Air-Conditioning, Heating and Refrigeration Technology Institute

Final Report

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PERFORMANCE STANDARDS FOR WALK-IN REFRIGERATOR AND FREEZER SYSTEMS

Final Report

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Research Objectives and Approach

The objective of this project was to substantiate and provide support for AHRI Standard 1250/1251, 'Standard for Performance Rating of Walk-In Coolers and Freezers' (AHRI 2009b, 2009c). This objective was achieved by investigating walk-in cooler and freezer refrigeration load profiles and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit. This investigation included the following tasks:

- Literature Review
- Analysis of Model Load Profiles
- Analysis of Monitored Data from Field Sites
- Review and Selection of Modeling Tools
- Validation of *eQuest* Model
- *eQuest* Simulations Of Walk-In Cooler And Freezer Performance
- Analysis of Simulation Results
- Conclusions

Summary Of Findings

In summary, the most important findings of this project include the following:

- The AWEF generally increases with increasing compressor run time and with decreasing average ambient temperature. However, the behavior of a walk-in system is further complicated because a reduced average ambient temperature usually results in a reduced compressor run time. So these two general trends tend to compete against each other and the combined effect on the AWEF of a walk-in refrigeration system depends upon the walk-in refrigeration system's operating characteristics.

- In general, the AHRI load profile agrees well with load profiles reported by other researchers. However, a few discrepancies exist in the AHRI load profile, including less door area for large walk-in coolers/freezers, absence of crack infiltration, and higher product loading for small walk-ins.

- The small AHRI cooler load correlates well with measured data from small in-service walk-in coolers, while there is less agreement between the large AHRI cooler and measured data for large in-service coolers. The loads for the AHRI small and large freezers are considerably less than the measured data from in-service walk-in freezers.

- Comparison of simulated climate zone AWEF's versus simulated AHRI 1250/1251 method-of-test AWEF's for walk-in freezers shows very good agreement. However, significant differences exist between the simulated climate zone AWEF's and the simulated AHRI 1250/1251 method-of-test AWEF's for walk-in coolers.

Recommendations

Based upon the results of this project, the research team makes the following recommendations:

1. The research team recommends that an additional research project be initiated that would focus on monitoring walk-ins located in all seven climate zones that make up the continental United States.

2. The research team recommends that the calculation procedures of AHRI 1250/1251 be reviewed, especially the AHRI 1250/1251 Rating Equations for coolers and, in particular, the product loading for the coolers specified in the underlying AHRI Load Spreadsheet (2009a).

3 . The research team recommends that an additional research project be initiated that would focus on determining and verifying a more balanced refrigeration load profile for walk-ins, especially for coolers.

4 . The research team recommends that an additional research project be initiated that would focus on developing *eQuest* models of the small walk-in cooler/freezer (64 ft^2 plan area) and the large walk-in cooler/freezer (2500 ft^2 plan area) as they are described in the AHRI Load Spreadsheet (2009a) with the appropriate refrigeration load profiles as also specified in the AHRI Load Spreadsheet (2009a), thereby providing a one-to-one comparison between the AHRI Method of Test and Kansas City weather data.

5 . The research team recommends that additional work be done to determine the causes of the differences between the AHRI 1250 results and the climate zone results for AWEF and compressor runtime.

INTRODUCTION

Research Objectives and Approach

The objective of this project was to substantiate and provide support for AHRI Standard 1250/1251, 'Standard for Performance Rating of Walk-In Coolers and Freezers' (AHRI 2009b, 2009c). This objective was achieved by investigating walk-in cooler and freezer refrigeration load profiles and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit. This investigation included the following tasks:

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Motivation

Walk-in coolers (refrigerators) and freezers are medium temperature and low temperature refrigerated spaces that can range in size from less than 50 square feet up to 3000 square feet, with ceiling heights from 8 to 30 feet (CEC 2007; U.S. Congress 2007; CEC 2008). Most commercial facilities that process, supply, sell or prepare perishable food items require a walk-in. Walk-ins are usually either low or medium temperature, but sometimes, they may combine both, with the low temperature space accessible from the medium temperature space. Smaller walk-ins usually have one access door, but may have reach-in doors for easy access to the refrigerated products.

