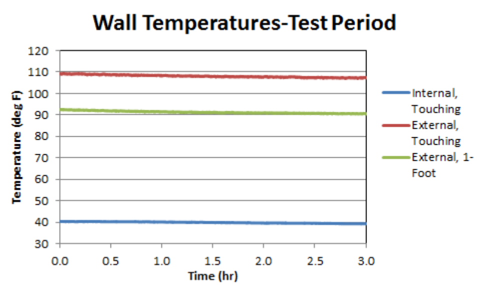
# APPENDIX C: CONTINUED

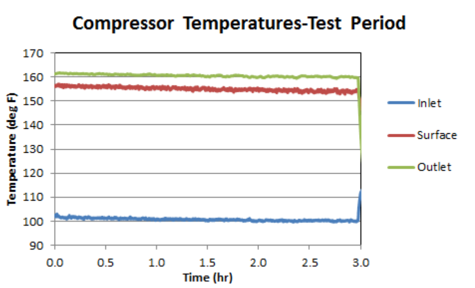
**(90ºF coldest)**

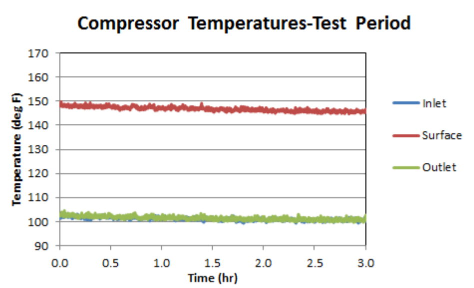


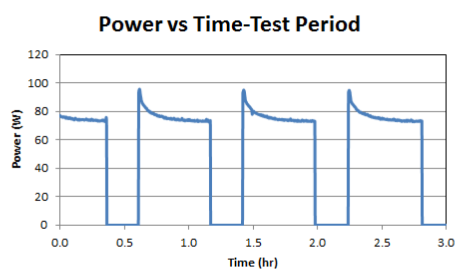



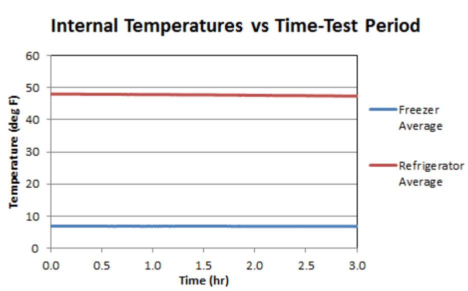
# APPENDIX C: CONTINUED

## Unconditioned Space Temperature: 100°F (median thermostat)

*Unit A*

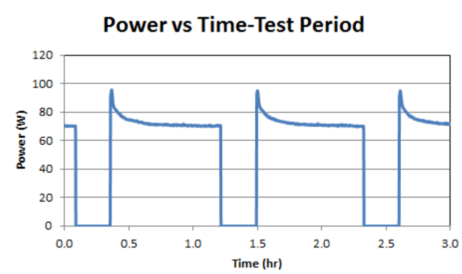
| | | |
|---|---|---|
| EP | 0.161 | kwh |
| T | 188 | min |
| K | 1 | |
| ET | 1.238 | kWh/day |
| EY | 451.8 | kWh/yr |
| Cost | $ 48.12 | |

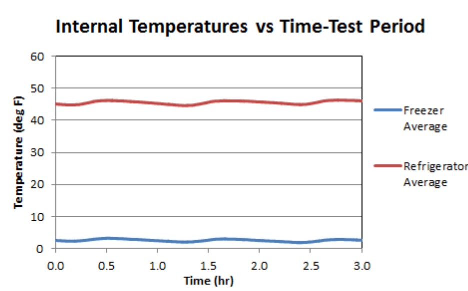



*Unit B*

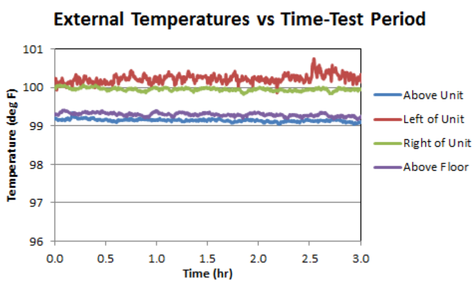
| | | |
|---|---|---|
| EP | 0.168 | kwh |
| T | 188 | min |
| K | 1 | |
| ET | 1.293 | kWh/day |
| EY | 472.0 | kWh/yr |
| Cost | $ 50.27 | |

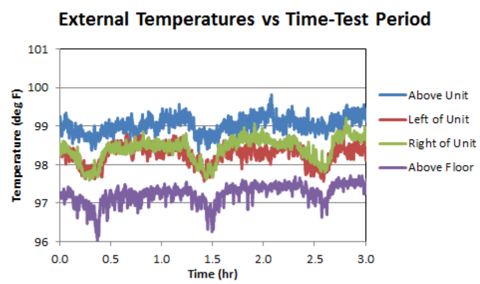


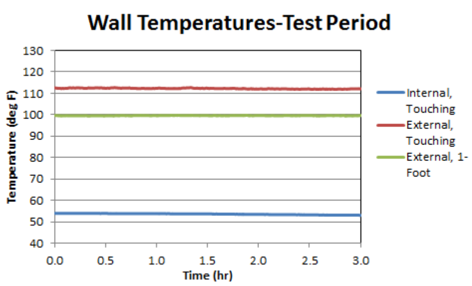



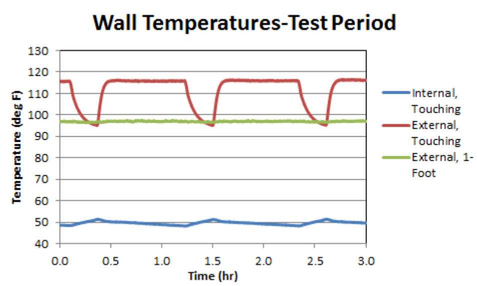
# APPENDIX C: CONTINUED

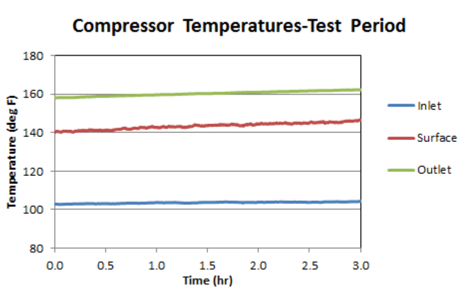
## (100ºF median)

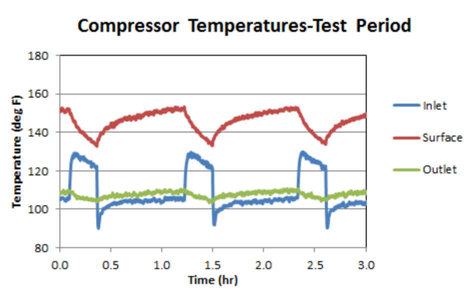


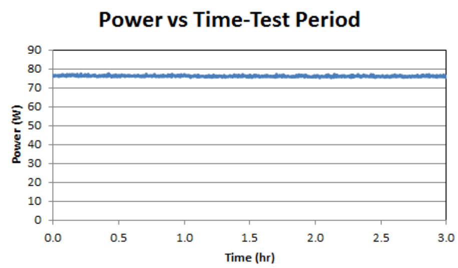



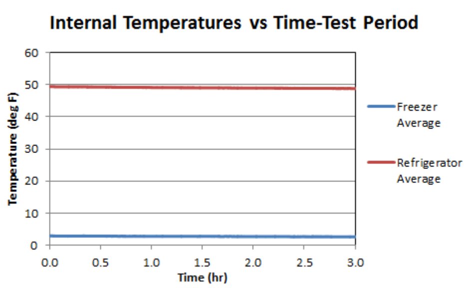
# APPENDIX C: CONTINUED

## Unconditioned Space Temperature: 110ºF (median thermostat)

*Unit A*

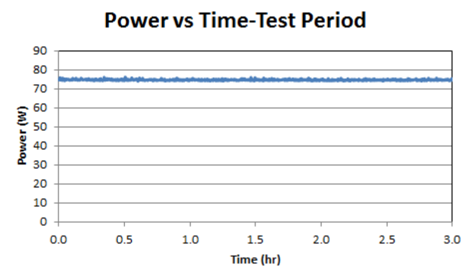
| | | |
|---|---|---|
| EP | 0.237 | kwh |
| T | 187 | min |
| K | 1 | |
| ET | 1.830 | kWh/day |
| EY | 667.8 | kWh/yr |
| Cost | $ 71.12 | |

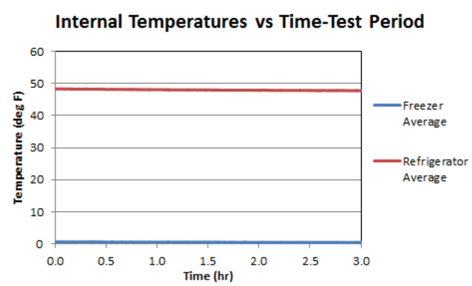


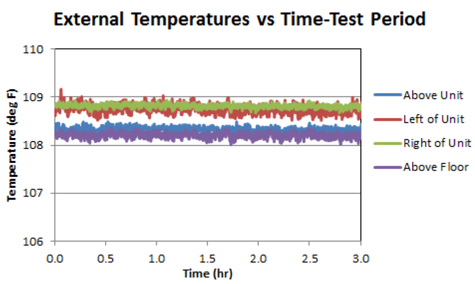

*Unit B*

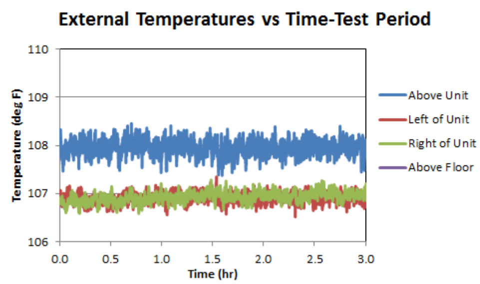
| | | |
|---|---|---|
| EP | 0.233 | kwh |
| T | 187 | min |
| K | 1 | |
| ET | 1.794 | kWh/day |
| EY | 654.8 | kWh/yr |
| Cost | $ 69.73 | |

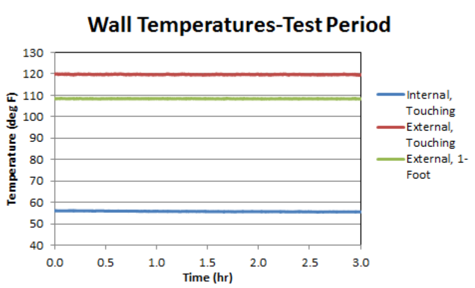


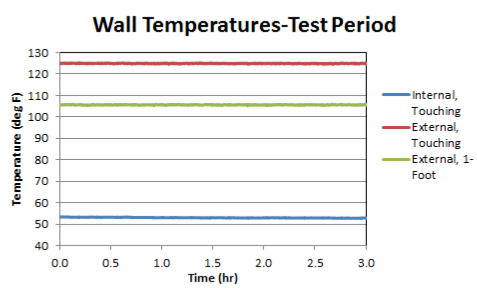



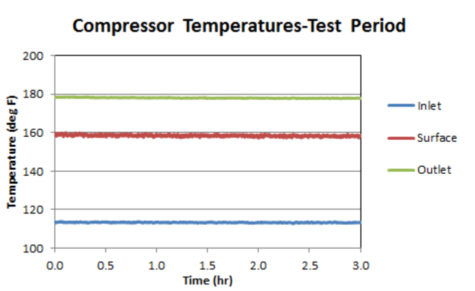
## (110ºF median)

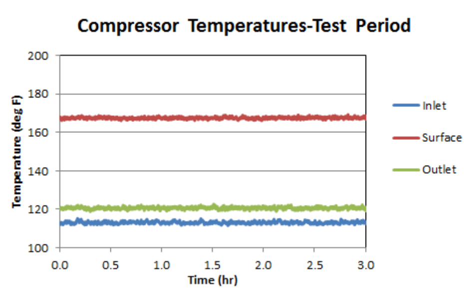


# APPENDIX D: TEMPERATURE AND POWER PLOTS FOR STANDARD-SIZE UNITS

**Unconditioned Space Temperature: 33ºF (median thermostat)**

*Unit A*

| | | |
|---|---|---|
| EP1 | 0.116 | kwh |
| T1 | 557 | min |
| EP2 | 0.131 | kwh |
| T2 | 190 | min |
| K | 1 | |
| CT | 3.17 | hours |
| ET | 0.646 | kWh/day |
| EY | 235.79 | kWh/year |
| Cost | $ 25.11 | |

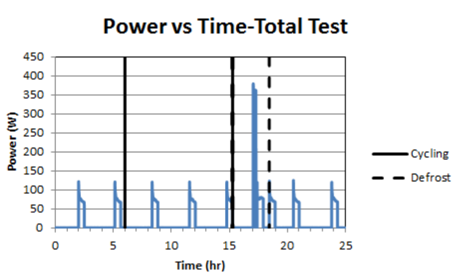
*Unit B*

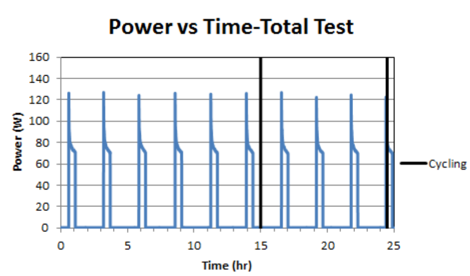
(As Is)

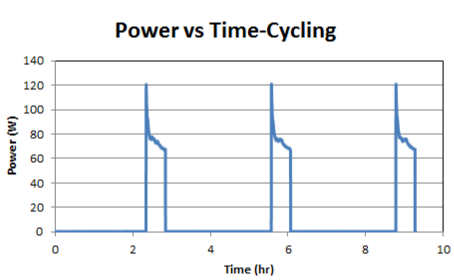
| | | |
|---|---|---|
| EP1 | 0.125 | kwh |
| T1 | 570 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 0.317 | kWh/day |
| EY | 115.65 | kWh/year |
| Cost | $ 12.32 | |

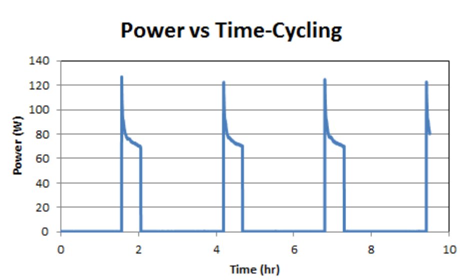
(Borrowed Defrost)

| | | |
|---|---|---|
| EP1 | 0.125 | kwh |
| T1 | 570 | min |
| EP2 | 0.131 | kwh |
| T2 | 190 | min |
| K | 1 | |
| CT | 3.17 | hours |
| ET | 0.655 | kWh/day |
| EY | 238.93 | kWh/year |
| Cost | $ 25.45 | |



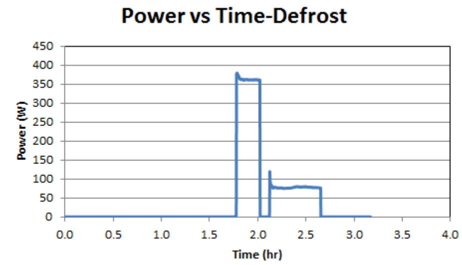



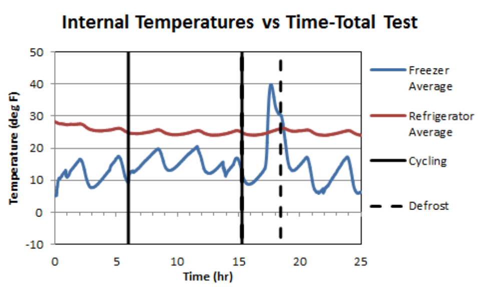



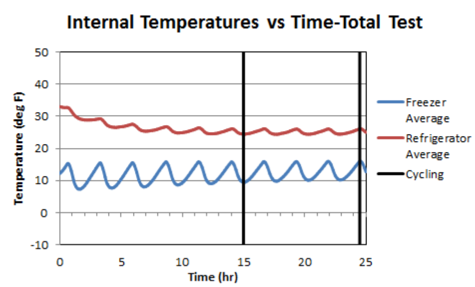



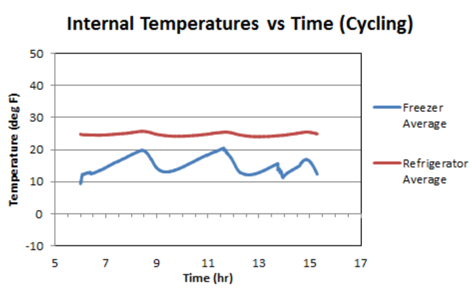
## APPENDIX D: CONTINUED

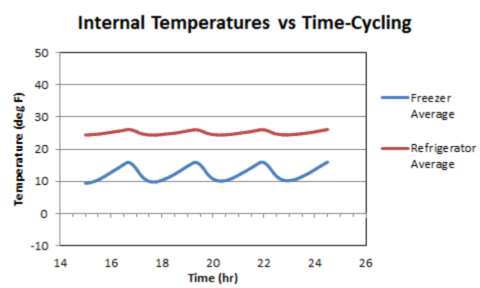
**(33ºF median)**



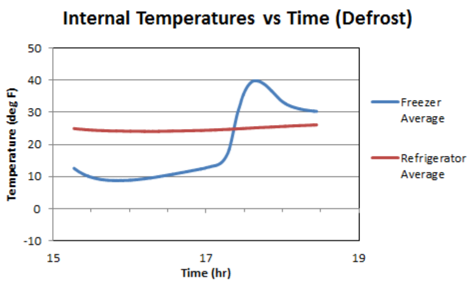



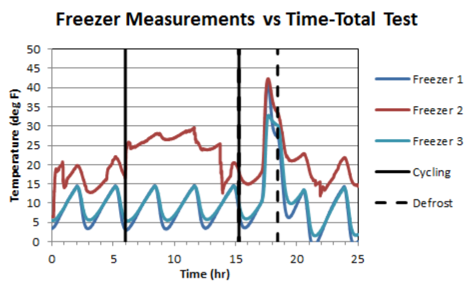



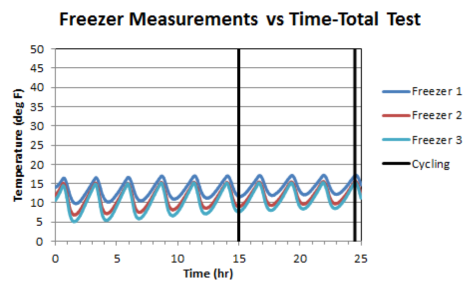
# APPENDIX D: CONTINUED

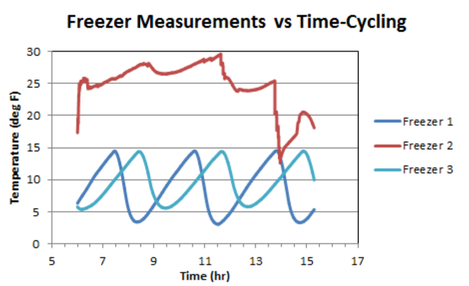
**(33ºF median)**

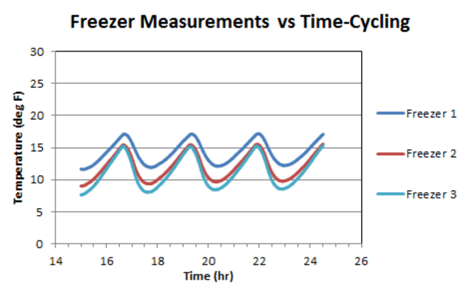


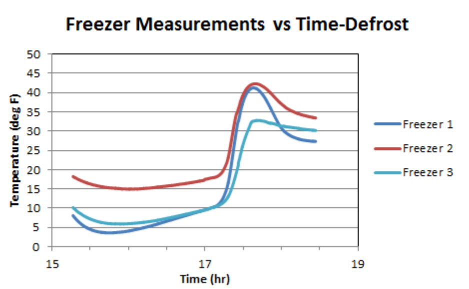
**(33ºF median)**

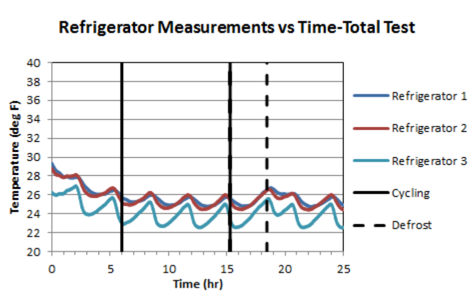

Freezer Measurements vs Time-Total Test
Temperature (deg F)
0 5 10 15 20 25 30 35 40 45 50
0 5 10 15 20 25
Time (hr)
Freezer 1
Freezer 2
Freezer 3
Cycling
Defrost

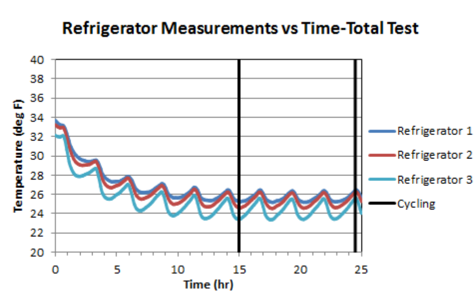

Freezer Measurements vs Time-Total Test
Temperature (deg F)
0 5 10 15 20 25 30 35 40 45 50
0 5 10 15 20 25
Time (hr)
Freezer 1
Freezer 2
Freezer 3
Cycling


Freezer Measurements vs Time-Cycling
Temperature (deg F)
0 5 10 15 20 25 30
5 7 9 11 13 15 17
Time (hr)
Freezer 1
Freezer 2
Freezer 3


Freezer Measurements vs Time-Cycling
Temperature (deg F)
0 5 10 15 20 25 30
14 16 18 20 22 24 26
Time (hr)
Freezer 1
Freezer 2
Freezer 3

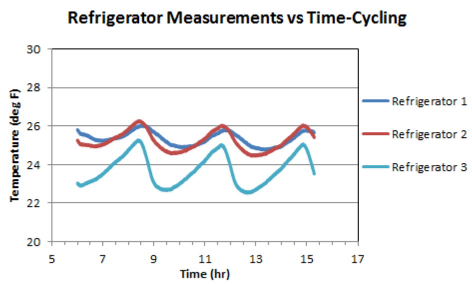

Freezer Measurements vs Time-Defrost
Temperature (deg F)
0 5 10 15 20 25 30 35 40 45 50
15 17 19
Time (hr)
Freezer 1
Freezer 2
Freezer 3

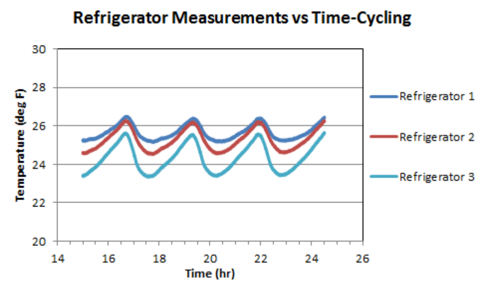

Refrigerator Measurements vs Time-Total Test
Temperature (deg F)
20 22 24 26 28 30 32 34 36 38 40
0 5 10 15 20 25
Time (hr)
Refrigerator 1
Refrigerator 2
Refrigerator 3
Cycling
Defrost

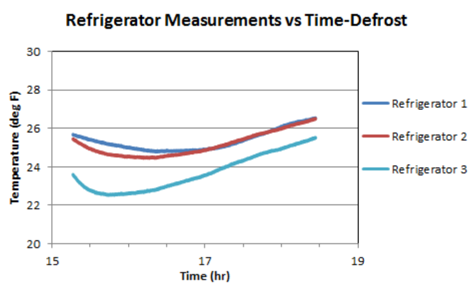

Refrigerator Measurements vs Time-Total Test
Temperature (deg F)
20 22 24 26 28 30 32 34 36 38 40
0 5 10 15 20 25
Time (hr)
Refrigerator 1
Refrigerator 2
Refrigerator 3
Cycling