Walk-ins are constructed using 3.5", 4" or 5.5" thick insulated panels. They have the basic components of a refrigeration system: evaporator, compressor, condenser and expansion device. Most walk-ins have dedicated refrigeration systems except when a central refrigeration system is used, such as in a supermarket. The evaporator is located inside the walk-in box and consists of a heat exchanger and fans. The compressor and condenser can be located on top or on the side of the walk-in, or the compressor can be located near the walk-in and the condenser remotely located, or both the compressor and condenser can be remotely located.

A walk-in may be purchased as a complete package from a manufacturer and constructed on-site or prefabricated on skids and delivered to the site. Walk-ins may also be constructed from individual components selected by a contractor. Walk-ins may be placed inside or outside an existing building.

In the mid 1990s, Westphalen et al. (1996) reported that walk-ins in the United States used 180 trillion BTUs per year, with a potential for energy savings of up to 58 trillion BTUs per year. Numerous research projects have studied the effects that various components, such as high-efficiency lighting, automatic door closers, high efficiency glazing systems, electronically commutated fan motors, and increased R-factors for insulated panels, can have on the energy usage of walk-ins. However, to date, no research has been done on the annual energy efficiency of a commercial walk-in as a system, including the effects of control systems, construction details and refrigeration system design.

There is considerable potential for energy savings through the use of high efficiency walk-in cooler/freezer refrigeration systems. The acceptance and use of a performance based standard for walk-in coolers and freezers will provide the most effective market system to achieve these energy savings. A performance based approach will allow greater flexibility in the design and application of the overall walk-in system to achieve energy efficiency goals. Companies that manufacture and sell walk-in systems will have a performance based standard and improved knowledge about the design and application factors that contribute to increased energy efficiency.

LITERATURE REVIEW

As a first step, an extensive computerized literature search was performed to identify available measured data from field sites and laboratory tests regarding walk-in refrigerator/freezer evaporator load and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit.

In addition, the research team conducted an industrial survey in which they interviewed members of the commercial refrigeration industry to obtain measured data regarding walk-in coolers and freezers from monitored field sites and laboratory tests.

Furthermore, specifications for walk-in coolers and freezers, and refrigeration systems as well as load calculation software, equipment selection software and design guides were obtained from manufacturers' websites.

Also during the literature search, publications, documentation and user's manuals for software tools capable of modeling walk-in cooler/freezer refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit, were collected and reviewed.

The various laws and regulations regarding walk-in refrigerators/freezers were collected and reviewed to ascertain the minimum prescriptive walk-in design parameters for the development of a typical model walk-in to be used in the computer simulations.

Finally, the literature search also identified and reviewed publications regarding rating metrics for refrigeration and air conditioning equipment/systems.

A computerized literature search was performed that revealed over 300 references published between 1980 and 2010 pertaining to the operation, performance and refrigeration load of walk-in coolers and freezers as well as refrigeration system simulation. The results of this literature search are given in the **'Bibliography'**.

Validation of the model walk-in box load profile, shown in the first column of Table 2 for coolers and Table 3 for freezers in the section **'Analysis of Model Load Profiles'** and given in the AHRI Load Spreadsheet (AHRI 2009a), is critical to the success of this research project because this load spreadsheet was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c). Therefore, the research team devoted considerable effort to identifying measured data in the literature regarding model walk-in cooler/freezer refrigeration load profiles and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit. The various model load profiles found in the literature were analyzed and compared to the model walk-in box load profile given in the AHRI Load Spreadsheet that was used as a basis for the Standard 1250/1251 rating equations. The results of this literature review and analysis are given in the section **'Analysis of Model Load Profiles'**.

Furthermore, the research team conducted an industrial survey in which they contacted the following individuals regarding measured data from field sites and laboratory tests:

- Jon McHugh, McHugh Energy Consultants, Inc.
- Doug Scott, VaCom Technologies
- Rebecca Legett, Navigant Consulting, Inc.
- Ramin Faramarzi, Southern California Edison
- Scott Mitchell, Southern California Edison
- Devin Rauss, Southern California Edison
- David Cowen, Fisher Nickel, Inc.
- David Zabrowski, Fisher Nickel, Inc.
- Emre Schveighoffer, National Resource Management, Inc.

Most of these individuals had no knowledge of any existing monitored data on walk-in coolers and freezers.

Doug Scott mentioned that his company had developed a 'simulation assumptions baseline document' for a walk-in cooler/freezer simulation study that he was doing for Southern California Edison. The research team attempted to gain access to this document which could have been useful, in lieu of monitored data, for the analysis of the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a).

Rebecca Legett directed the research team to the DOE 2010 Preliminary Technical Support Document (DOE 2010b) that gives an 'energy use characterization' that discusses the assumptions used to calculate the walk-in refrigeration load. This information was useful, in lieu of monitored data, for the analysis of the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a).

Ramin Faramarzi informed the research team that the Southern California Edison Technology Test Center was in the process of starting a series of experimental tests on walk-in coolers that could provide useful data for a carry-on project to supplement the results of this current project, should such an opportunity present itself.

David Cowen provided monitored data from a series of laboratory tests performed by the Pacific Gas & Electric Company (PG&E) on an instrumented walk-in freezer at the Food Service Technology Center (FSTC).

The research team also had several long conversations with Emre Schveighoffer of National Resource Management, Inc., whose company monitors numerous walk-ins for various convenience stores, restaurants, supermarkets and institutions. He offered to set up a guest login so that the research team could access detailed measured data. These commercial field site data were analyzed to determine the operating characteristics and refrigeration load of in-service walk-in coolers and freezers. The load data from these field sites were compared to the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) that was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c) The results of the analysis of this measured data are given in the section **'Analysis of Monitored Data from Field Sites'**.

Specifications for walk-in coolers and freezers and refrigeration systems as well as load calculation software, equipment selection software and design guides were obtained from the following manufacturers' websites:

- Bohn (www.thecoldstandard.com) (Bohn 2011)
- Carlyle (www.carlylecompressor.com) (Carlyle 2010)
- Carroll Coolers, Inc. (www.carrollcoolers.com) (Carroll Coolers 2009)
- Copeland (www.emersonclimate.com) (Copeland 2009)
- Heatcraft (www.heatcraftrpd.com) (Heatcraft 2011)
- KeepRite (www.keepriterefrigeration.com) (KeepRite Refrigeration 2011)
- Kolpak (www.kolpak.com) (Kolpak 2011)
- Krack (www.krack.com) (Krack 2007)
- Larkin (www.larkinproducts.com) (Larkin 2011)
- Master-Bilt (www.master-bilt.com) (Master-Bilt 2010)
- Nor-Lake (www.norlake.com) (Nor-Lake 2007)
- U.S. Cooler (www.uscooler.com) (U.S. Cooler 2011)

The literature review revealed two computer modeling techniques that could be used to determine the energy efficiency of walk-in cooler and freezer refrigeration systems as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit. One technique involves the use of detailed refrigeration system modeling tools while the other technique involves the use of whole building energy simulation programs.

The capabilities of several publically available refrigeration system and whole building energy modeling tools were reviewed and evaluated to determine their suitability for estimating a walk-in refrigeration system's capacity and energy usage as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in box and the condensing unit. A state-of-the-art, publically available whole building energy model, *eQuest* (James J. Hirsch and Associates 2009), was selected to simulate the performance of walk-in box refrigeration systems in various climate zones and according to the procedure given in AHRI 1250/1251. The findings of this review and analysis of modeling tools are given in the section **'Review and Selection of Modeling Tools'**.