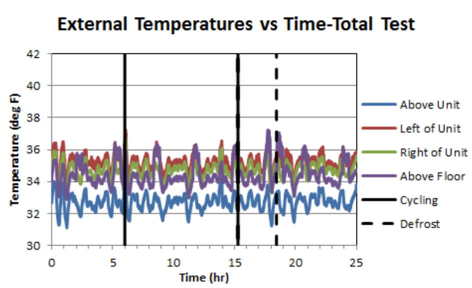
# APPENDIX D: CONTINUED

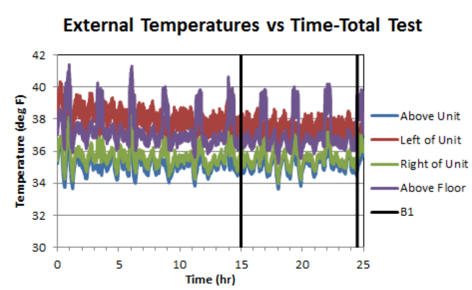
## (33ºF median)

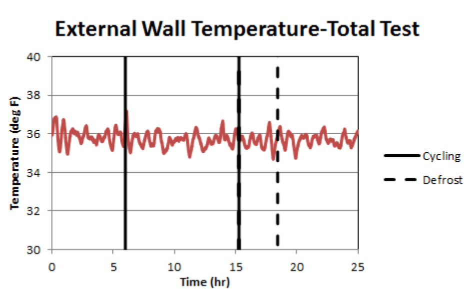


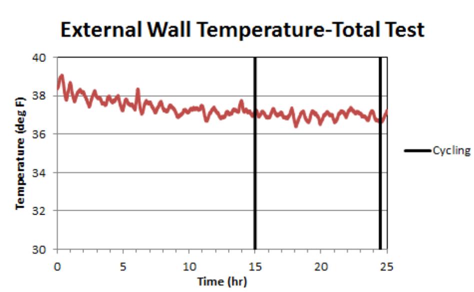



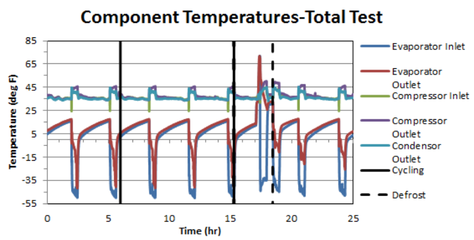



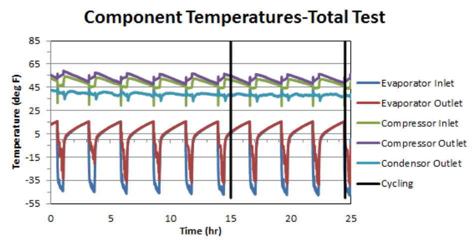



# APPENDIX D: CONTINUED

**(33ºF median)**



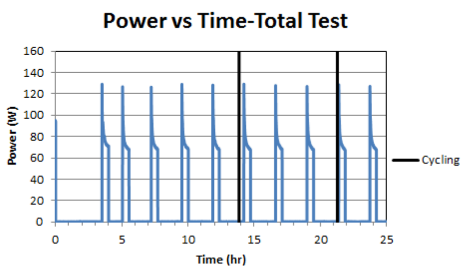



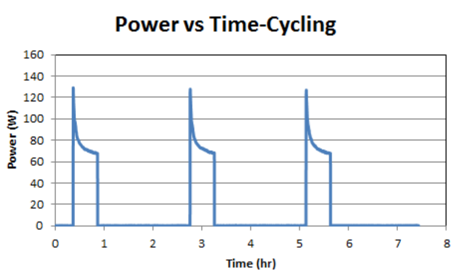
# APPENDIX D: CONTINUED

## Unconditioned Space Temperature: 40ºF (median thermostat)

*Unit A*

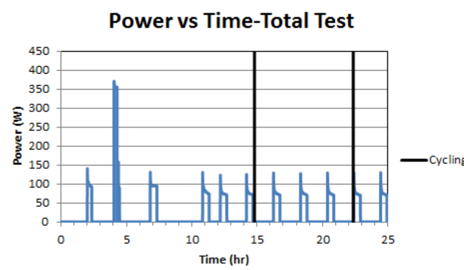
| | | |
|---|---|---|
| EP1 | 0.116 | kwh |
| T1 | 446 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 0.376 | kWh/day |
| EY | 137.11 | kWh/year |
| Cost | $ 14.60 | |

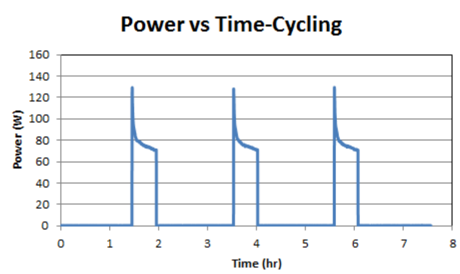



*Unit B*

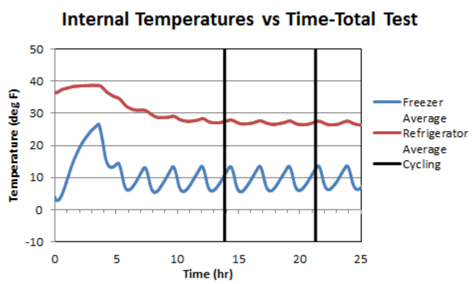
| | | |
|---|---|---|
| EP1 | 0.117 | kwh |
| T1 | 453 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 0.371 | kWh/day |
| EY | 135.47 | kWh/year |
| Cost | $ 14.43 | |

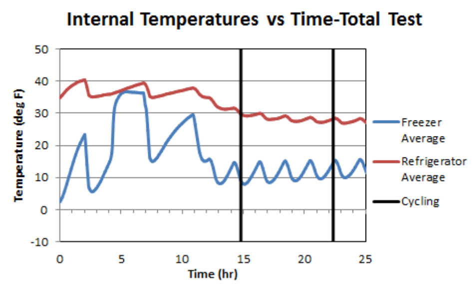


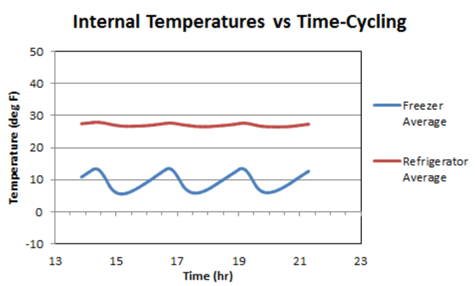



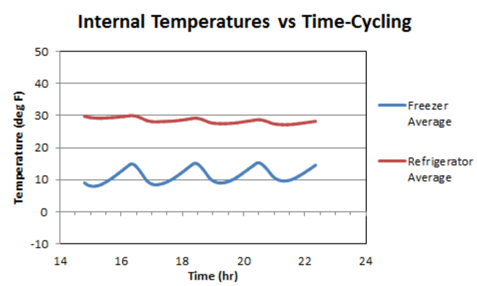
# APPENDIX D: CONTINUED

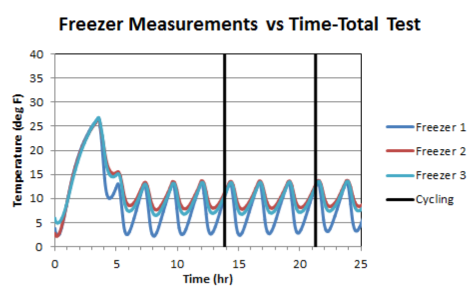
## (40ºF median)

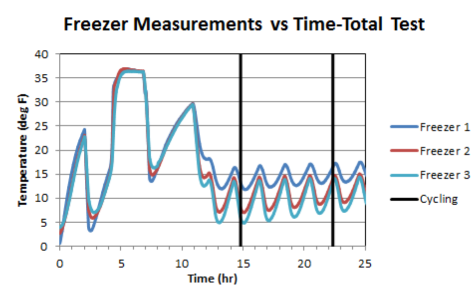


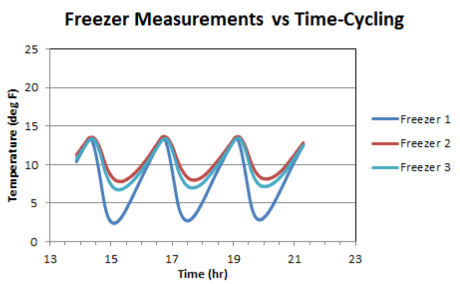



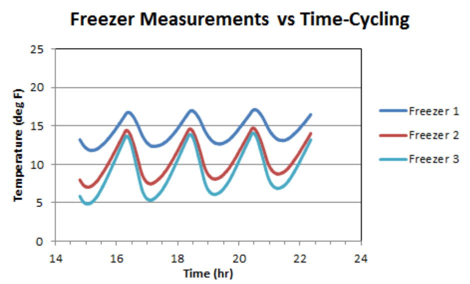



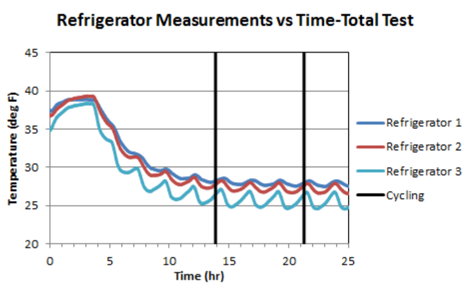



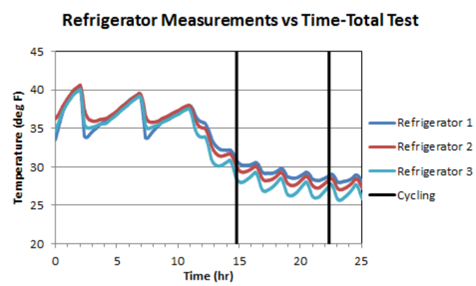
# APPENDIX D: CONTINUED

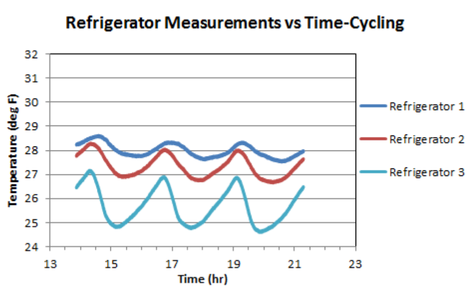
**(40ºF median)**

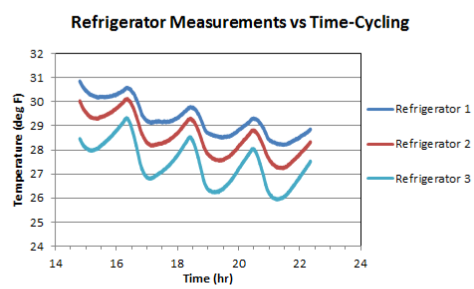


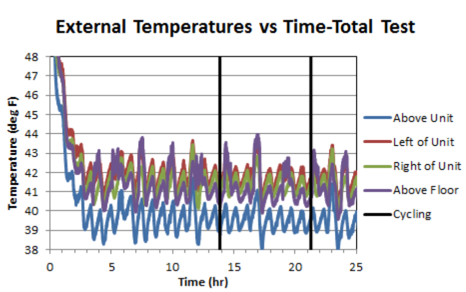



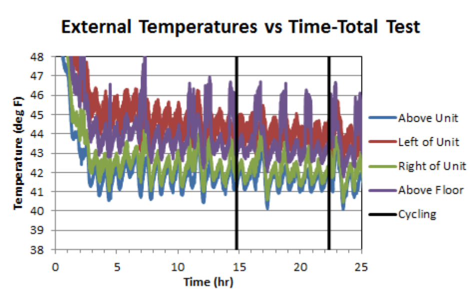



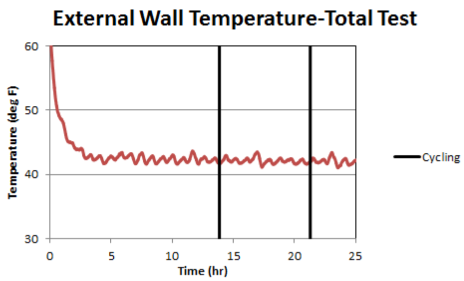



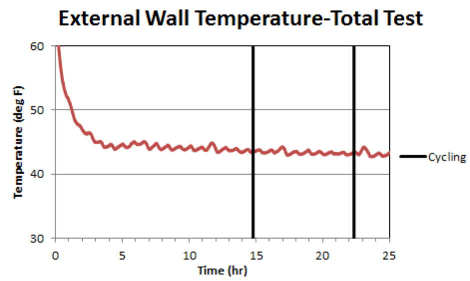



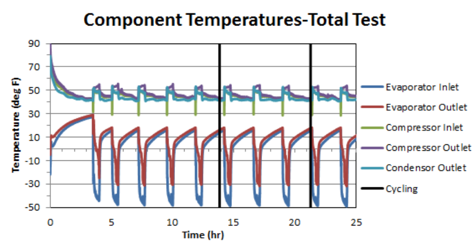



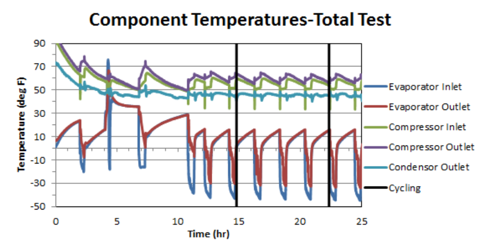
## APPENDIX D: CONTINUED

**(40ºF median)**



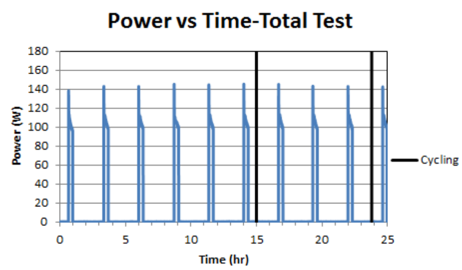



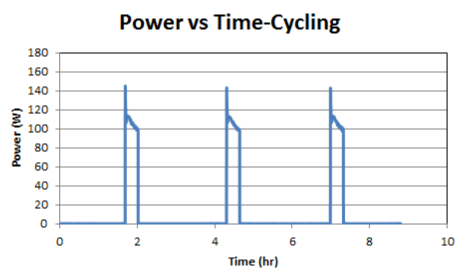
# APPENDIX D: CONTINUED

## Unconditioned Space Temperature: 55ºF (median thermostat)

### *Unit A*

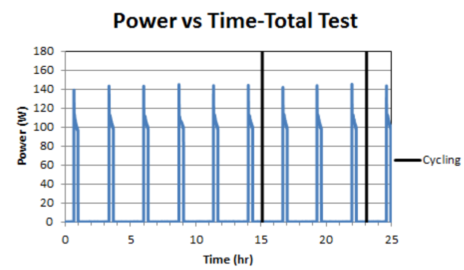
| | | |
|---|---|---|
| EP1 | 0.111 | kwh |
| T1 | 528 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 0.302 | kWh/day |
| EY | 110.07 | kWh/year |
| Cost | $ 11.72 | |

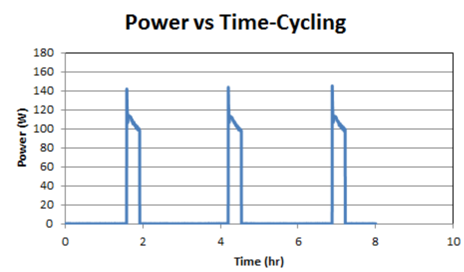



### *Unit B*

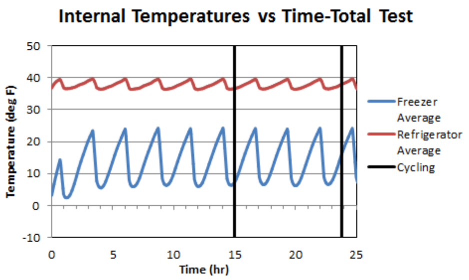
| | | |
|---|---|---|
| EP1 | 0.111 | kwh |
| T1 | 480 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 0.332 | kWh/day |
| EY | 121.08 | kWh/year |
| Cost | $ 12.90 | |

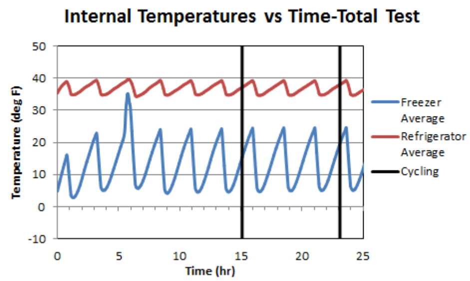


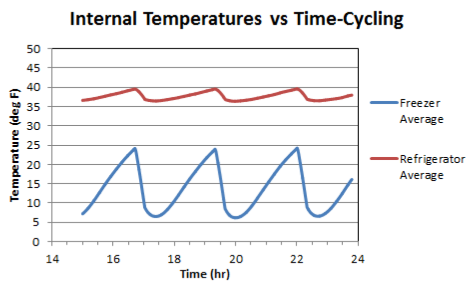



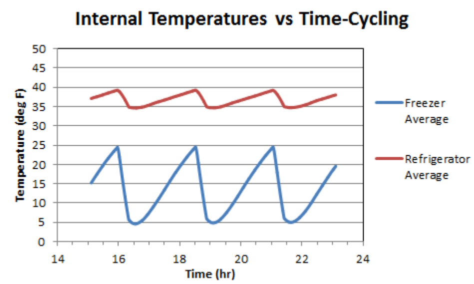
# APPENDIX D: CONTINUED

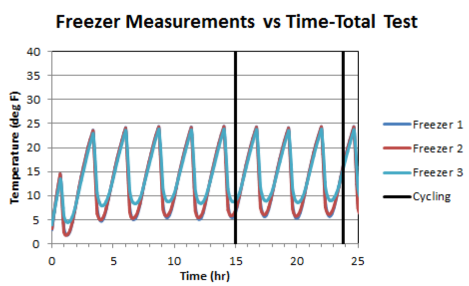
## (55ºF median)

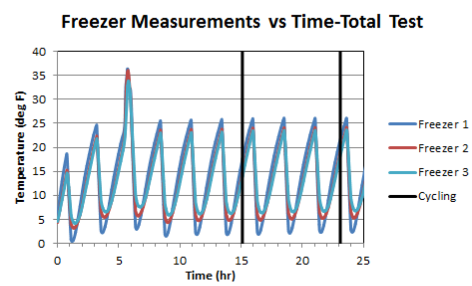


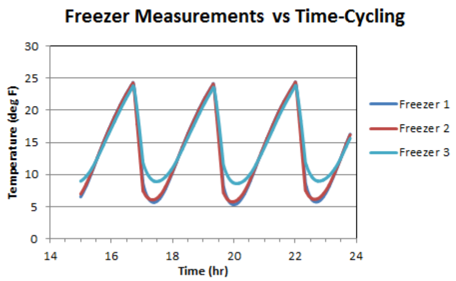



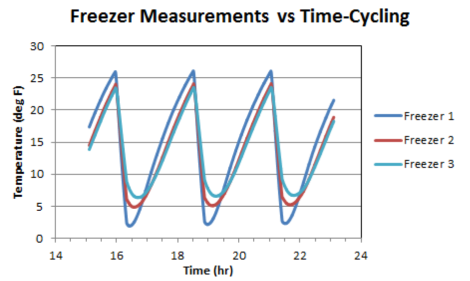



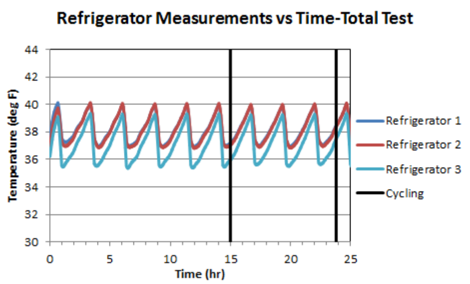



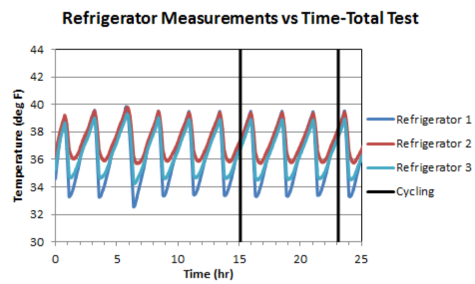
# APPENDIX D: CONTINUED

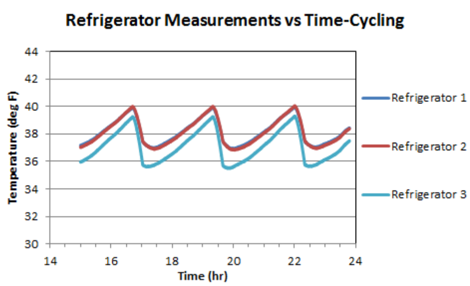
**(55ºF median)**

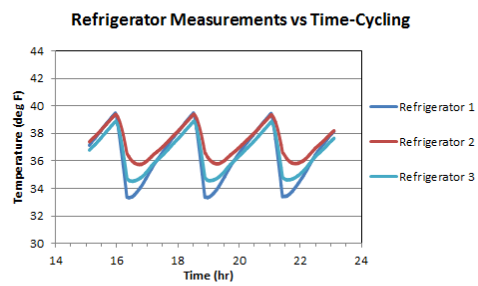


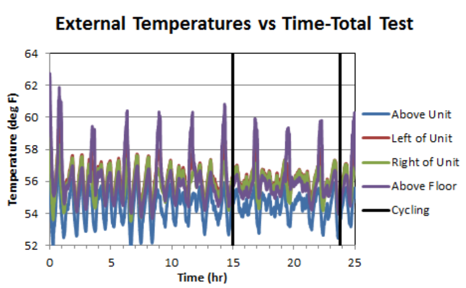



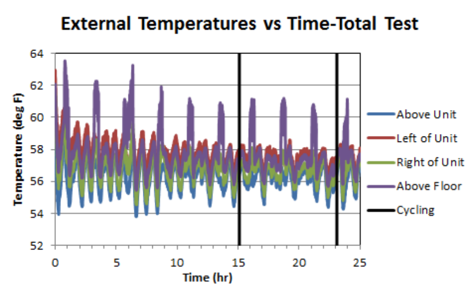



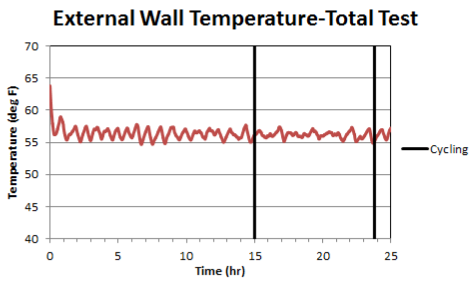



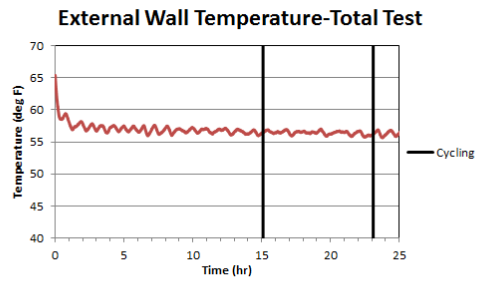



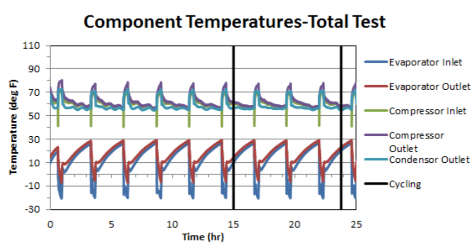



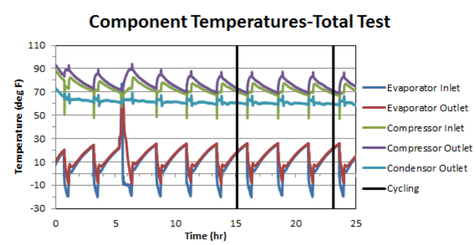
## APPENDIX D: CONTINUED

### (55ºF median)



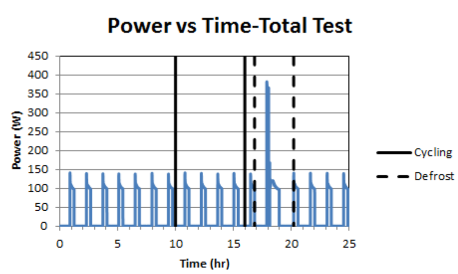



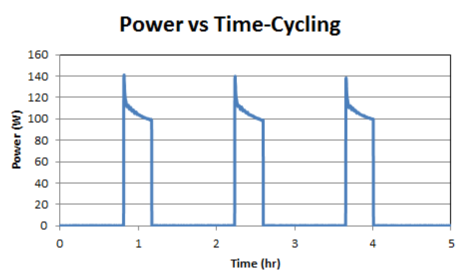
# APPENDIX D: CONTINUED

## Unconditioned Space Temperature: 70°F (median thermostat)

*Unit A*

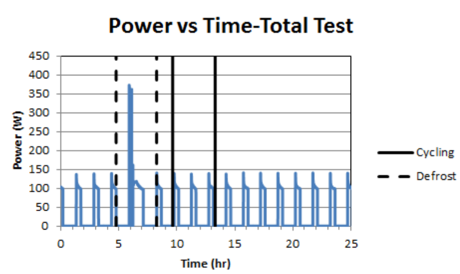
| | | |
|---|---|---|
| EP1 | 0.156 | kwh |
| T1 | 360 | min |
| EP2 | 0.148 | kwh |
| T2 | 203 | min |
| K | 1 | |
| CT | 3.4 | hours |
| ET | 0.836 | kWh/day |
| EY | 305.03 | kWh/year |
| Cost | $ 32.49 | |

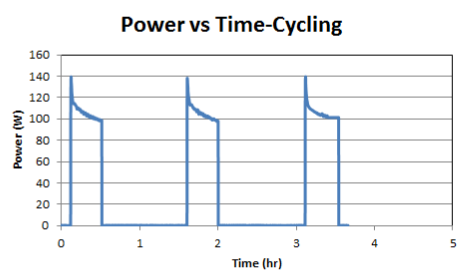



*Unit B*

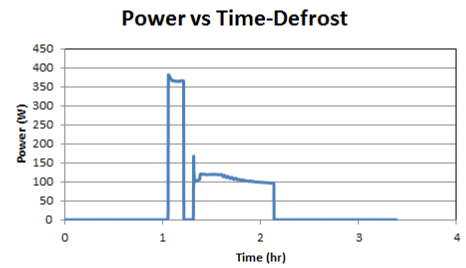
| | | |
|---|---|---|
| EP1 | 0.130 | kwh |
| T1 | 220 | min |
| EP2 | 0.178 | kwh |
| T2 | 210 | min |
| K | 1 | |
| CT | 3.5 | hours |
| ET | 1.039 | kWh/day |
| EY | 379.39 | kWh/year |
| Cost | $ 40.41 | |

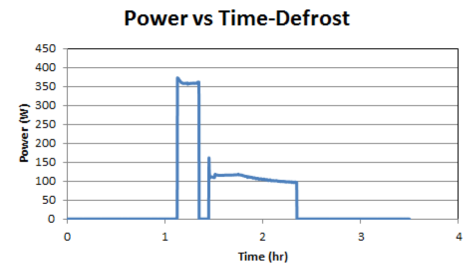


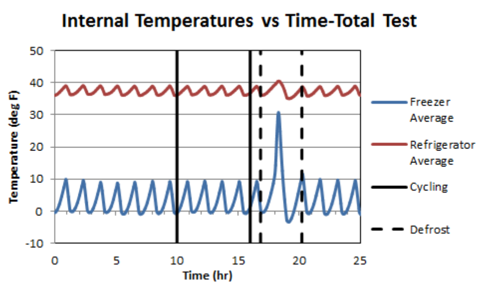



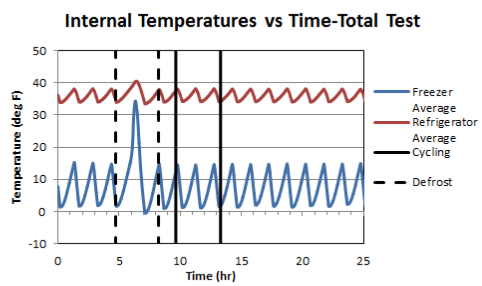
# APPENDIX D: CONTINUED

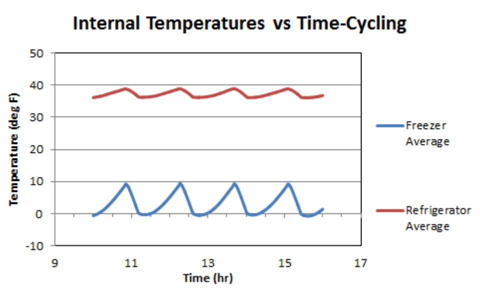
## (70ºF median)

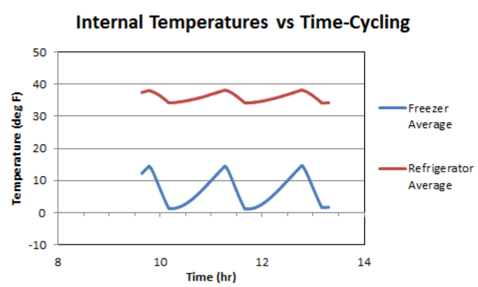


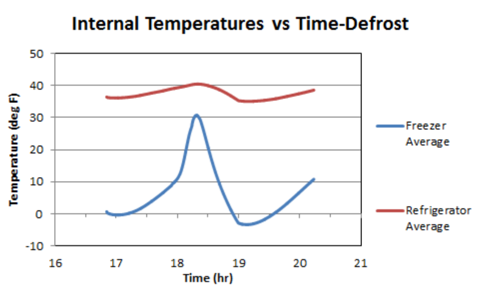



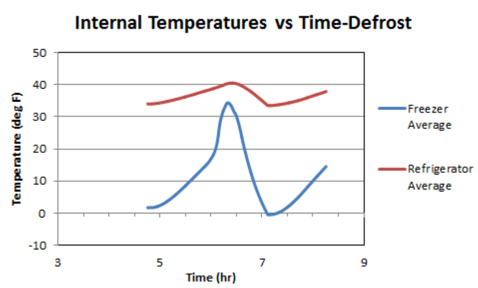



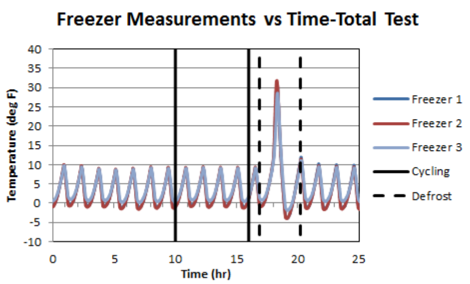



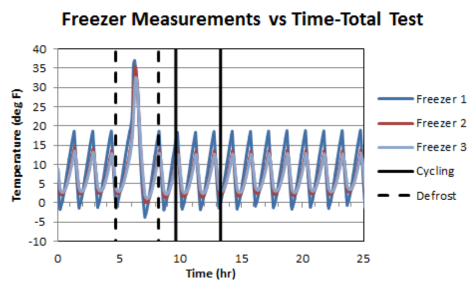



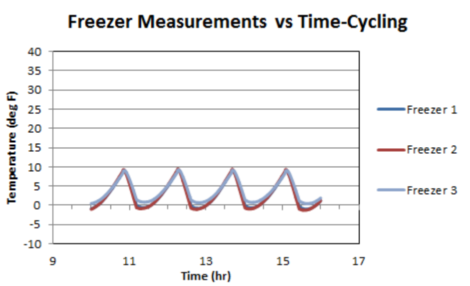



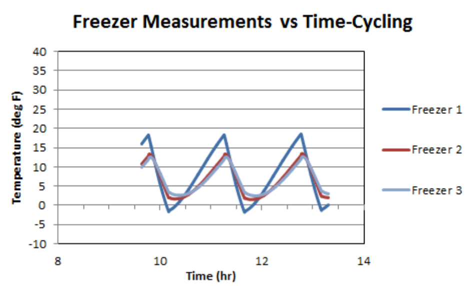
# APPENDIX D: CONTINUED

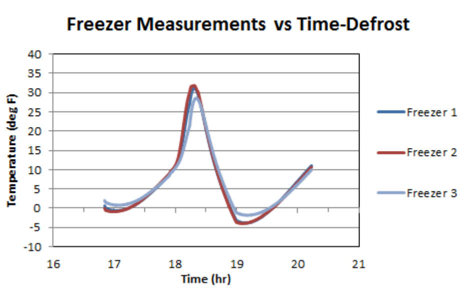
**(70ºF median)**

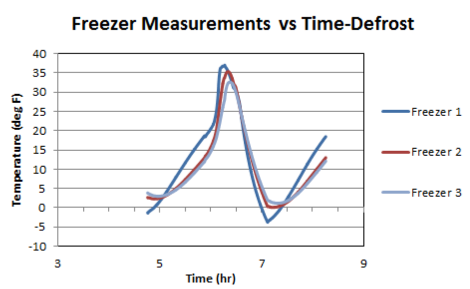


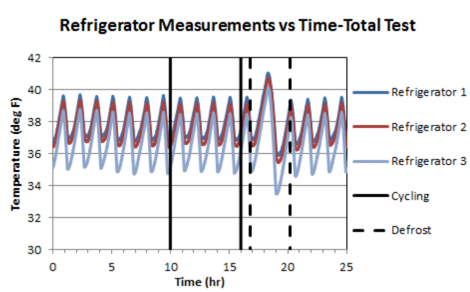



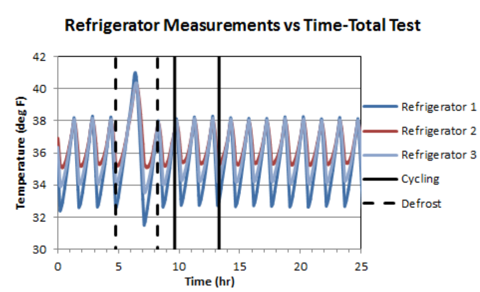



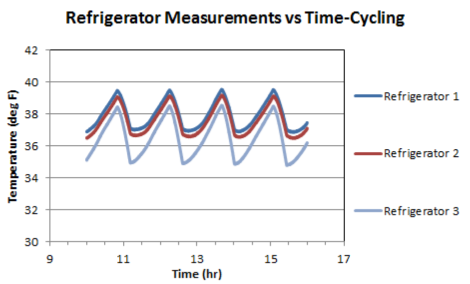



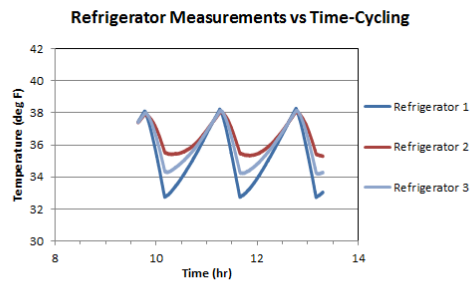



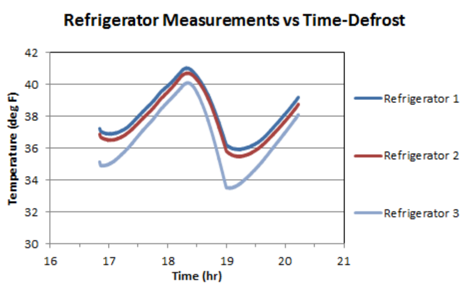



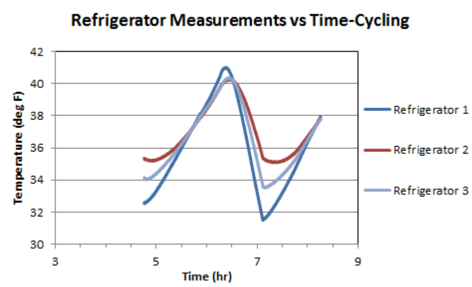



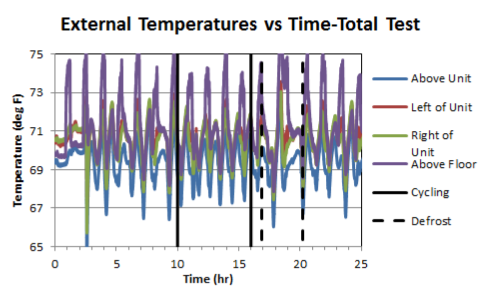
## (70ºF median)

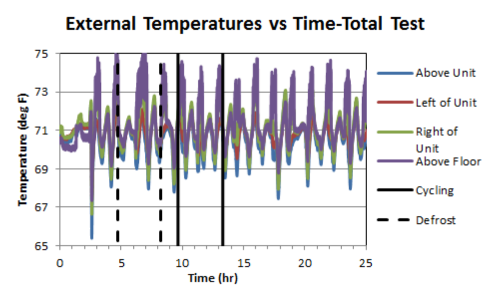

Refrigerator Measurements vs Time-Cycling
Temperature (deg F)
Time (hr)
Refrigerator 1
Refrigerator 2
Refrigerator 3

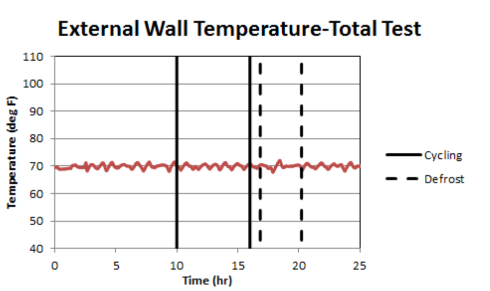

Refrigerator Measurements vs Time-Cycling
Temperature (deg F)
Time (hr)
Refrigerator 1
Refrigerator 2
Refrigerator 3

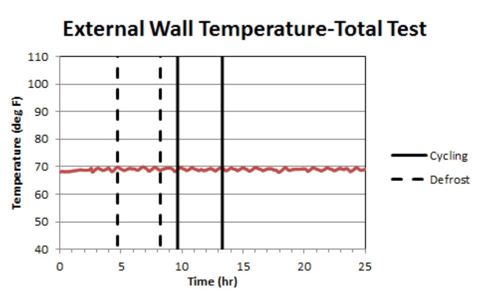

Refrigerator Measurements vs Time-Defrost
Temperature (deg F)
Time (hr)
Refrigerator 1
Refrigerator 2
Refrigerator 3


Refrigerator Measurements vs Time-Cycling
Temperature (deg F)
Time (hr)
Refrigerator 1
Refrigerator 2
Refrigerator 3


External Temperatures vs Time-Total Test
Temperature (deg F)
Time (hr)
Above Unit
Left of Unit
Right of Unit
Above Floor
Cycling
Defrost

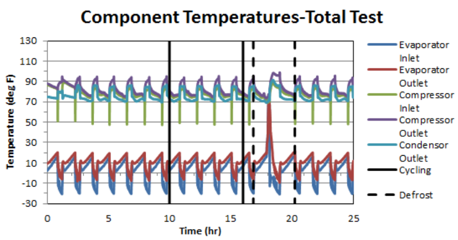

External Temperatures vs Time-Total Test
Temperature (deg F)
Time (hr)
Above Unit
Left of Unit
Right of Unit
Above Floor
Cycling
Defrost

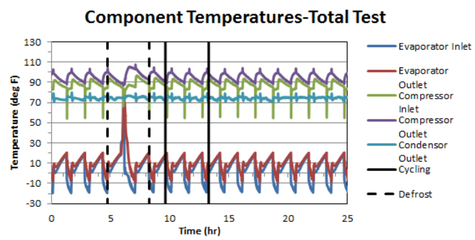

External Wall Temperature-Total Test
Temperature (deg F)
Time (hr)
Cycling
Defrost


External Wall Temperature-Total Test
Temperature (deg F)
Time (hr)
Cycling
Defrost

# APPENDIX D: CONTINUED

**(70ºF median)**



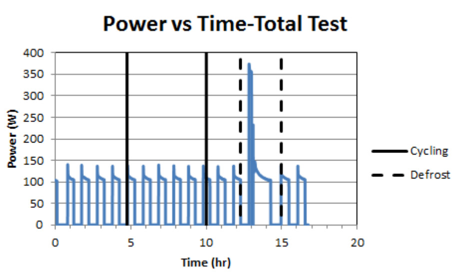



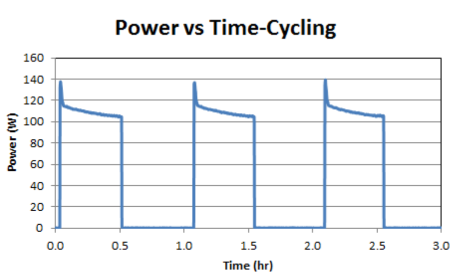
# APPENDIX D: CONTINUED

## Unconditioned Space Temperature: 90°F (median thermostat)

*Unit A*

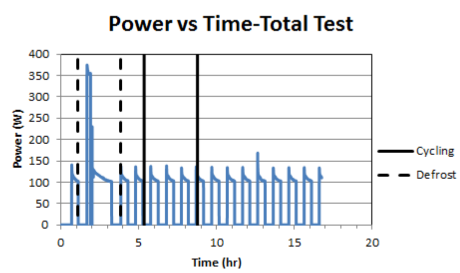
| | | |
|---|---|---|
| EP1 | 0.278 | kwh |
| T1 | 316 | min |
| EP2 | 0.197 | kwh |
| T2 | 161 | min |
| K | 1 | |
| CT | 2.7 | hours |
| ET | 1.517 | kWh/day |
| EY | 553.6 | kWh/year |
| Cost | $ 58.96 | |

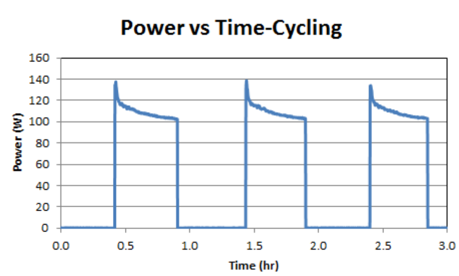



*Unit B*

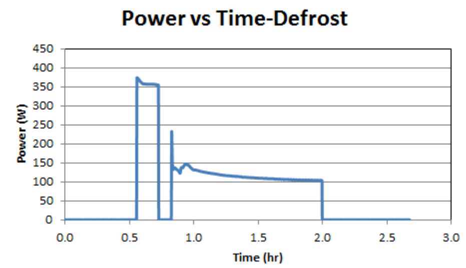
| | | |
|---|---|---|
| EP1 | 0.163 | kwh |
| T1 | 206 | min |
| EP2 | 0.224 | kwh |
| T2 | 164 | min |
| K | 1 | |
| CT | 2.7 | hours |
| ET | 1.560 | kWh/day |
| EY | 569.3 | kWh/year |
| Cost | $ 60.63 | |

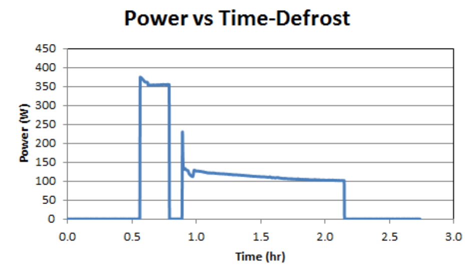


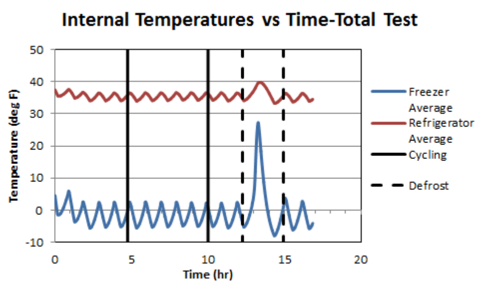



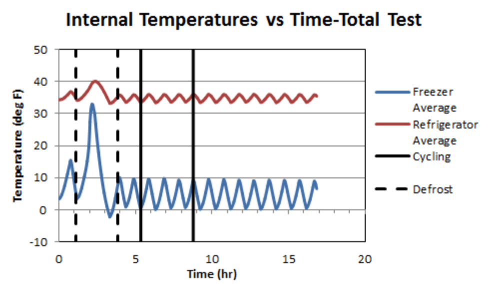
# APPENDIX D: CONTINUED

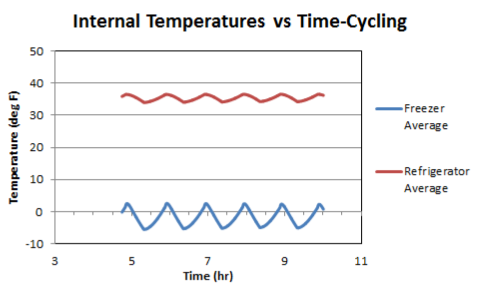
**(90ºF median)**

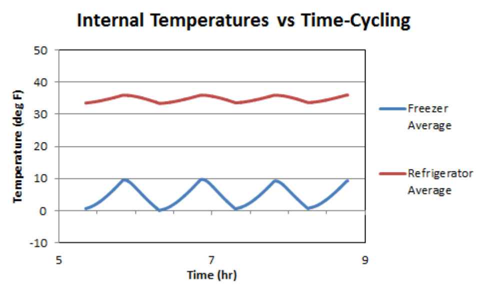


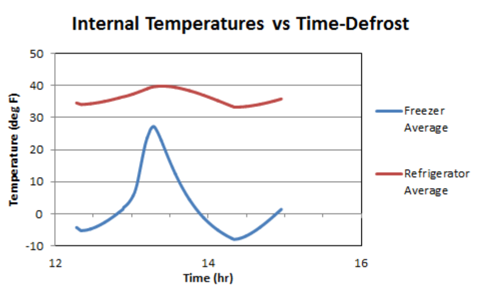



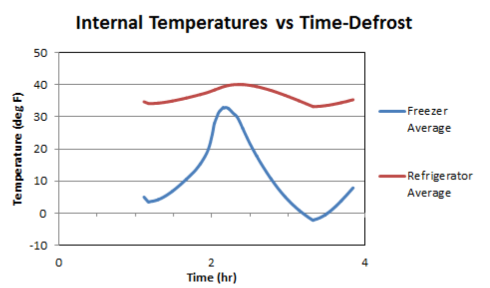



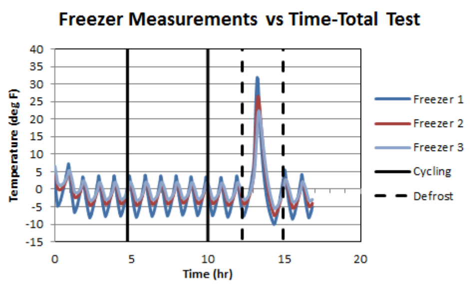



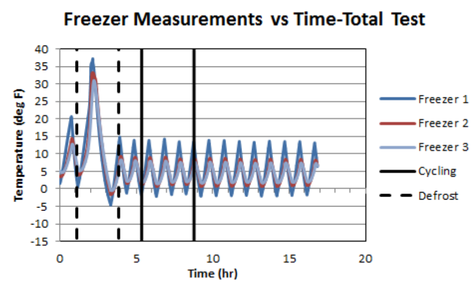



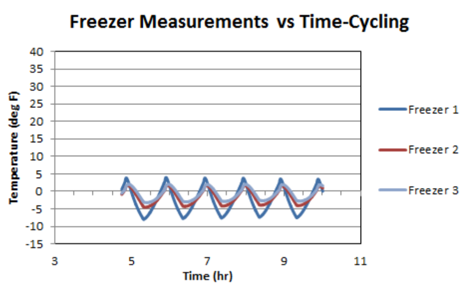



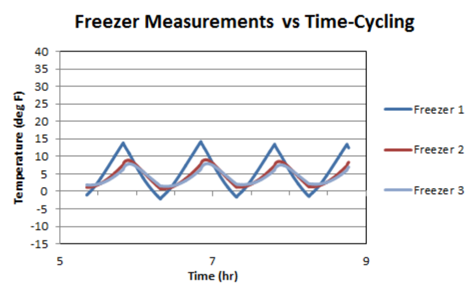
## APPENDIX D: CONTINUED

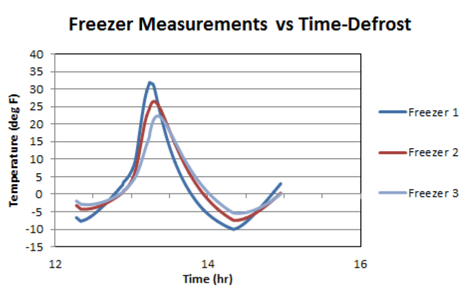
### (90ºF median)

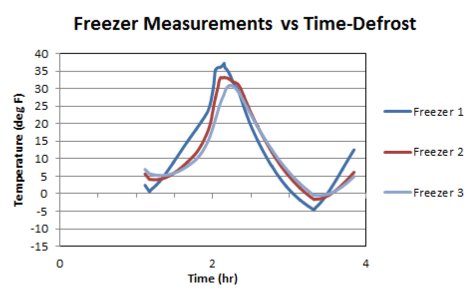


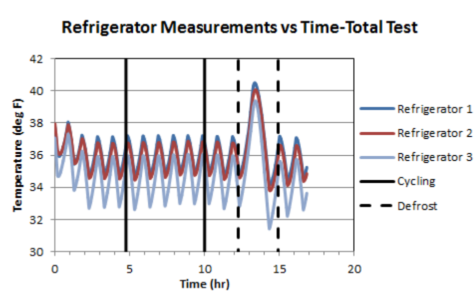



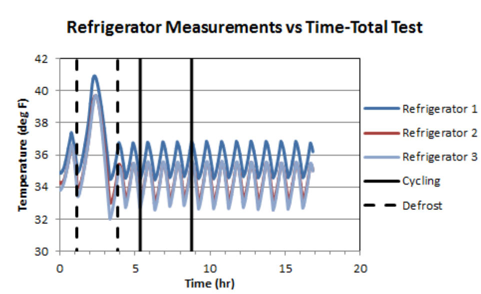



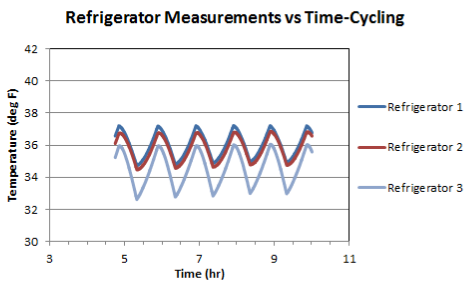



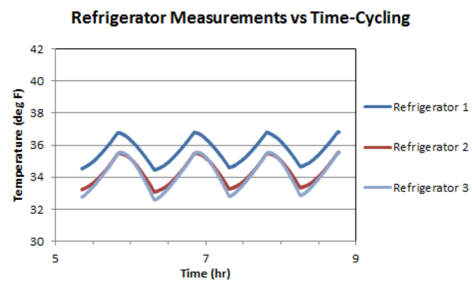



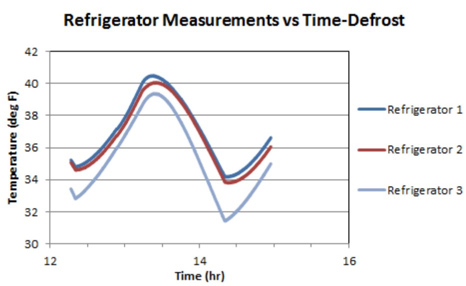



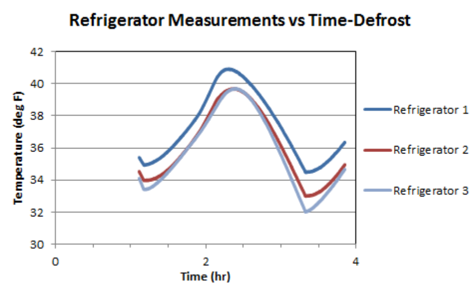
# APPENDIX D: CONTINUED

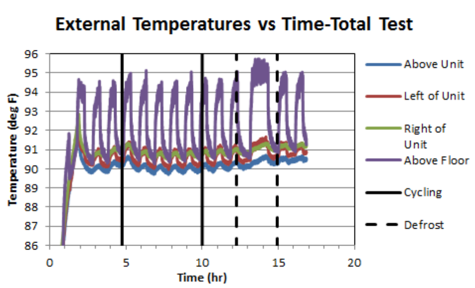
## (90ºF median)

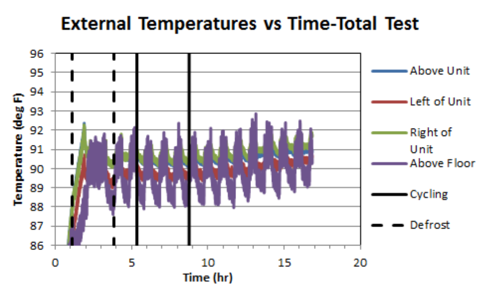


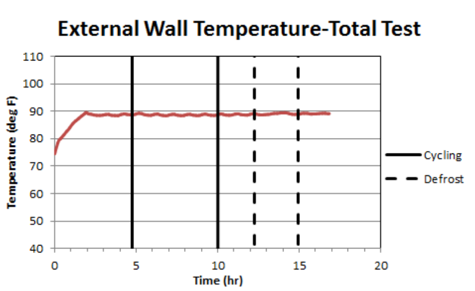



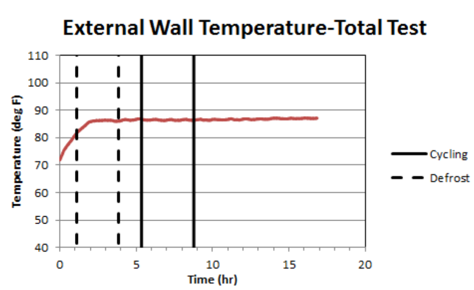



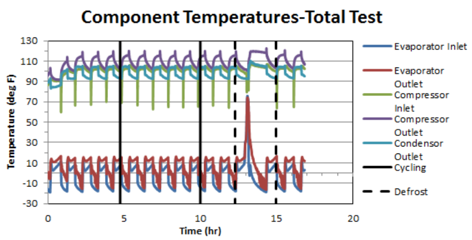



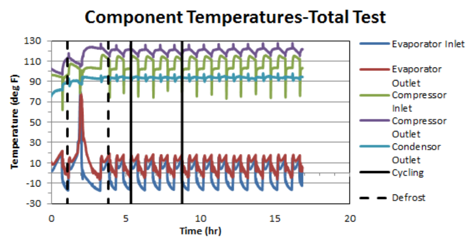



# APPENDIX D: CONTINUED

**(90ºF median)**



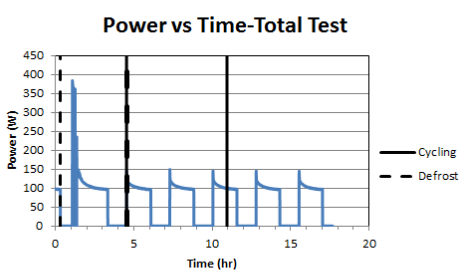



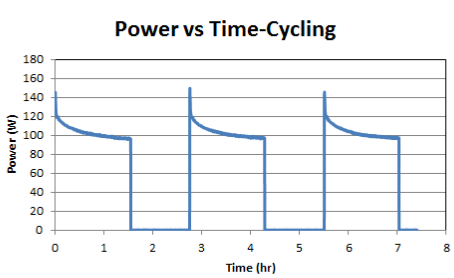
# APPENDIX D: CONTINUED

## Unconditioned Space Temperature: 90ºF (coldest thermostat)

*Unit A*

| | | |
|---|---|---|
| EP1 | 0.477 | kwh |
| T1 | 444 | min |
| EP2 | 0.282 | kwh |
| T2 | 253 | min |
| K | 1 | |
| CT | 4.2 | hours |
| ET | 1.575 | kWh/day |
| EY | 574.8 | kWh/year |
| Cost | $ 61.21 | |



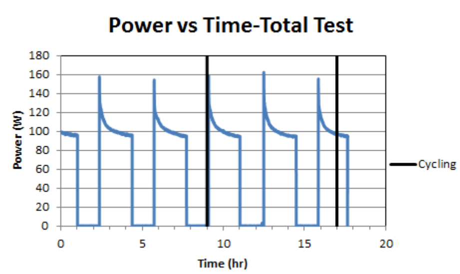

*Unit B*

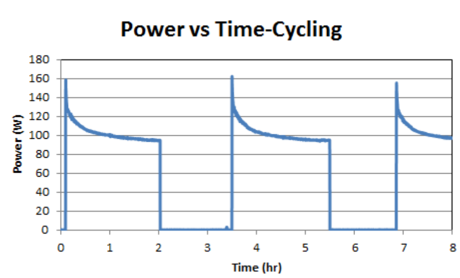
(As Is)

| | | |
|---|---|---|
| EP1 | 0.523 | kwh |
| T1 | 480 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 1.570 | kWh/day |
| EY | 572.9 | kWh/year |
| Cost | $ 61.01 | |

(Borrowed Defrost)

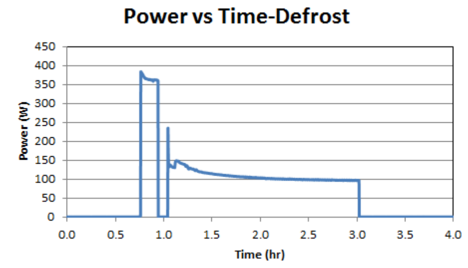
| | | |
|---|---|---|
| EP1 | 0.523 | kwh |
| T1 | 480 | min |
| EP2 | 0.282 | kwh |
| T2 | 253 | min |
| K | 1 | |
| CT | 4.2 | hours |
| ET | 1.585 | kWh/day |
| EY | 578.7 | kWh/year |
| Cost | $ 61.63 | |

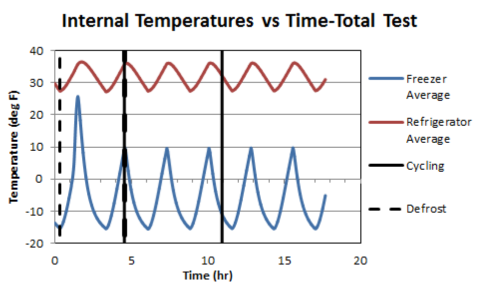


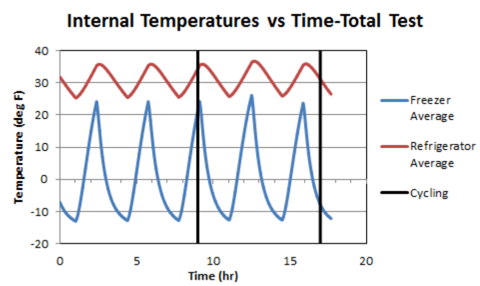



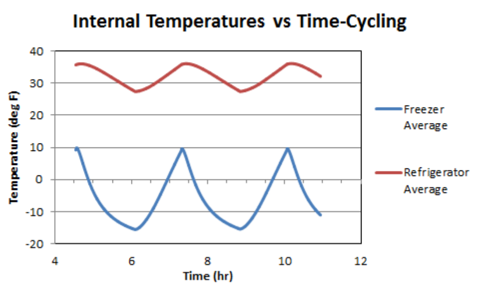
# APPENDIX D: CONTINUED

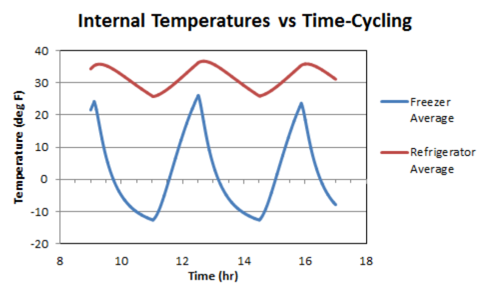
**(90ºF coldest)**

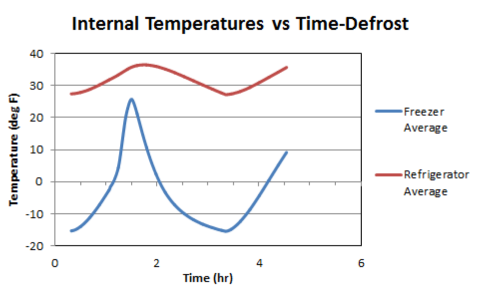


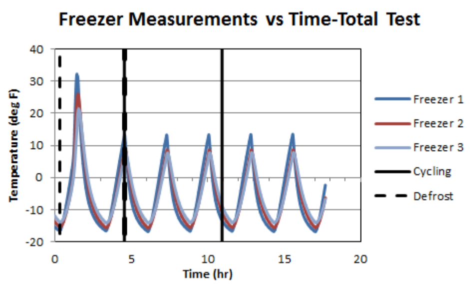



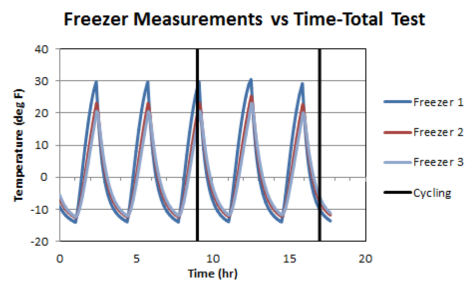



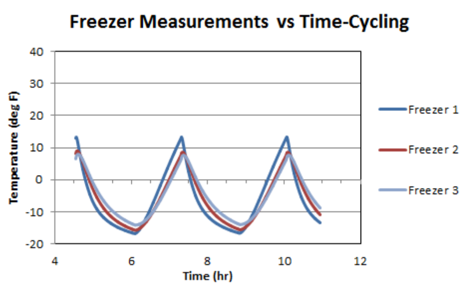



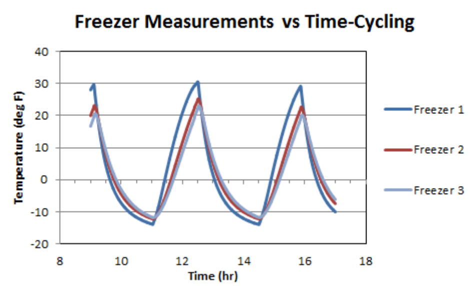
# APPENDIX D: CONTINUED

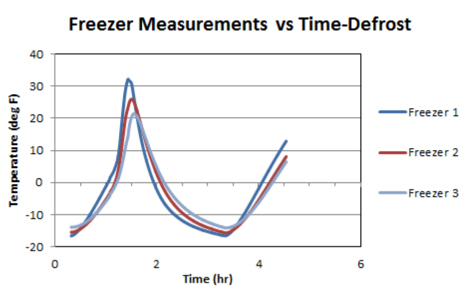
## (90ºF coldest)

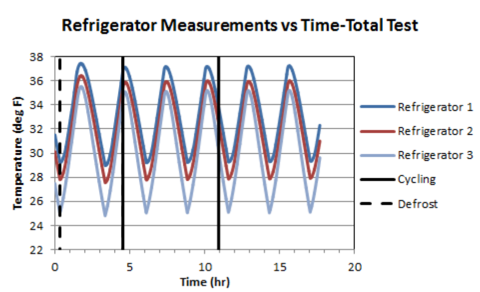


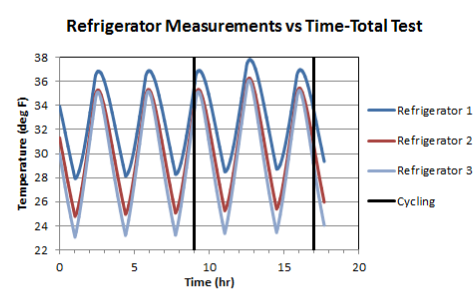



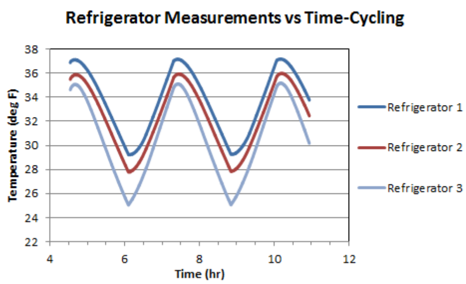



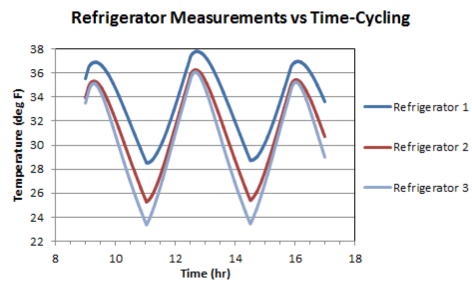



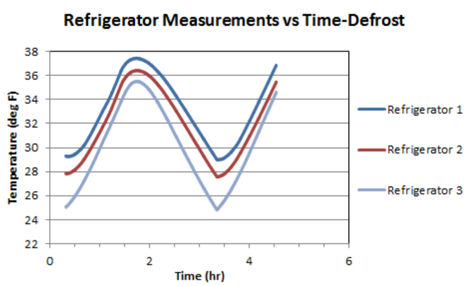



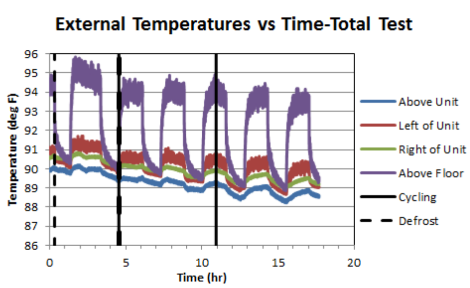
# APPENDIX D: CONTINUED

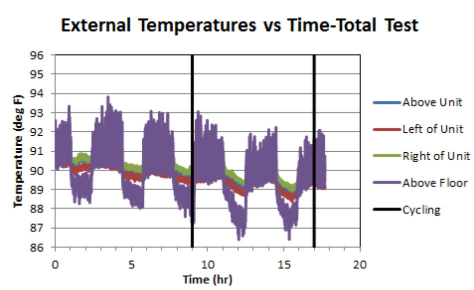
## (90ºF coldest)

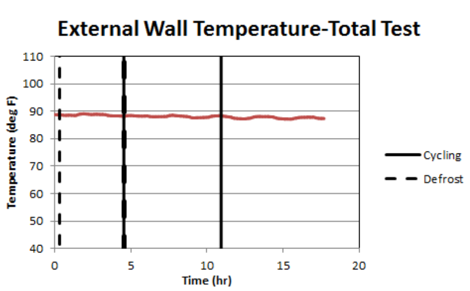


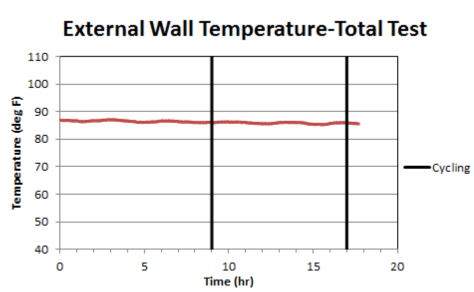



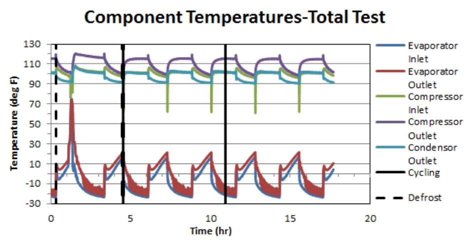



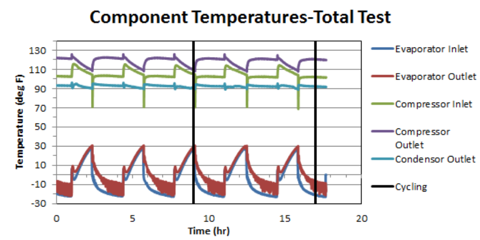



## APPENDIX D: CONTINUED

**(90ºF coldest)**



# APPENDIX D: CONTINUED

### Unconditioned Space Temperature: 100ºF (median thermostat)

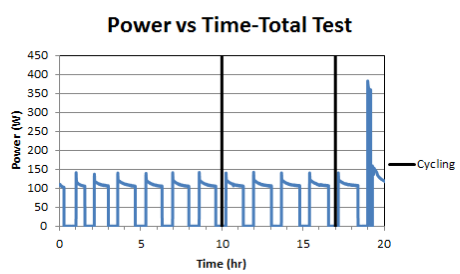
*Unit A* *Unit B*

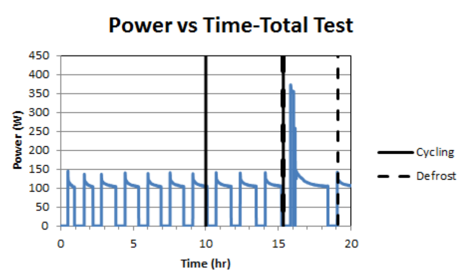
(As Is) (Borrowed Defrost)

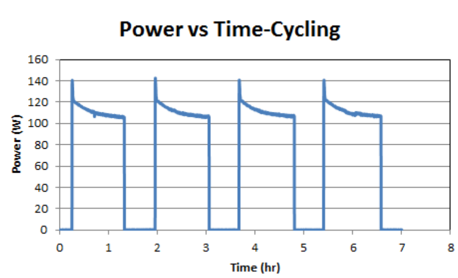
| | | |
|---|---|---|
| EP1 | 0.501 | kwh |
| T1 | 420 | min |
| EP2 | - | kwh |
| T2 | - | min |
| K | 1 | |
| CT | - | hours |
| ET | 1.718 | kWh/day |
| EY | 627.05 | kWh/year |
| Cost | $ 66.78 | |

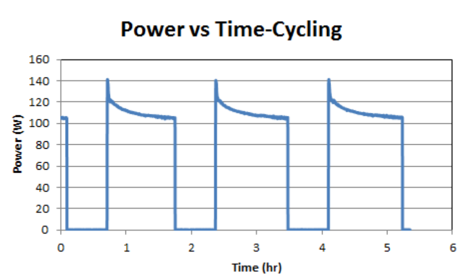
| | | |
|---|---|---|
| EP1 | 0.501 | kwh |
| T1 | 420 | min |
| EP2 | 0.339 | kwh |
| T2 | 230 | min |
| K | 1 | |
| CT | 3.8 | hours |
| ET | 1.923 | kWh/day |
| EY | 701.71 | kWh/year |
| Cost | $ 74.73 | |

| | | |
|---|---|---|
| EP1 | 0.373 | kwh |
| T1 | 321 | min |
| EP2 | 0.339 | kwh |
| T2 | 230 | min |
| K | 1 | |
| CT | 3.8 | hours |
| ET | 1.902 | kWh/day |
| EY | 694.08 | kWh/year |
| Cost | $ 73.92 | |



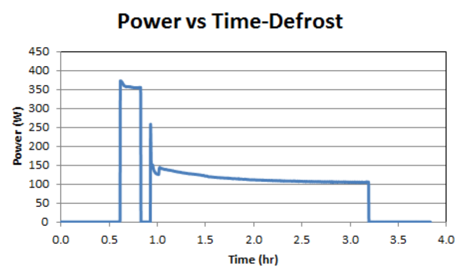



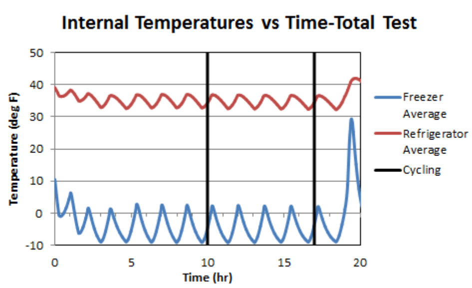



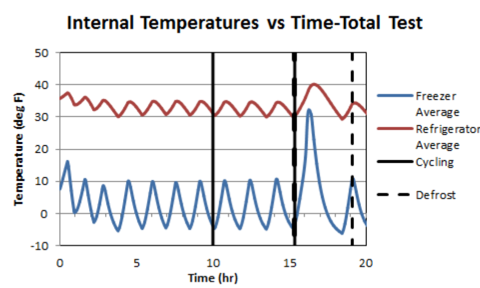



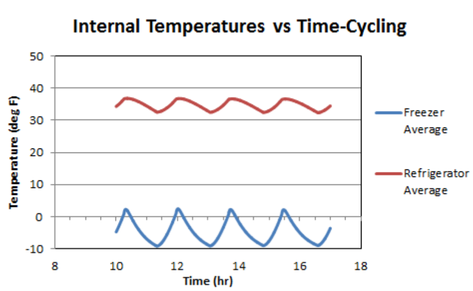
## APPENDIX D: CONTINUED

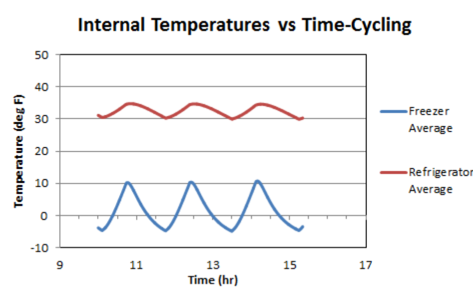
**(100ºF median)**

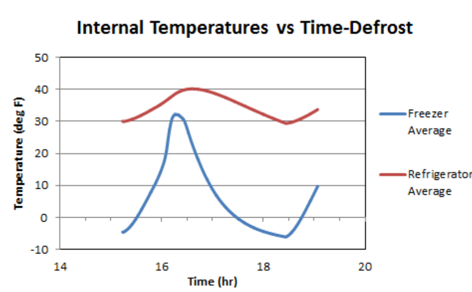


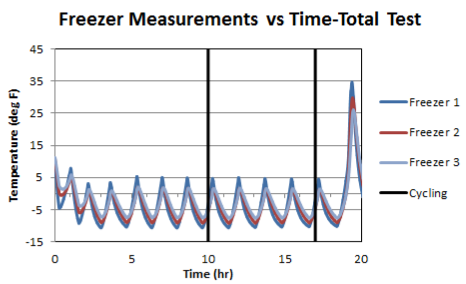



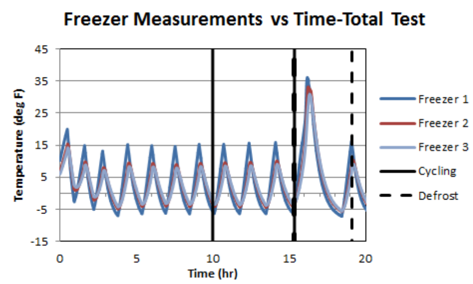



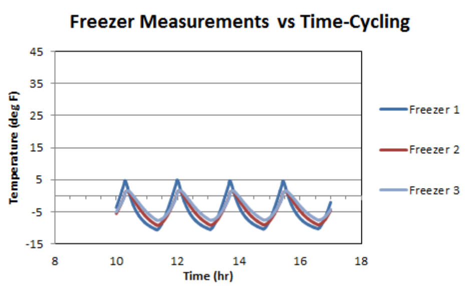



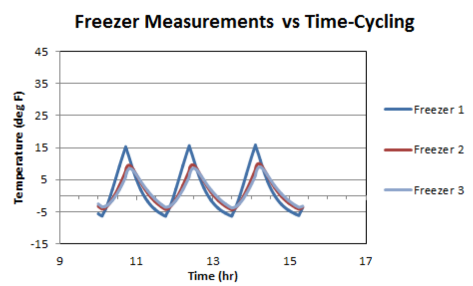



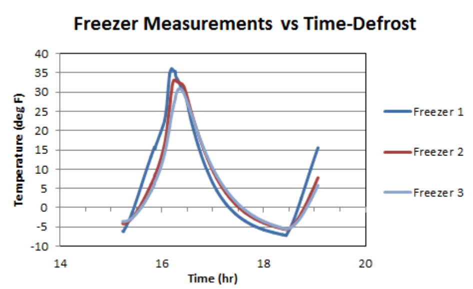
## (100ºF median)

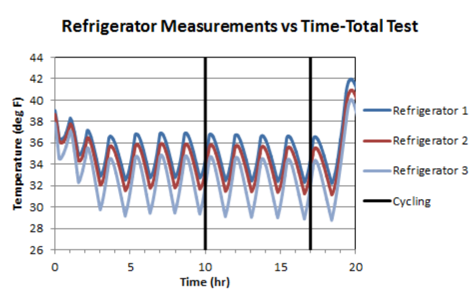


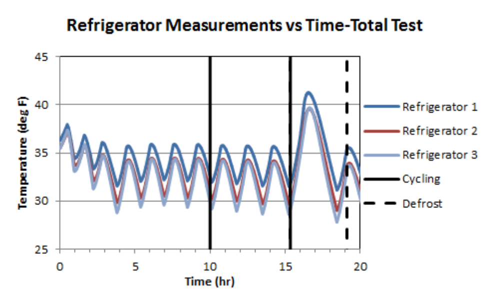



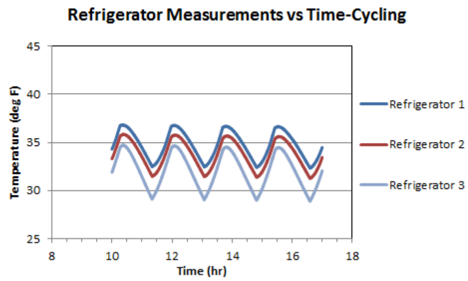



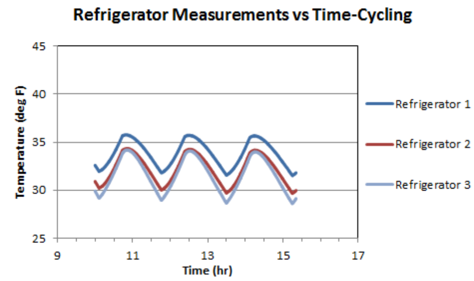



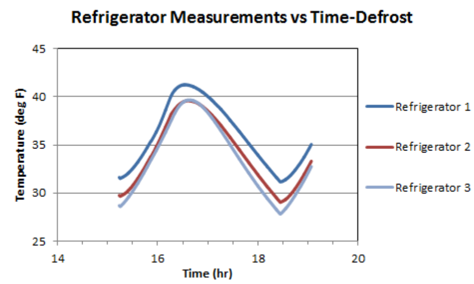



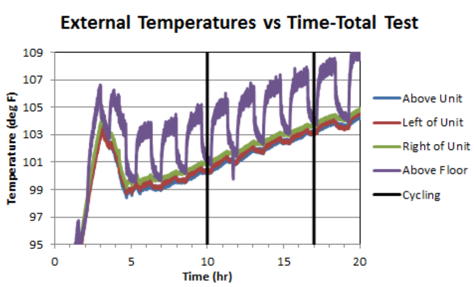
# APPENDIX D: CONTINUED

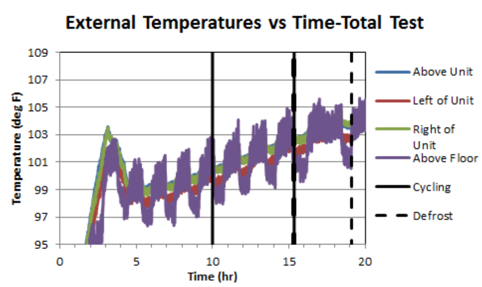
## (100ºF median)

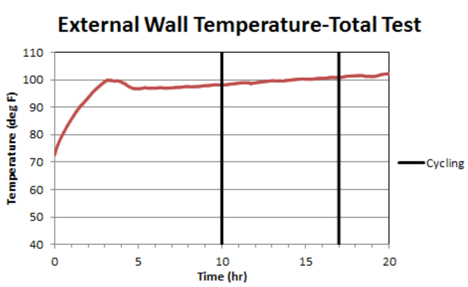


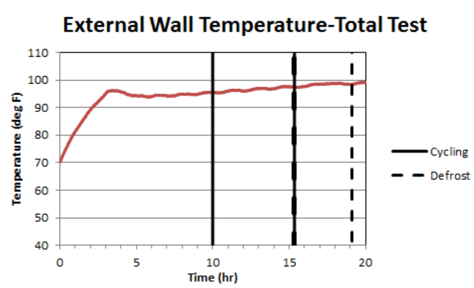



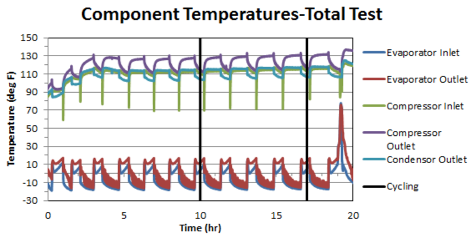



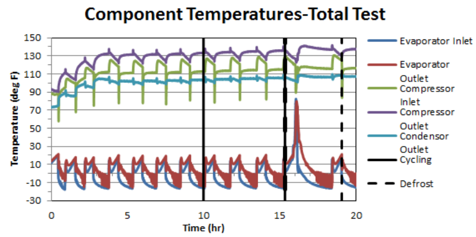



# APPENDIX D: CONTINUED

**(100ºF median)**



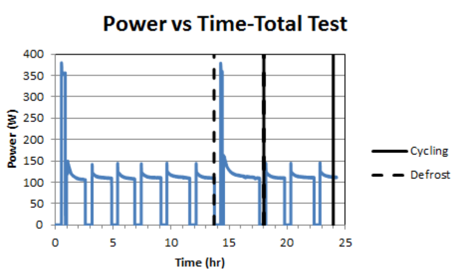



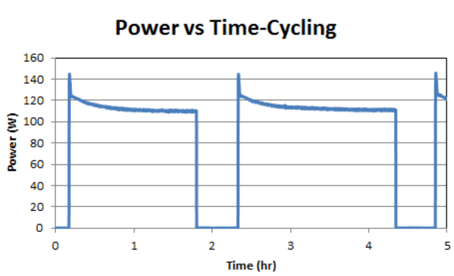
# APPENDIX D: CONTINUED

## Unconditioned Space Temperature: 110ºF (median thermostat)

*Unit A*

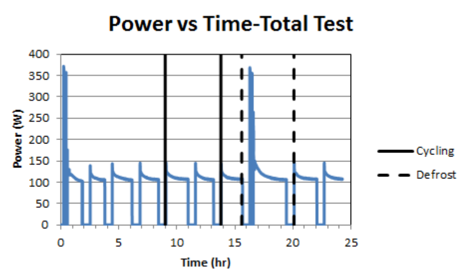
| | | |
|---|---|---|
| EP1 | 0.545 | kwh |
| T1 | 358 | min |
| EP2 | 0.421 | kwh |
| T2 | 266 | min |
| K | 1 | |
| CT | 4.4 | hours |
| ET | 2.234 | kWh/day |
| EY | 815.29 | kWh/year |
| Cost | $ 86.83 | |

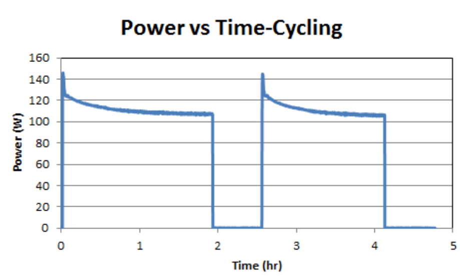



*Unit B*

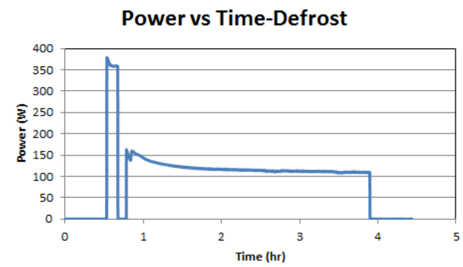
| | | |
|---|---|---|
| EP1 | 0.389 | kwh |
| T1 | 251.5 | min |
| EP2 | 0.389 | kwh |
| T2 | 286 | min |
| K | 1 | |
| CT | 4.5 | hours |
| ET | 2.083 | kWh/day |
| EY | 760.38 | kWh/year |
| Cost | $ 80.98 | |

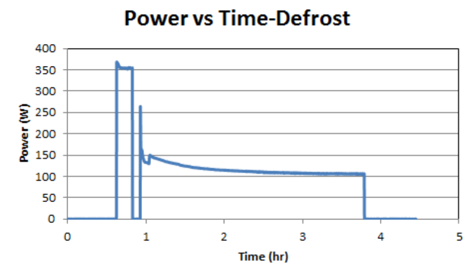


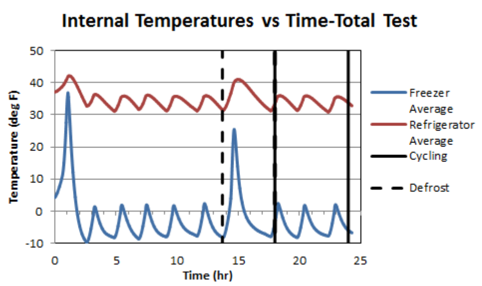



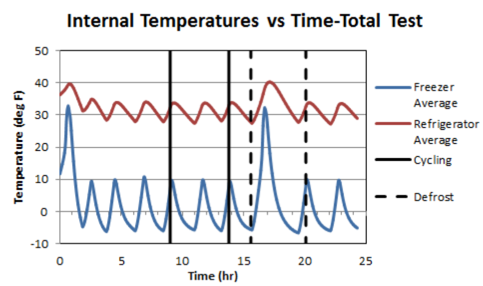
# APPENDIX D: CONTINUED

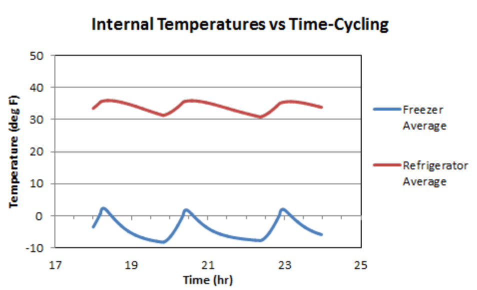
**(110ºF median)**

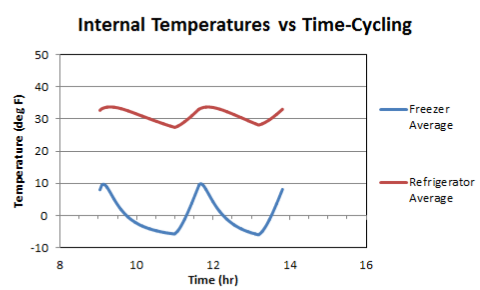


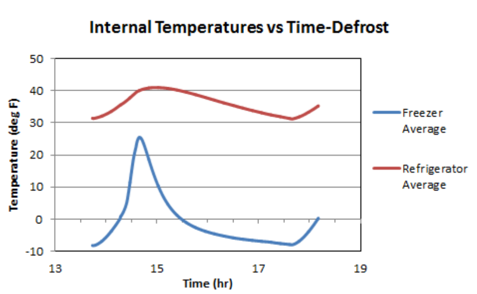



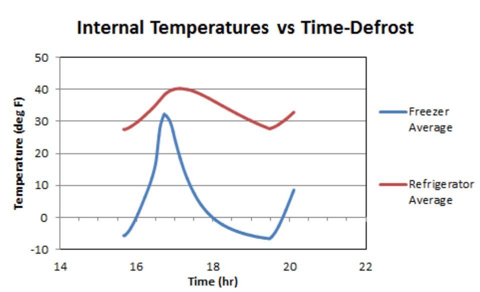



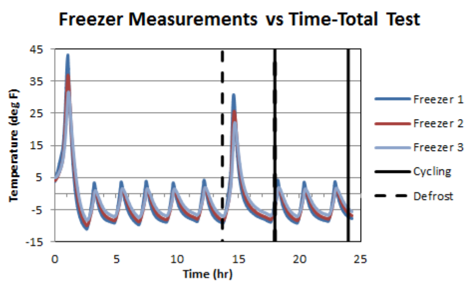



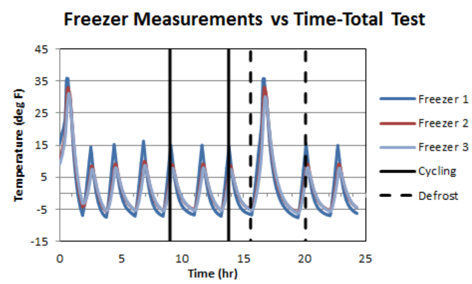



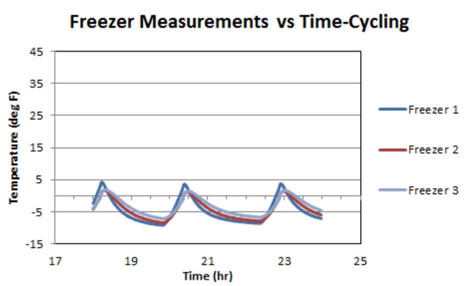



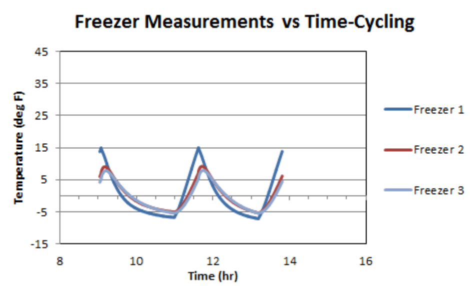
# APPENDIX D: CONTINUED

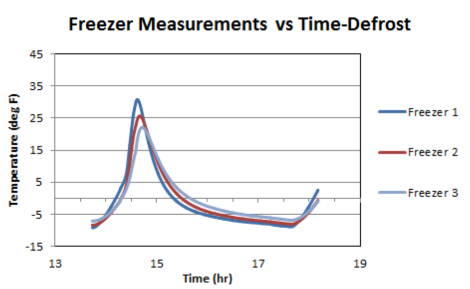
**(110ºF median)**

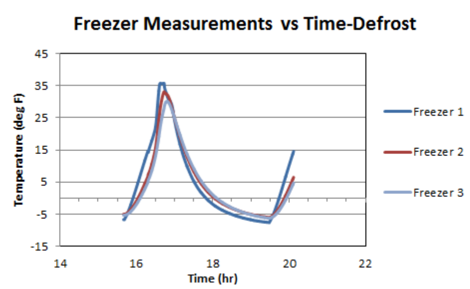


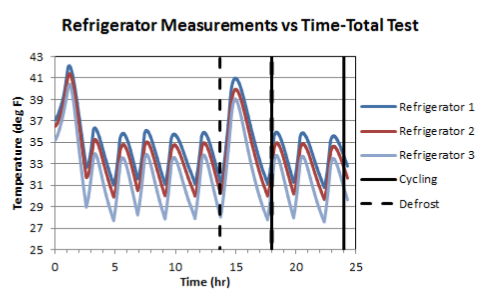



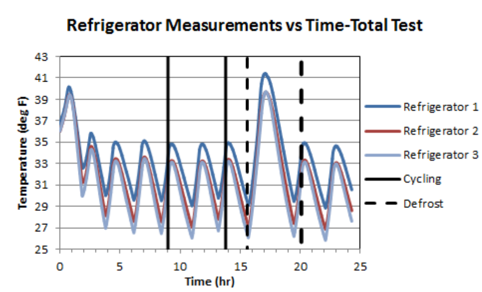



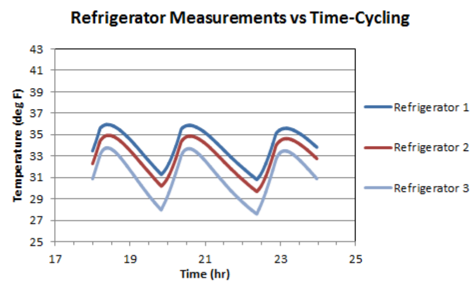



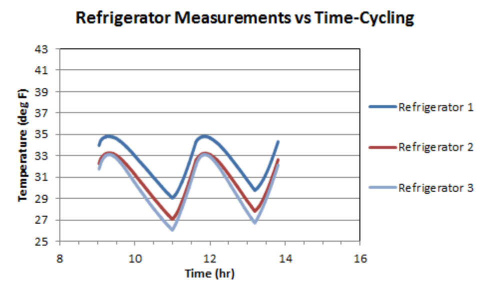



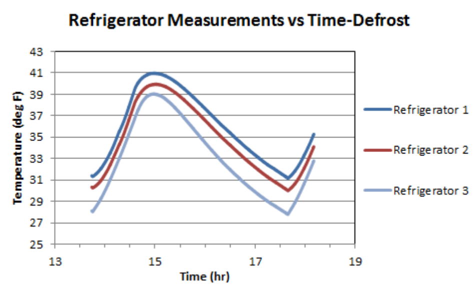



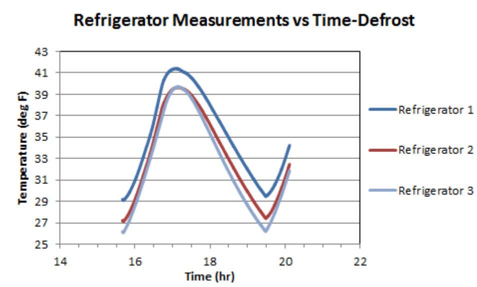
# APPENDIX D: CONTINUED

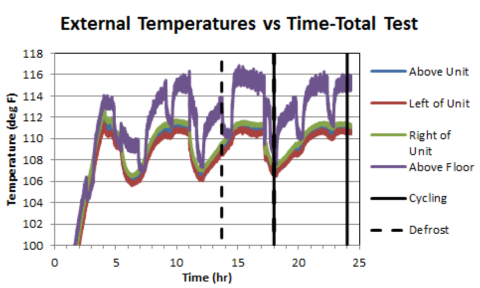
## (110ºF median)

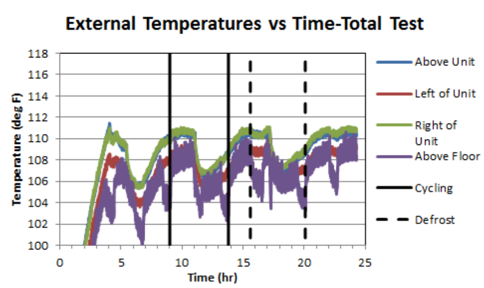


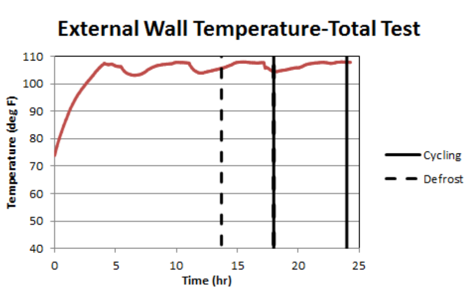



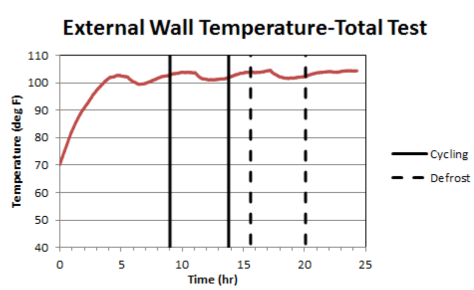



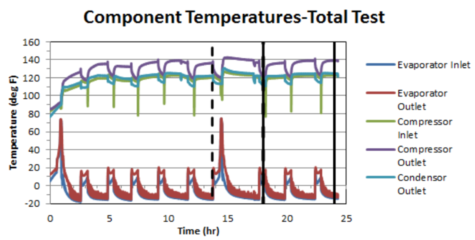



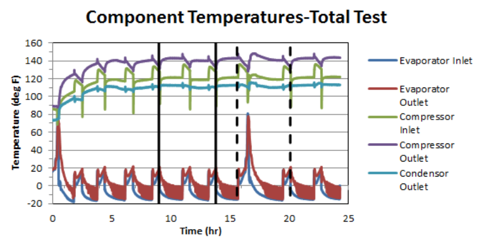



# APPENDIX D: CONTINUED

**(110ºF median)**



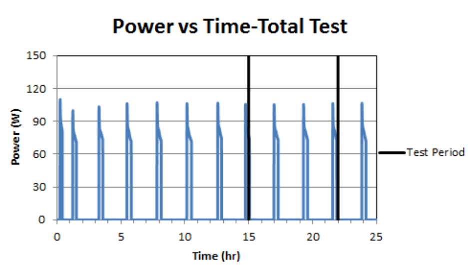



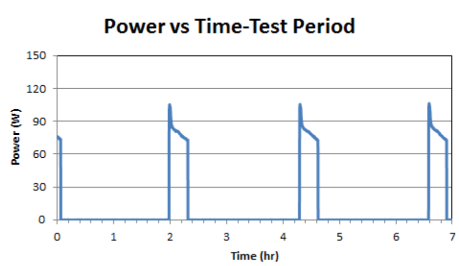
# APPENDIX E: TEMPERATURE AND POWER PLOTS FOR CHEST FREEZER UNITS

## Unconditioned Space Temperature: 40°F (median thermostat)

*Unit A*

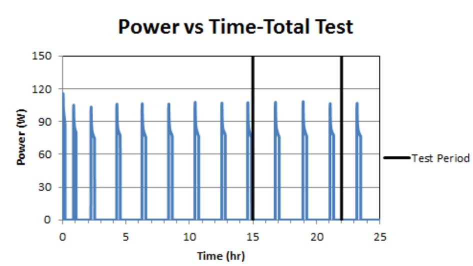
| | | |
|---|---|---|
| EP | 0.085 | kwh |
| T | 420 | min |
| K | 0.7 | |
| ET | 0.203 | kWh/day |
| EY | 74.23 | kWh/yr |
| Cost | $ 8.91 | |

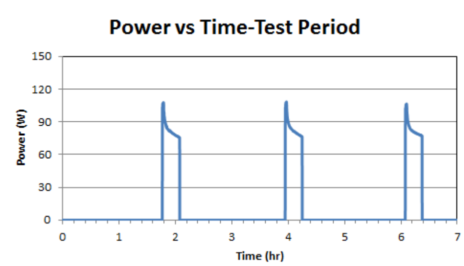



*Unit B*

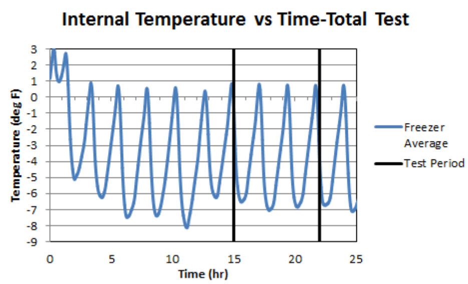
| | | |
|---|---|---|
| EP | 0.076 | kwh |
| T | 420 | min |
| K | 0.7 | |
| ET | 0.182 | kWh/day |
| EY | 66.49 | kWh/yr |
| Cost | $ 7.98 | |

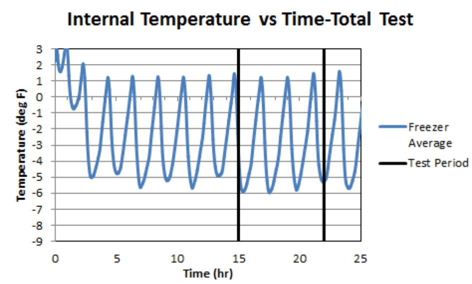


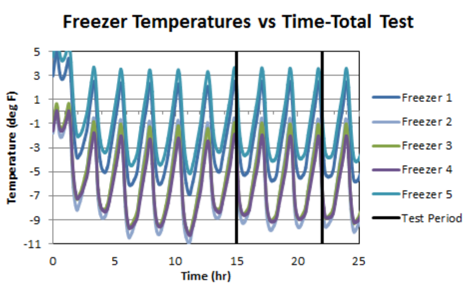



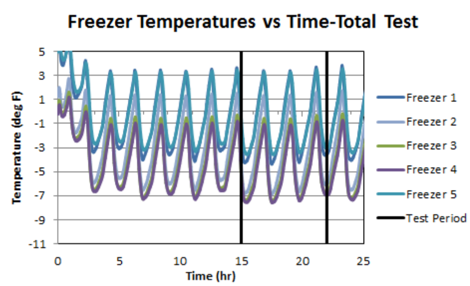
# APPENDIX E: CONTINUED

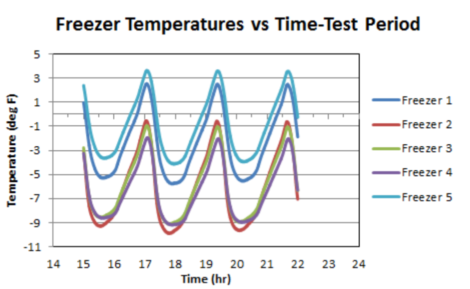
**(40ºF median)**

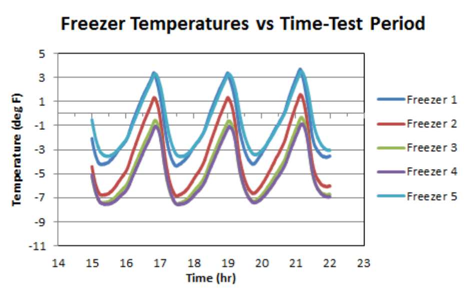


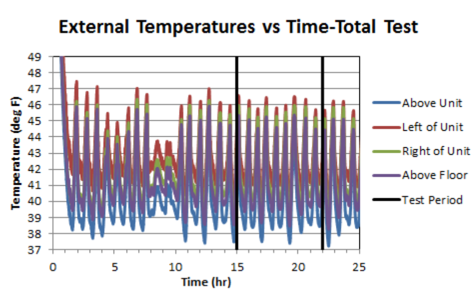



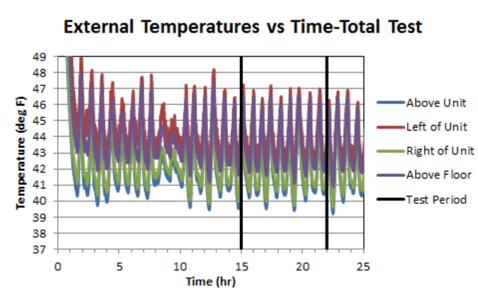



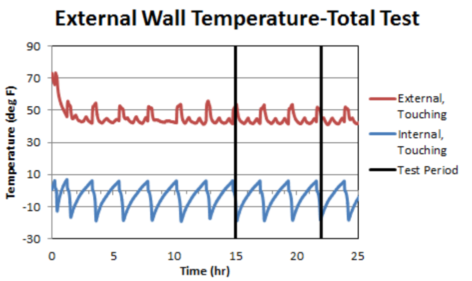



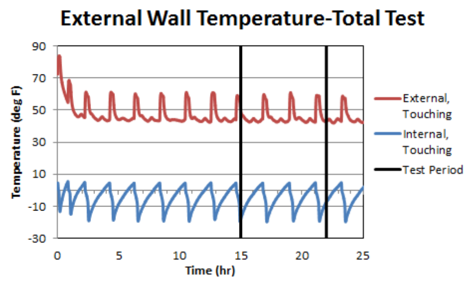



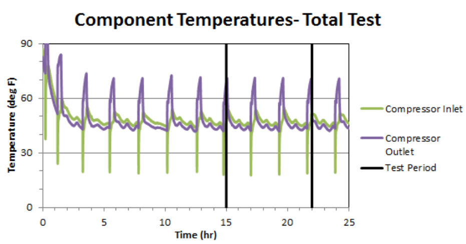



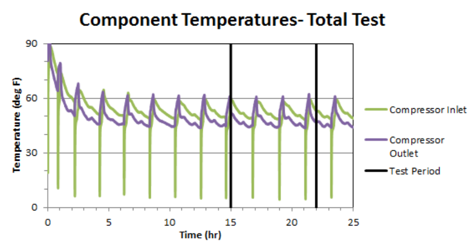
# APPENDIX E: CONTINUED

## (40ºF median)



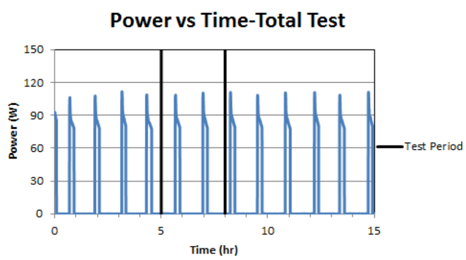



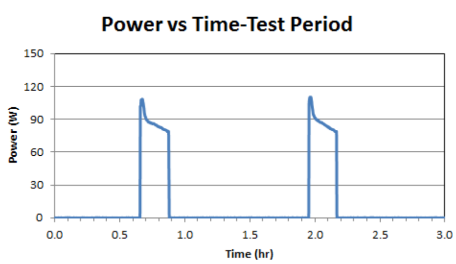
# APPENDIX E: CONTINUED

## Unconditioned Space Temperature: 55ºF (median thermostat)

*Unit A*

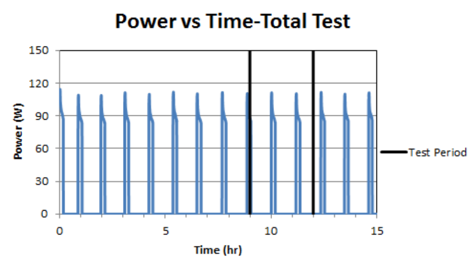
| | | |
|---|---|---|
| EP | 0.038 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.215 | kWh/day |
| EY | 78.34 | kWh/yr |
| Cost | $ 9.40 | |

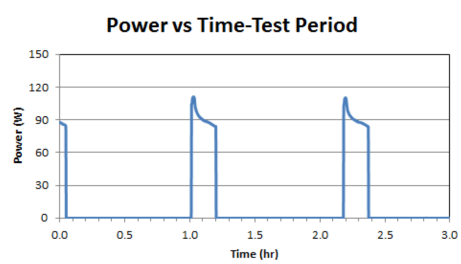



*Unit B*

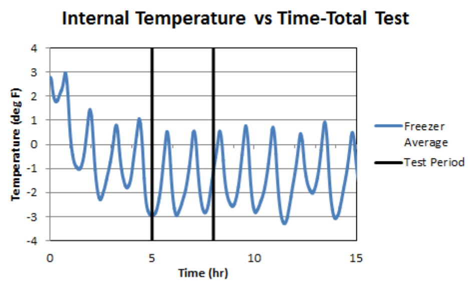
| | | |
|---|---|---|
| EP | 0.039 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.220 | kWh/day |
| EY | 80.48 | kWh/yr |
| Cost | $ 9.66 | |

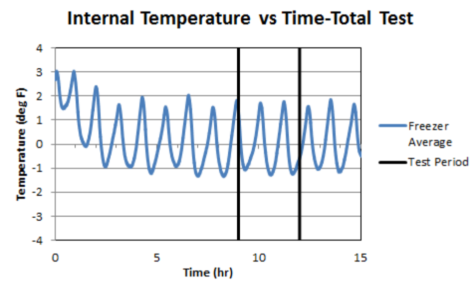


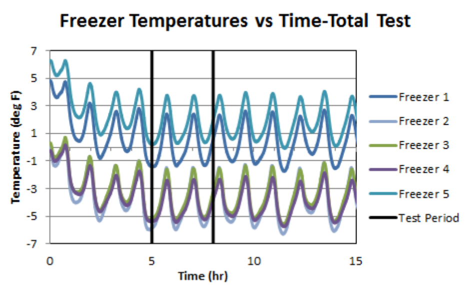



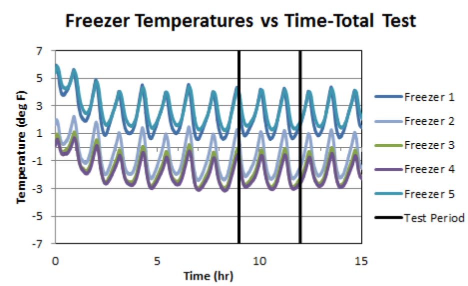
# APPENDIX E: CONTINUED

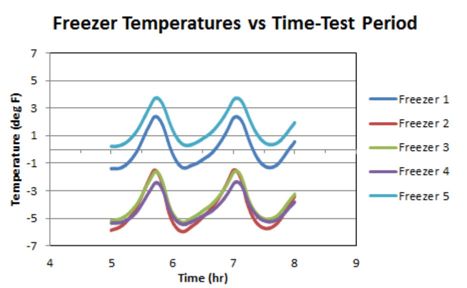
## (55ºF median)

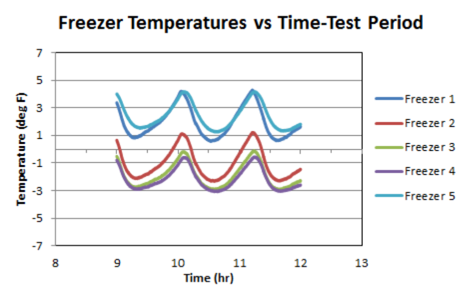


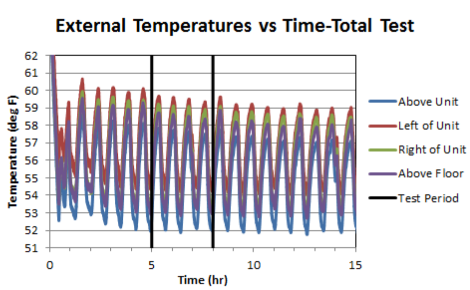



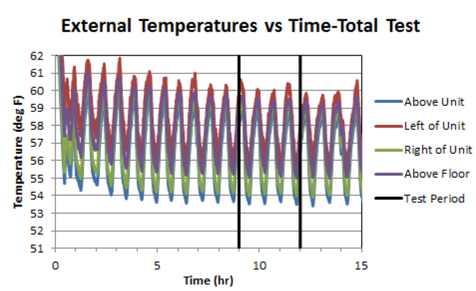



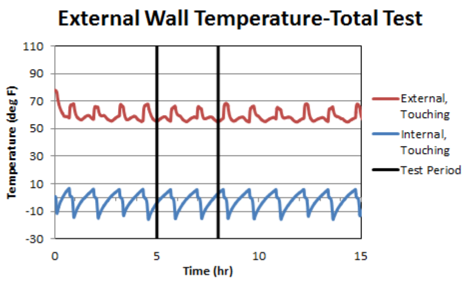



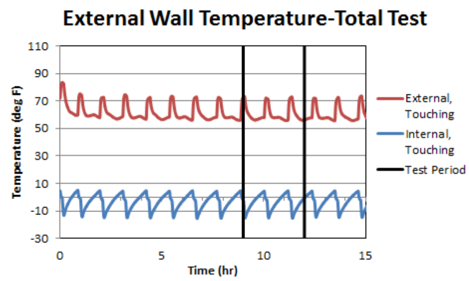



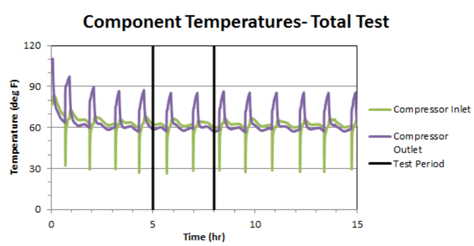



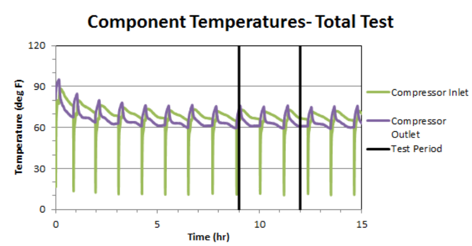
# APPENDIX E: CONTINUED

## (55ºF median)



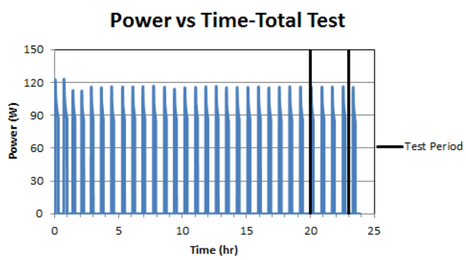



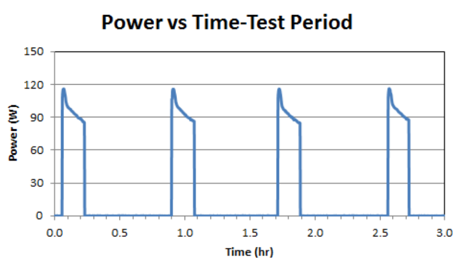



## Unconditioned Space Temperature: 70°F (median thermostat)

*Unit A*

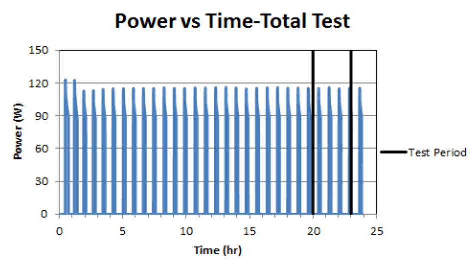
| | | |
|---|---|---|
| EP | 0.066 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.367 | kWh/day |
| EY | 133.95 | kWh/yr |
| Cost | $ 16.07 | |

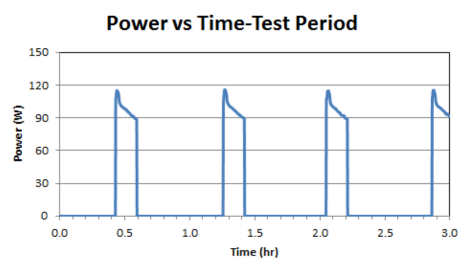


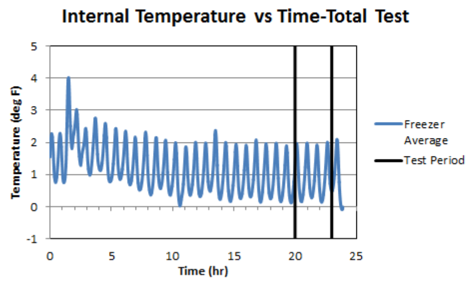

*Unit B*

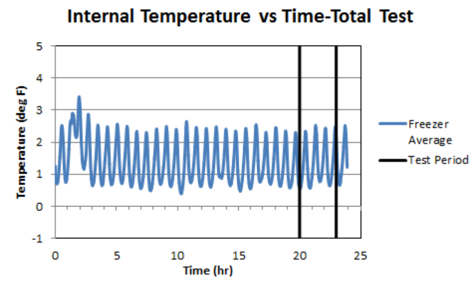
| | | |
|---|---|---|
| EP | 0.062 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.349 | kWh/day |
| EY | 127.38 | kWh/yr |
| Cost | $ 15.29 | |

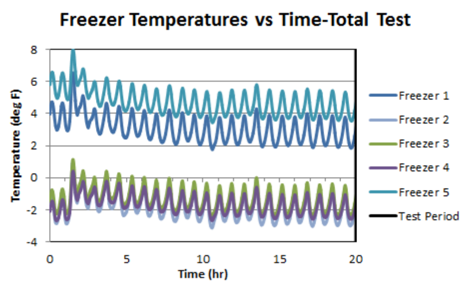


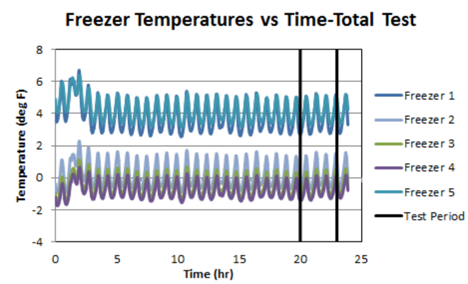



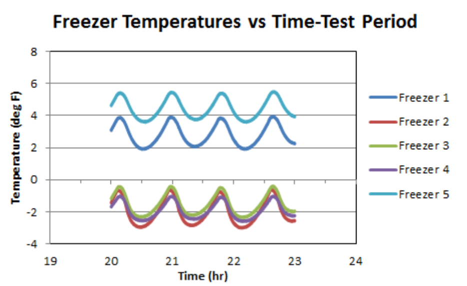
## (70ºF median)

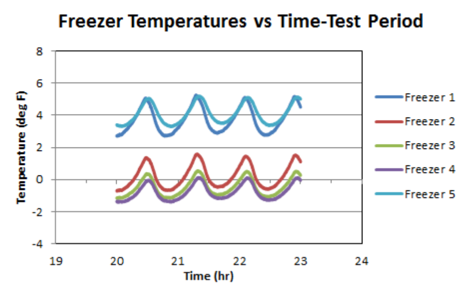

Internal Temperature vs Time-Total Test
Temperature (deg F)
Time (hr)
Freezer Average
Test Period

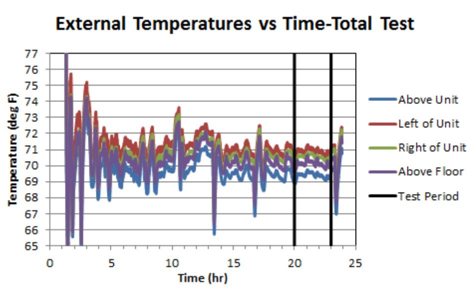

Internal Temperature vs Time-Total Test
Temperature (deg F)
Time (hr)
Freezer Average
Test Period

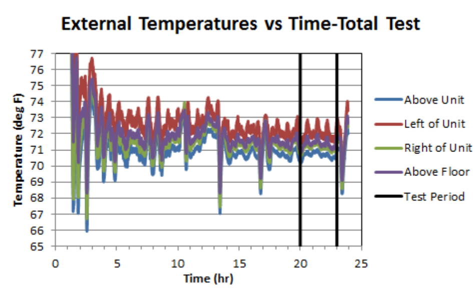

Freezer Temperatures vs Time-Total Test
Temperature (deg F)
Time (hr)
Freezer 1
Freezer 2
Freezer 3
Freezer 4
Freezer 5
Test Period


Freezer Temperatures vs Time-Total Test
Temperature (deg F)
Time (hr)
Freezer 1
Freezer 2
Freezer 3
Freezer 4
Freezer 5
Test Period


Freezer Temperatures vs Time-Test Period
Temperature (deg F)
Time (hr)
Freezer 1
Freezer 2
Freezer 3
Freezer 4
Freezer 5

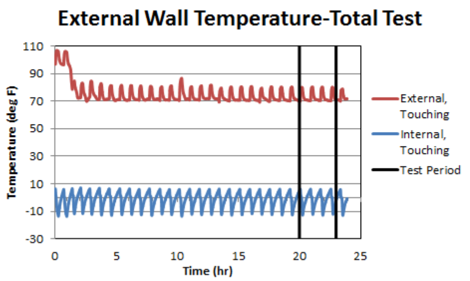

Freezer Temperatures vs Time-Test Period
Temperature (deg F)
Time (hr)
Freezer 1
Freezer 2
Freezer 3
Freezer 4
Freezer 5

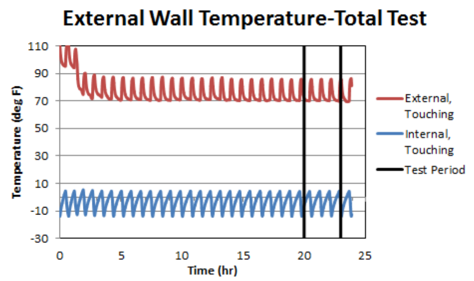

External Temperatures vs Time-Total Test
Temperature (deg F)
Time (hr)
Above Unit
Left of Unit
Right of Unit
Above Floor
Test Period

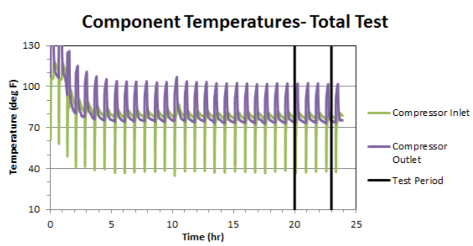

External Temperatures vs Time-Total Test
Temperature (deg F)
Time (hr)
Above Unit
Left of Unit
Right of Unit
Above Floor
Test Period

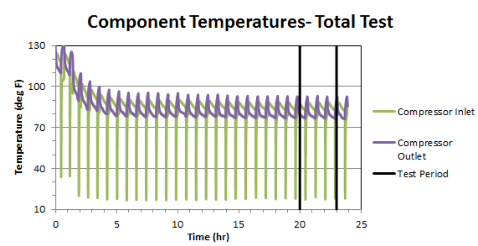
# APPENDIX E: CONTINUED

**(70ºF median)**



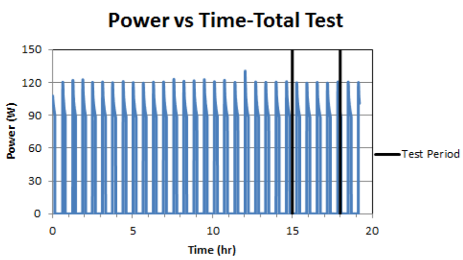



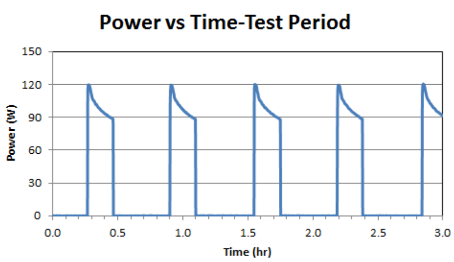



## Unconditioned Space Temperature: 90ºF (median thermostat)

*Unit A*

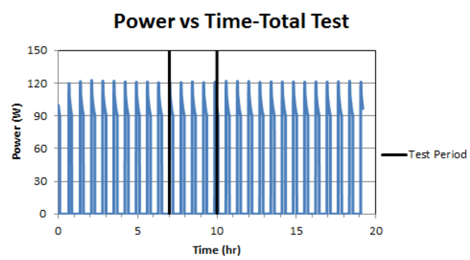
| | | |
|---|---|---|
| EP | 0.095 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.533 | kWh/day |
| EY | 194.46 | kWh/yr |
| Cost | $ 23.34 | |

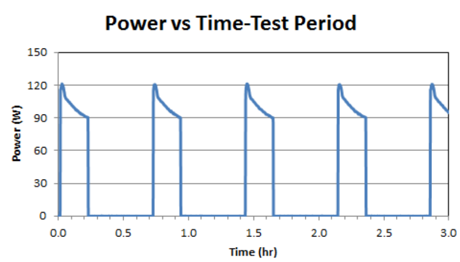



*Unit B*

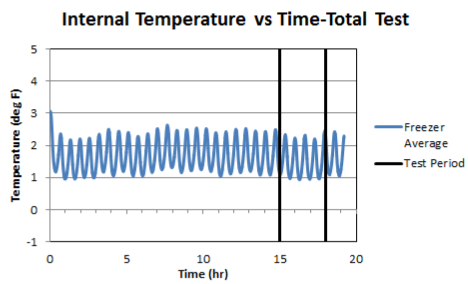
| | | |
|---|---|---|
| EP | 0.101 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.568 | kWh/day |
| EY | 207.44 | kWh/yr |
| Cost | $ 24.89 | |

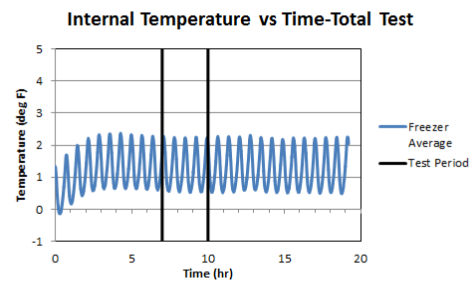


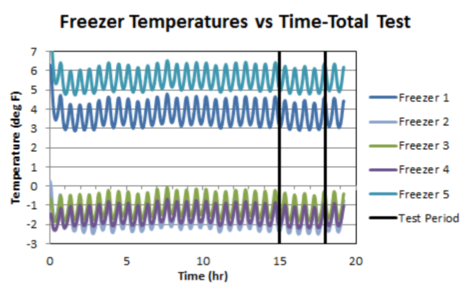



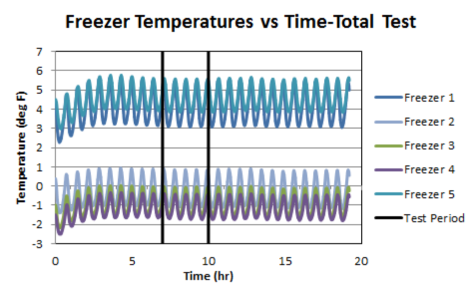
# APPENDIX E: CONTINUED

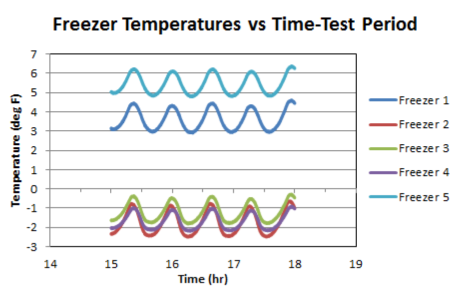
## (90ºF median)

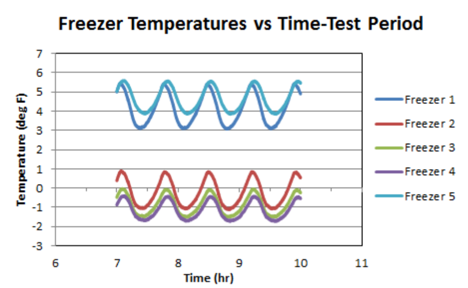


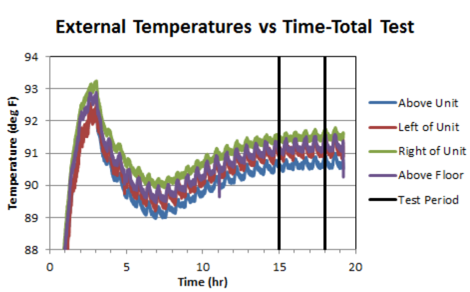



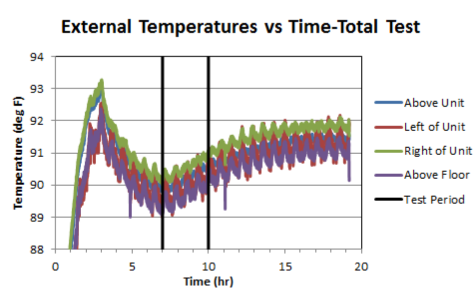



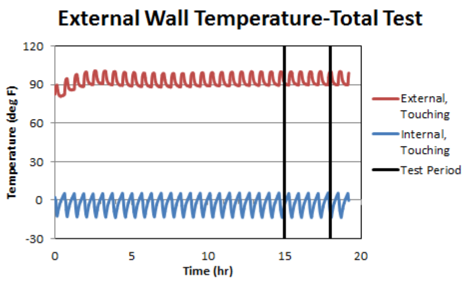



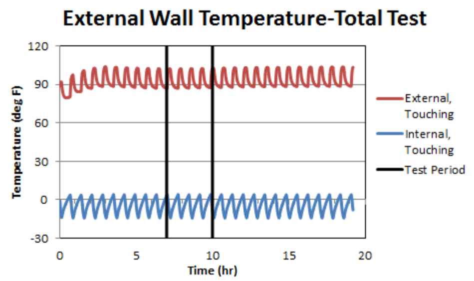



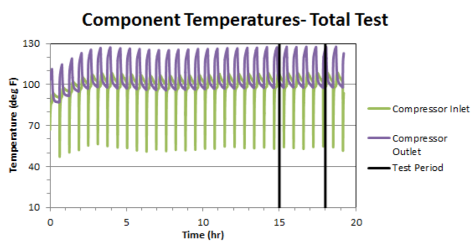



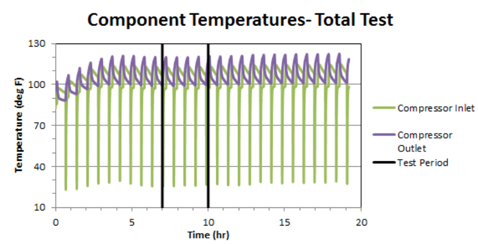
# APPENDIX E: CONTINUED

## (90ºF median)



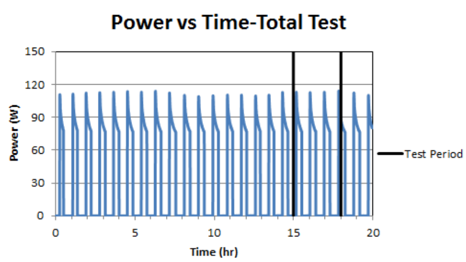



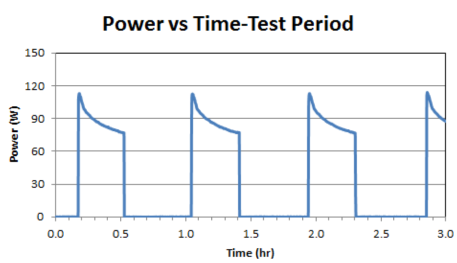
# APPENDIX E: CONTINUED

## Unconditioned Space Temperature: 90ºF (coldest thermostat)

*Unit A*

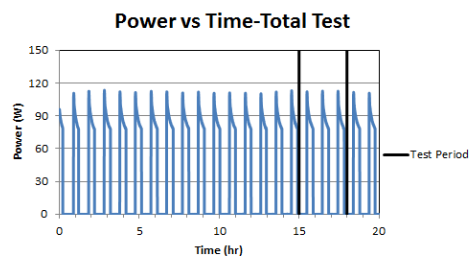
| | | |
|---|---|---|
| EP | 0.109 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.612 | kWh/day |
| EY | 223.31 | kWh/yr |
| Cost | $ 26.80 | |

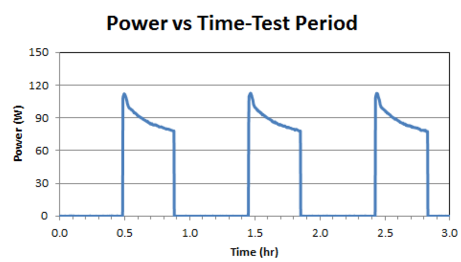



*Unit B*

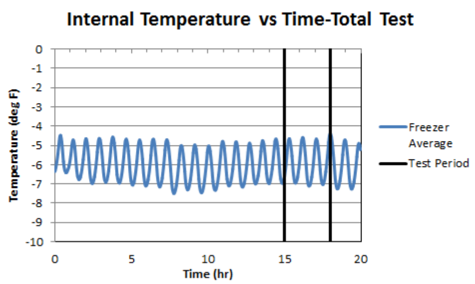
| | | |
|---|---|---|
| EP | 0.106 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.593 | kWh/day |
| EY | 216.59 | kWh/yr |
| Cost | $ 25.99 | |

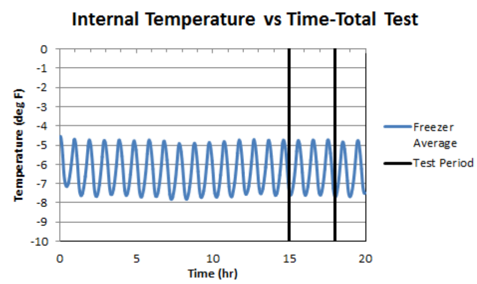


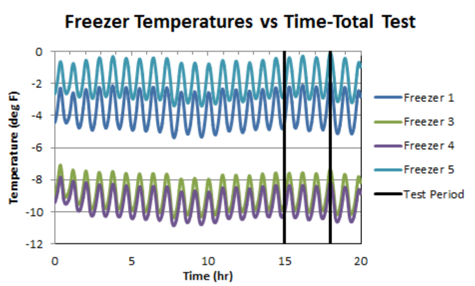



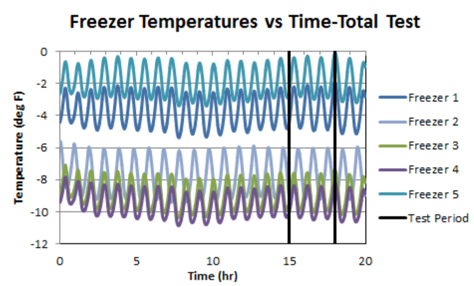
# APPENDIX E: CONTINUED

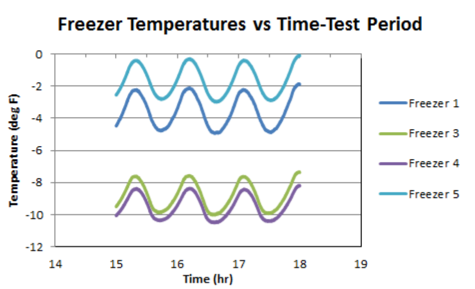
## (90ºF coldest)

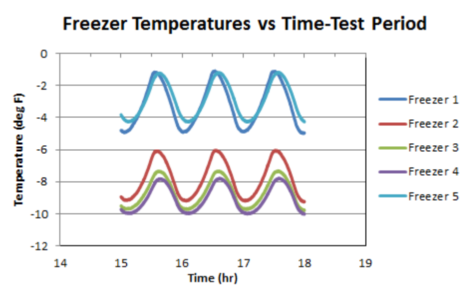


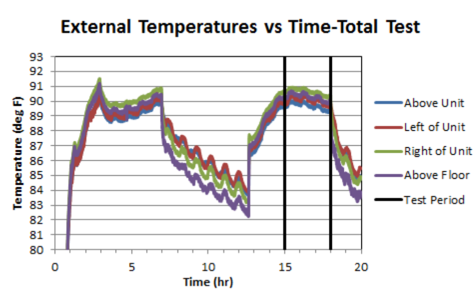



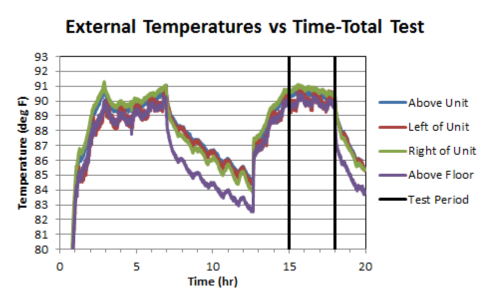



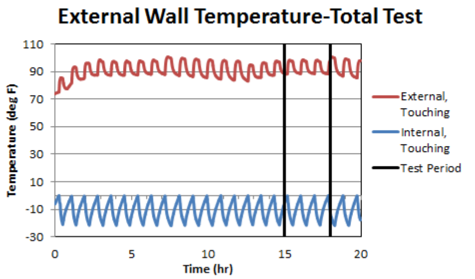



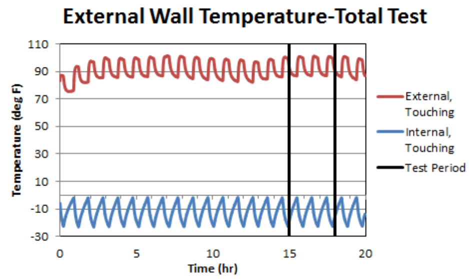



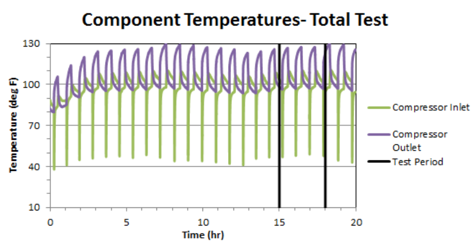



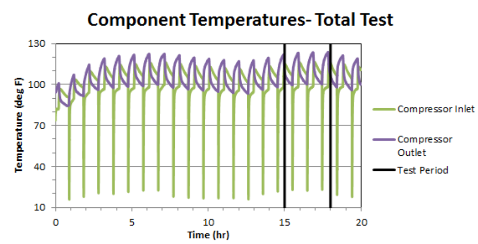
# APPENDIX E: CONTINUED

**(90ºF coldest)**



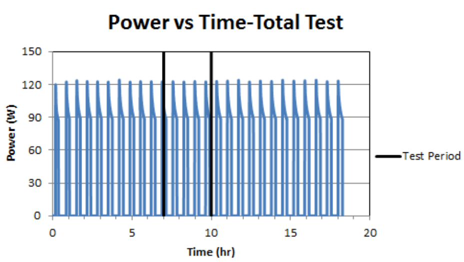



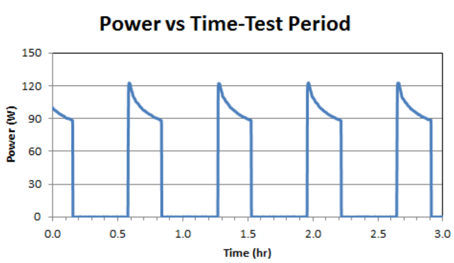



## Unconditioned Space Temperature: 100°F (median thermostat)

*Unit A*

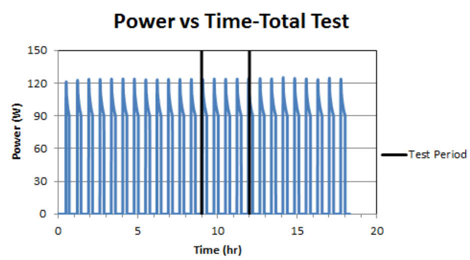
| | | |
|---|---|---|
| EP | 0.118 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.659 | kWh/day |
| EY | 240.60 | kWh/yr |
| Cost | $ 28.87 | |

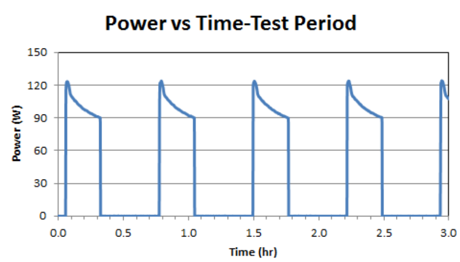



*Unit B*

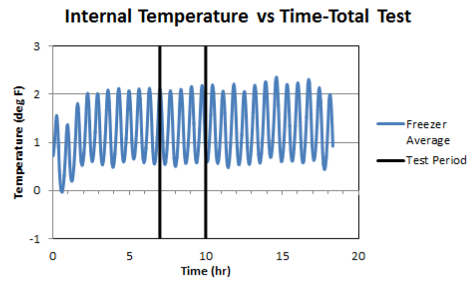
| | | |
|---|---|---|
| EP | 0.117 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.653 | kWh/day |
| EY | 238.18 | kWh/yr |
| Cost | $ 28.58 | |

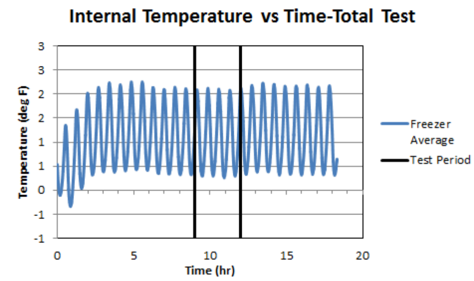


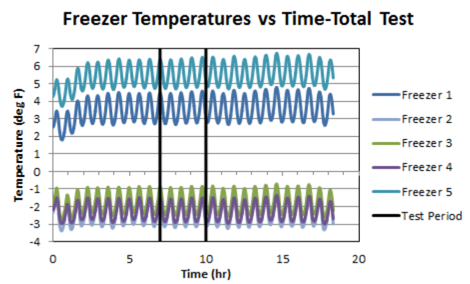



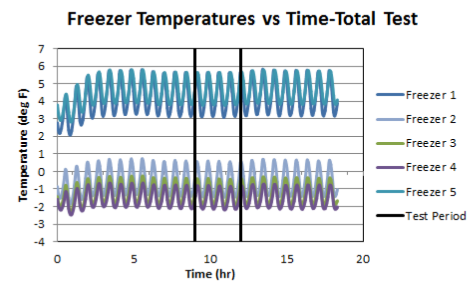
# APPENDIX E: CONTINUED

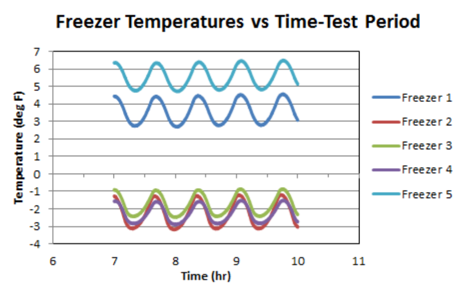
## (100ºF median)

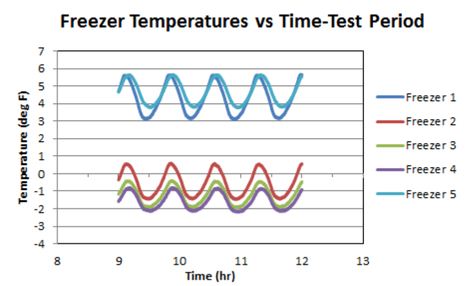


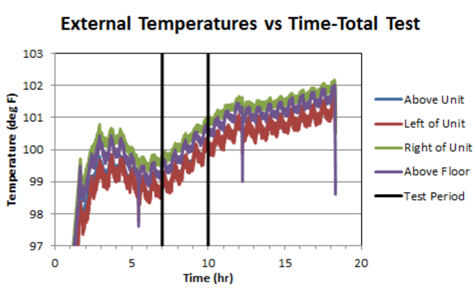



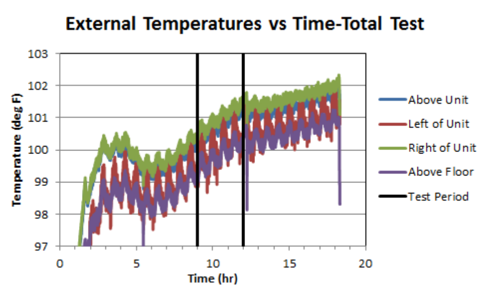



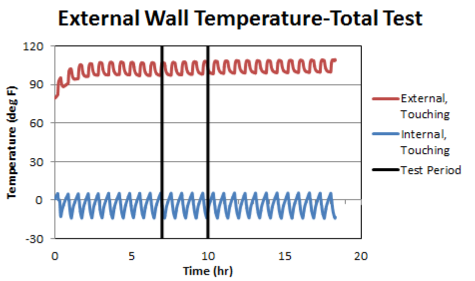



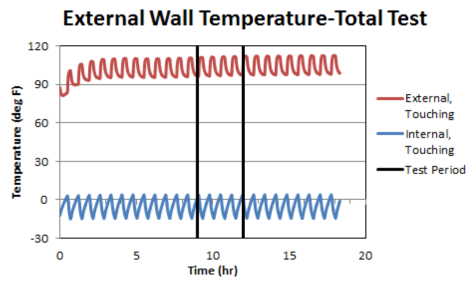



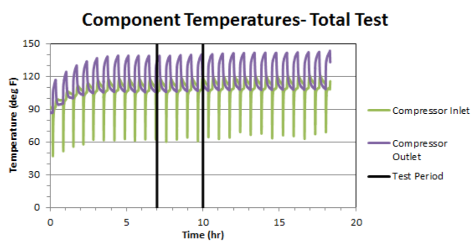



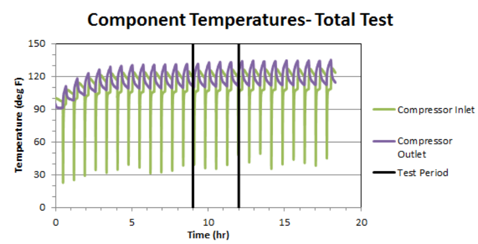
# APPENDIX E: CONTINUED

## (100ºF median)



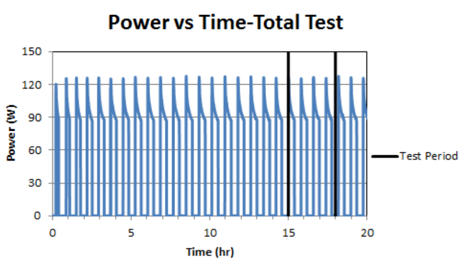



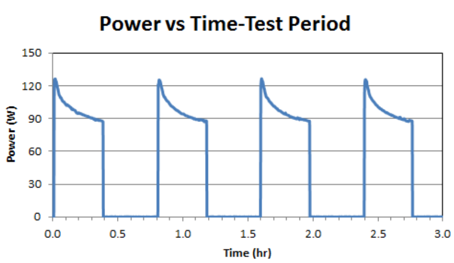
# APPENDIX E: CONTINUED

## Unconditioned Space Temperature: 110°F (median thermostat)

*Unit A*

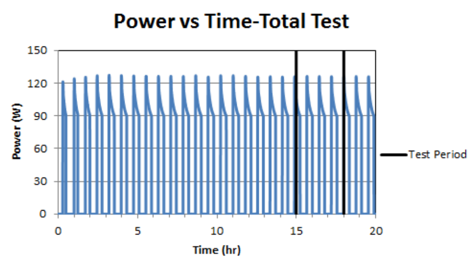
| | | |
|---|---|---|
| EP | 0.147 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.822 | kWh/day |
| EY | 300.04 | kWh/yr |
| Cost | $ 36.00 | |

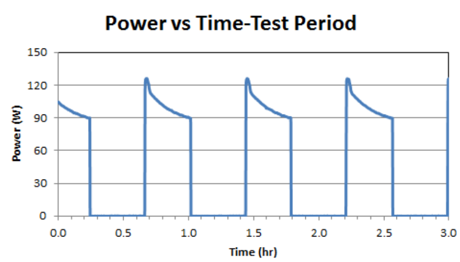



*Unit B*

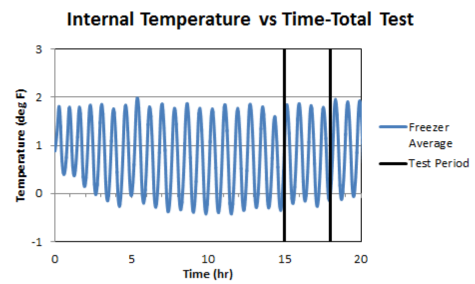
| | | |
|---|---|---|
| EP | 0.132 | kwh |
| T | 180 | min |
| K | 0.7 | |
| ET | 0.737 | kWh/day |
| EY | 268.88 | kWh/yr |
| Cost | $ 32.27 | |

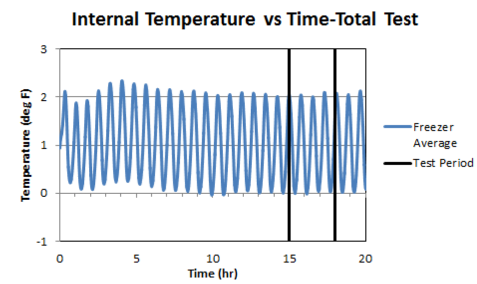


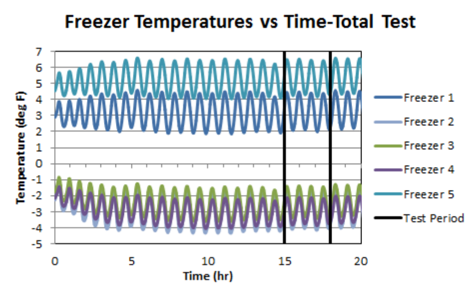



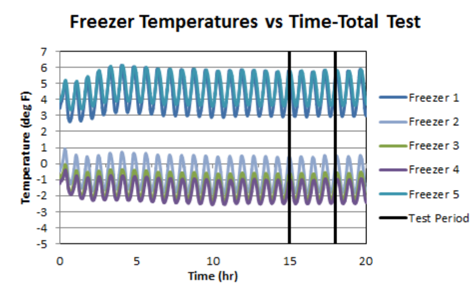
# APPENDIX E: CONTINUED

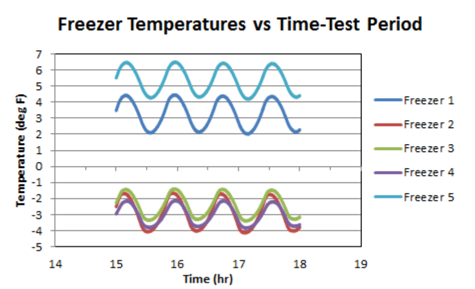
## (110ºF median)

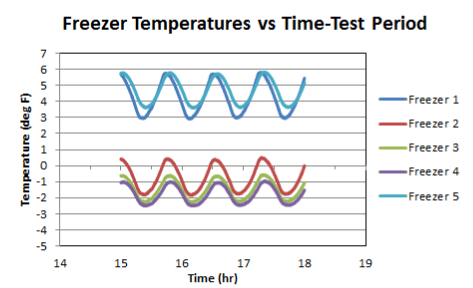


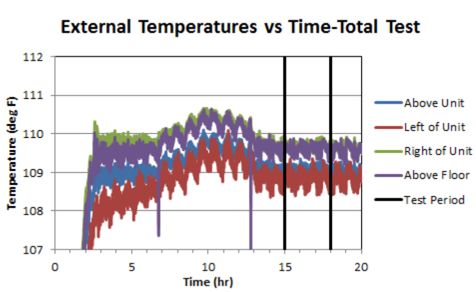



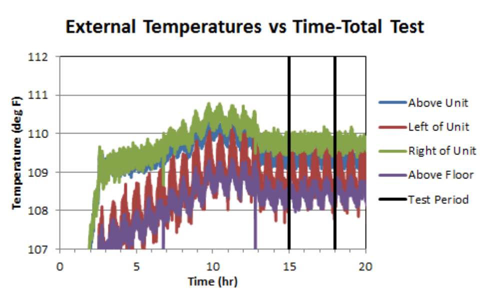



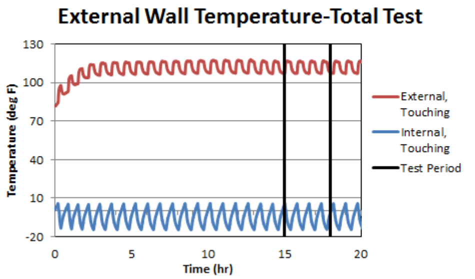



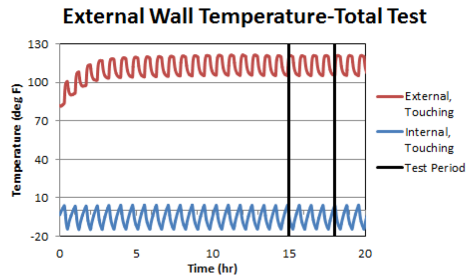



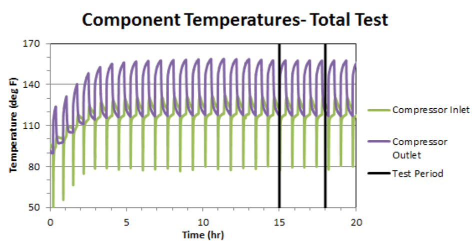



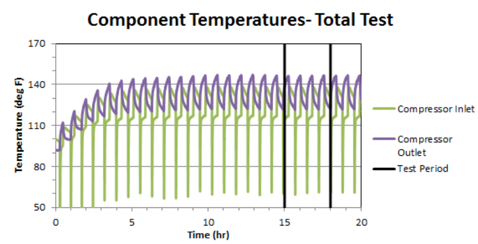
## APPENDIX E: CONTINUED

### (110ºF median)



# APPENDIX F: SAMPLES OF DATA

## Raw Data Sample of Temperature Measurements

## (90ºF, median setting, Standard-size Unit A)

Fridge A
90 Deg F- Median Setting

| | | Freezer 1 | | Freezer 2 | | Freezer 3 | | Fridge 1 | | Fridge 2 | | Fridge 3 | | Ext. Top | | Ext. Left | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | b | M | b | M | b | M | b | M | b | M | b | M | b | M | b |
| | | 1.0051 | -0.1437 | 1.0098 | -0.5617 | 1.0052 | 0.399 | 1.0047 | 0.13 | 0.999 | 0.8211 | 1.0082 | -0.0839 | 1.0287 | -2.2701 | 1.0008 | 0.7685 |
| | | *Meas* | *Corrected* | *Meas* | *Corrected* | *Meas* | *Corrected* | *Meas* | *Corrected* | *Meas* | *Corrected* | *Meas* | *Corrected* | *Meas* | *Corrected* | *Meas* | *Corrected* |
| **Time (s)** | **Time (hr)** | **1** | **1** | **2** | **2** | **3** | **3** | **4** | **4** | **5** | **5** | **6** | **6** | **7** | **7** | **8** | **8** |
| 0 | 0 | 2.527675 | 2.396866 | 6.111096 | 5.609285 | 6.102601 | 6.533335 | 37.47891 | 37.78506 | 37.15119 | 37.93514 | 36.82075 | 37.03878 | 76.77356 | 76.70686 | 76.45076 | 77.28042 |
| 1 | 0.000278 | 2.540704 | 2.409962 | 6.083372 | 5.581289 | 6.124503 | 6.55535 | 37.47933 | 37.78549 | 37.14557 | 37.92953 | 36.85229 | 37.07058 | 76.8143 | 76.74877 | 76.47753 | 77.30721 |
| 2 | 0.000556 | 2.51825 | 2.387393 | 6.090992 | 5.588984 | 6.115581 | 6.546382 | 37.47935 | 37.7855 | 37.15898 | 37.94292 | 36.82984 | 37.04794 | 76.83326 | 76.76827 | 76.47631 | 77.30599 |
| 3 | 0.000833 | 2.511766 | 2.380876 | 6.07247 | 5.57028 | 6.074258 | 6.504844 | 37.46924 | 37.77534 | 37.13245 | 37.91642 | 36.80805 | 37.02598 | 76.85201 | 76.78757 | 76.43331 | 77.26295 |
| 4 | 0.001111 | 2.477907 | 2.346844 | 6.056675 | 5.55433 | 6.076794 | 6.507393 | 37.45658 | 37.76262 | 37.13231 | 37.91628 | 36.8105 | 37.02845 | 76.88481 | 76.8213 | 76.45211 | 77.28178 |
| 5 | 0.001389 | 2.4647 | 2.33357 | 6.069918 | 5.567703 | 6.087802 | 6.518459 | 37.46289 | 37.76896 | 37.16151 | 37.94545 | 36.82071 | 37.03874 | 76.88383 | 76.82029 | 76.46596 | 77.29563 |
| 6 | 0.001667 | 2.477568 | 2.346504 | 6.066174 | 5.563923 | 6.083611 | 6.514246 | 37.48388 | 37.79005 | 37.15012 | 37.93407 | 36.8037 | 37.02159 | 76.89314 | 76.82987 | 76.47939 | 77.30908 |
| 7 | 0.001944 | 2.446405 | 2.315182 | 6.038307 | 5.535782 | 6.062451 | 6.492976 | 37.45136 | 37.75738 | 37.14221 | 37.92617 | 36.79664 | 37.01448 | 76.89218 | 76.82889 | 76.46649 | 77.29617 |
| 8 | 0.002222 | 2.423615 | 2.292275 | 6.021005 | 5.518311 | 6.055433 | 6.485921 | 37.46445 | 37.77053 | 37.13716 | 37.92112 | 36.78381 | 37.00154 | 76.91988 | 76.85738 | 76.47938 | 77.30907 |
| 9 | 0.0025 | 2.403688 | 2.272247 | 6.019518 | 5.516809 | 6.05797 | 6.488471 | 37.4561 | 37.76215 | 37.12061 | 37.90459 | 36.78238 | 37.00009 | 76.95391 | 76.89239 | 76.49778 | 77.32748 |
| 10 | 0.002778 | 2.409011 | 2.277597 | 6.032413 | 5.529831 | 6.056557 | 6.487051 | 37.46683 | 37.77292 | 37.13306 | 37.91703 | 36.80564 | 37.02354 | 76.94561 | 76.88385 | 76.55619 | 77.38593 |
| 11 | 0.003056 | 2.375573 | 2.243988 | 5.988871 | 5.485862 | 6.011228 | 6.441486 | 37.43256 | 37.73849 | 37.12296 | 37.90694 | 36.76529 | 36.98287 | 76.91665 | 76.85405 | 76.56838 | 77.39814 |
| 12 | 0.003333 | 2.380727 | 2.249169 | 6.001598 | 5.498714 | 6.037816 | 6.468213 | 37.44182 | 37.7478 | 37.13137 | 37.91534 | 36.78883 | 37.00659 | 76.96211 | 76.90082 | 76.60028 | 77.43006 |
| 13 | 0.003611 | 2.359025 | 2.227356 | 5.992533 | 5.48956 | 6.032776 | 6.463146 | 37.46545 | 37.77154 | 37.13643 | 37.9204 | 36.78179 | 36.9995 | 76.94512 | 76.88335 | 76.59687 | 77.42665 |
| 14 | 0.003889 | 2.361293 | 2.229636 | 5.987635 | 5.484614 | 6.048893 | 6.479347 | 37.43352 | 37.73946 | 37.14466 | 37.92862 | 36.78657 | 37.00432 | 76.92045 | 76.85796 | 76.59524 | 77.42502 |
| 15 | 0.004167 | 2.352959 | 2.221259 | 5.982924 | 5.479857 | 6.02272 | 6.453038 | 37.45272 | 37.75875 | 37.12975 | 37.91372 | 36.76689 | 36.98448 | 76.88113 | 76.81752 | 76.62178 | 77.45158 |
| 16 | 0.004444 | 2.304801 | 2.172855 | 5.969458 | 5.466259 | 5.998971 | 6.429166 | 37.4531 | 37.75913 | 37.1176 | 37.90159 | 36.76641 | 36.984 | 76.84074 | 76.77597 | 76.61721 | 77.447 |
| 17 | 0.004722 | 2.32278 | 2.190926 | 5.972136 | 5.468963 | 6.015062 | 6.44534 | 37.43928 | 37.74525 | 37.12192 | 37.9059 | 36.78282 | 37.00054 | 76.86379 | 76.79968 | 76.64108 | 77.47089 |
| 18 | 0.005 | 2.294046 | 2.162046 | 5.941322 | 5.437847 | 5.995877 | 6.426056 | 37.41946 | 37.72533 | 37.12239 | 37.90637 | 36.77206 | 36.98969 | 76.91733 | 76.85476 | 76.63453 | 77.46434 |
| 19 | 0.005278 | 2.265574 | 2.133428 | 5.906743 | 5.402929 | 5.965325 | 6.395345 | 37.41976 | 37.72563 | 37.09547 | 37.87948 | 36.75378 | 36.97126 | 76.9209 | 76.85843 | 76.6204 | 77.4502 |
| 20 | 0.005556 | 2.242377 | 2.110113 | 5.91766 | 5.413953 | 5.968192 | 6.398227 | 37.39619 | 37.70195 | 37.09263 | 37.87663 | 36.76 | 36.97754 | 76.95894 | 76.89756 | 76.62469 | 77.45449 |
| 21 | 0.005833 | 2.268782 | 2.136653 | 5.939002 | 5.435504 | 5.98506 | 6.415182 | 37.43363 | 37.73957 | 37.1141 | 37.89809 | 36.75038 | 36.96783 | 76.97446 | 76.91353 | 76.63981 | 77.46962 |
| 22 | 0.006111 | 2.237634 | 2.105346 | 5.909813 | 5.406029 | 5.964817 | 6.394834 | 37.42315 | 37.72904 | 37.1006 | 37.8846 | 36.75069 | 36.96815 | 76.97188 | 76.91088 | 76.63105 | 77.46085 |
| 23 | 0.006389 | 2.217396 | 2.085005 | 5.906233 | 5.402414 | 5.953188 | 6.383145 | 37.42574 | 37.73164 | 37.09584 | 37.87985 | 36.76106 | 36.9786 | 76.97106 | 76.91003 | 76.62076 | 77.45055 |
| 24 | 0.006667 | 2.200872 | 2.068396 | 5.901427 | 5.397561 | 5.946147 | 6.376067 | 37.41031 | 37.71613 | 37.10027 | 37.88427 | 36.74 | 36.95737 | 76.99462 | 76.93426 | 76.63568 | 77.46549 |
| 25 | 0.006944 | 2.197341 | 2.064847 | 5.901046 | 5.397176 | 5.942635 | 6.372537 | 37.41944 | 37.72531 | 37.08738 | 37.87139 | 36.74525 | 36.96266 | 77.04941 | 76.99063 | 76.6098 | 77.43959 |
| 26 | 0.007222 | 2.160269 | 2.027586 | 5.877149 | 5.373045 | 5.941994 | 6.371892 | 37.39896 | 37.70473 | 37.10058 | 37.88458 | 36.73426 | 36.95158 | 77.01343 | 76.95362 | 76.61086 | 77.44065 |
| 27 | 0.0075 | 2.145236 | 2.012477 | 5.859515 | 5.355238 | 5.917207 | 6.346976 | 37.40957 | 37.71539 | 37.09349 | 37.87749 | 36.71938 | 36.93658 | 77.02396 | 76.96444 | 76.60368 | 77.43347 |
| 28 | 0.007778 | 2.138744 | 2.005952 | 5.862004 | 5.357752 | 5.898229 | 6.3279 | 37.39081 | 37.69655 | 37.07041 | 37.85444 | 36.71228 | 36.92942 | 77.03777 | 76.97865 | 76.63727 | 77.46708 |
| 29 | 0.008056 | 2.135005 | 2.002194 | 5.860522 | 5.356255 | 5.914188 | 6.343942 | 37.40233 | 37.70812 | 37.07459 | 37.85861 | 36.71517 | 36.93233 | 77.0755 | 77.01746 | 76.61573 | 77.44552 |
| 30 | 0.008333 | 2.117597 | 1.984697 | 5.844105 | 5.339677 | 5.896431 | 6.326092 | 37.38217 | 37.68787 | 37.07947 | 37.86349 | 36.71141 | 36.92854 | 77.08714 | 77.02944 | 76.59938 | 77.42916 |
| 31 | 0.008611 | 2.085615 | 1.952552 | 5.836453 | 5.33195 | 5.896829 | 6.326493 | 37.39076 | 37.69649 | 37.08806 | 37.87207 | 36.73729 | 36.95463 | 77.10109 | 77.04379 | 76.62033 | 77.45013 |
| 32 | 0.008889 | 2.071194 | 1.938057 | 5.837319 | 5.332825 | 5.886068 | 6.315676 | 37.39591 | 37.70167 | 37.07853 | 37.86255 | 36.70442 | 36.9215 | 77.08954 | 77.03191 | 76.60919 | 77.43898 |

# APPENDIX F: CONTINUED

## Raw Data Sample of Power Measurements

## (90ºF, median setting, Standard-size Unit A)

| Date | Time | Time (s) | Time (min) | Time (hr) | Voltage (V) | Current (A) | Power Factor | PF (negated) | Power (W) | Power (kW) | kWh |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12/9/2014 | 3:29:49 PM | 0 | 0.000 | 0.000 | 115.7 | 0.941 | -0.958 | 0.958 | 104.301 | 0.1043 | 0.0003 |
| 12/9/2014 | 3:29:59 PM | 10 | 0.167 | 0.003 | 115.7 | 0.937 | -0.958 | 0.958 | 103.85764 | 0.1039 | 0.0003 |
| 12/9/2014 | 3:30:09 PM | 20 | 0.333 | 0.006 | 115.8 | 0.938 | -0.957 | 0.957 | 103.94972 | 0.1039 | 0.0003 |
| 12/9/2014 | 3:30:19 PM | 30 | 0.500 | 0.008 | 115.7 | 0.94 | -0.957 | 0.957 | 104.08141 | 0.1041 | 0.0003 |
| 12/9/2014 | 3:30:29 PM | 40 | 0.667 | 0.011 | 115.8 | 0.938 | -0.956 | 0.956 | 103.8411 | 0.1038 | 0.0003 |
| 12/9/2014 | 3:30:39 PM | 50 | 0.833 | 0.014 | 115.7 | 0.937 | -0.957 | 0.957 | 103.74923 | 0.1037 | 0.0003 |
| 12/9/2014 | 3:30:49 PM | 60 | 1.000 | 0.017 | 115.9 | 0.934 | -0.955 | 0.955 | 103.37932 | 0.1034 | 0.0003 |
| 12/9/2014 | 3:30:59 PM | 70 | 1.167 | 0.019 | 115.8 | 0.936 | -0.957 | 0.957 | 103.72808 | 0.1037 | 0.0003 |
| 12/9/2014 | 3:31:09 PM | 80 | 1.333 | 0.022 | 115.7 | 0.934 | -0.957 | 0.957 | 103.41706 | 0.1034 | 0.0003 |
| 12/9/2014 | 3:31:19 PM | 90 | 1.500 | 0.025 | 115.8 | 0.936 | -0.956 | 0.956 | 103.61969 | 0.1036 | 0.0003 |
| 12/9/2014 | 3:31:29 PM | 100 | 1.667 | 0.028 | 115.8 | 0.934 | -0.956 | 0.956 | 103.39828 | 0.1034 | 0.0003 |
| 12/9/2014 | 3:31:39 PM | 110 | 1.833 | 0.031 | 115.8 | 0.933 | -0.957 | 0.957 | 103.39562 | 0.1034 | 0.0003 |
| 12/9/2014 | 3:31:49 PM | 120 | 2.000 | 0.033 | 115.8 | 0.931 | -0.955 | 0.955 | 102.95836 | 0.1030 | 0.0003 |
| 12/9/2014 | 3:31:59 PM | 130 | 2.167 | 0.036 | 115.7 | 0.931 | -0.955 | 0.955 | 102.86945 | 0.1029 | 0.0003 |
| 12/9/2014 | 3:32:09 PM | 140 | 2.333 | 0.039 | 115.8 | 0.934 | -0.955 | 0.955 | 103.29013 | 0.1033 | 0.0003 |
| 12/9/2014 | 3:32:19 PM | 150 | 2.500 | 0.042 | 115.7 | 0.935 | -0.956 | 0.956 | 103.4196 | 0.1034 | 0.0003 |
| 12/9/2014 | 3:32:29 PM | 160 | 2.667 | 0.044 | 115.8 | 0.934 | -0.956 | 0.956 | 103.39828 | 0.1034 | 0.0003 |
| 12/9/2014 | 3:32:39 PM | 170 | 2.833 | 0.047 | 115.8 | 0.93 | -0.955 | 0.955 | 102.84777 | 0.1028 | 0.0003 |
| 12/9/2014 | 3:32:49 PM | 180 | 3.000 | 0.050 | 115.8 | 0.931 | -0.956 | 0.956 | 103.06617 | 0.1031 | 0.0003 |
| 12/9/2014 | 3:32:59 PM | 190 | 3.167 | 0.053 | 115.6 | 0.931 | -0.955 | 0.955 | 102.78054 | 0.1028 | 0.0003 |
| 12/9/2014 | 3:33:09 PM | 200 | 3.333 | 0.056 | 115.7 | 0.931 | -0.954 | 0.954 | 102.76173 | 0.1028 | 0.0003 |
| 12/9/2014 | 3:33:20 PM | 210 | 3.500 | 0.058 | 115.7 | 0.928 | -0.955 | 0.955 | 102.53797 | 0.1025 | 0.0003 |
| 12/9/2014 | 3:33:29 PM | 220 | 3.667 | 0.061 | 115.7 | 0.925 | -0.954 | 0.954 | 102.09947 | 0.1021 | 0.0003 |
| 12/9/2014 | 3:33:39 PM | 230 | 3.833 | 0.064 | 115.8 | 0.928 | -0.956 | 0.956 | 102.73405 | 0.1027 | 0.0003 |
| 12/9/2014 | 3:33:49 PM | 240 | 4.000 | 0.067 | 115.7 | 0.933 | -0.955 | 0.955 | 103.09044 | 0.1031 | 0.0003 |
| 12/9/2014 | 3:33:59 PM | 250 | 4.167 | 0.069 | 115.7 | 0.933 | -0.955 | 0.955 | 103.09044 | 0.1031 | 0.0003 |
| 12/9/2014 | 3:34:09 PM | 260 | 4.333 | 0.072 | 115.7 | 0.933 | -0.956 | 0.956 | 103.19838 | 0.1032 | 0.0003 |
| 12/9/2014 | 3:34:19 PM | 270 | 4.500 | 0.075 | 115.7 | 0.926 | -0.955 | 0.955 | 102.31698 | 0.1023 | 0.0003 |
| 12/9/2014 | 3:34:29 PM | 280 | 4.667 | 0.078 | 115.9 | 0.928 | -0.954 | 0.954 | 102.60766 | 0.1026 | 0.0003 |
| 12/9/2014 | 3:34:39 PM | 290 | 4.833 | 0.081 | 115.8 | 0.928 | -0.955 | 0.955 | 102.62659 | 0.1026 | 0.0003 |