As mentioned above, the industrial survey led the research team to David Cowen who provided monitored data from a series of laboratory tests performed by the Pacific Gas & Electric

Company (PG&E) on an instrumented walk-in freezer at the Food Service Technology Center (FSTC). These data were used to validate the ability of *eQuest* to model a walk-in cooler or freezer by comparing its calculated results to the experimental data. In addition, *eQuest* simulation results for a prototypical walk-in cooler were compared with results from various load calculation methods obtained from the review of manufacturers' websites. This validation is discussed in the section, **'Validation of *eQuest* Model'**.

The literature review revealed that there are several prescriptive design standards available for walk-in coolers and freezers, such as California Energy Commission's Title 20, 'Appliance Efficiency Regulations' (CEC 2007) and Section 312 of the Energy Independence and Security Act of 2007 (U.S. Congress 2007).

In addition, California Energy Commission's Title 24, '2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings' (CEC 2008) contains prescriptive design parameters for large refrigerated warehouses, of which, certain aspects may apply to small walk-in coolers and freezers.

The prescriptive design standards in Title 20 related to walk-in refrigerator and/or freezer systems apply only to the design of the envelope and the specification of the fan motors. Title 20 specifies that automatic door closers that firmly close all reach-in doors and walk-in doors must be used. The envelope insulation must be of at least R-28 for refrigerators and R-36 for freezers, and electronically commutated evaporator and condenser fan motors should be used.

In addition, Title 20 specifies that, if no anti-sweat heater control is used, transparent reach-in doors must be constructed of triple-pane glass and anti-sweat heater power draw should be no more than 40 watts for freezers or 17 watts for refrigerators per foot of door frame width. If anti-sweat heaters with controls are used and the heater power consumption is greater than 40 watts for freezers or 17 watts for refrigerators, then the anti-sweat heater controls must reduce the energy use of the heaters in an amount corresponding to the relative humidity of the air outside the door or to the condensation on the inner glass pane.

In an effort to develop the prescriptive design standards contained in California Energy Commission's Title 20 and Section 312 of the Energy Independence and Security Act of 2007, research has been performed to determine the energy efficiency benefits from the use of the following (SCE 2008; PG&E 2004):

- Infiltration reduction (strip curtains or spring-hinged doors)
- High efficiency lighting and lighting controls
- Floating head pressure control
- Evaporator fan speed controls that respond to space conditions
- Defrosting cycle termination based upon the air temperature at the coil exit
- Anti-sweat heaters with wattage limits and humidity control
- Floor insulation of at least R-28

Southern California Edison (SCE 2008) used *eQuest* (James J. Hirsch and Associates 2009), a whole building energy simulation model, to investigate the effects of the following upon walk-in refrigerator/freezer performance: floating head controls, variable speed evaporator fans and infiltration reduction devices.

In this modeling study, Southern California Edison found that infiltration could be reduced 75% by using strip curtains. They also found that variable speed fans that vary their speed according to the space or product load can yield an 8% to 10% annual energy savings as compared to fixed speed evaporator fans. Finally, they found that floating head pressure controls can yield an 8% to 14% annual energy savings as compared to systems that have fixed condenser set points.

In the report published by Pacific Gas & Electric (2004), energy savings realized from utilization of several of the efficiency measures mentioned above for walk-in coolers was estimated based on information published by Westphalen et al. (1996). It was found that in California, a 37% energy savings for walk-in coolers and a 55% energy savings for walk-in freezers could be realized by using various energy efficiency measures, including:

- Automatic door closers
- High efficiency reach-in doors
- Envelope insulation of at least R-28 for refrigerators and R-36 for freezers
- High efficiency evaporator and condenser fan motors

ANALYSIS OF MODEL LOAD PROFILES

The rating equations given in Standard 1250/1251 (AHRI 2009b, 2009c) for the performance rating of walk-in coolers and freezers are based upon the AHRI 1250/1251 model walk-in box load profile shown in the first column of Table 2 for coolers and Table 3 for freezers and given in the AHRI Load Spreadsheet (AHRI 2009a).

Therefore, validation of the AHRI 1250/1251 model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) is an important component of this research project. Hence, the research team devoted considerable effort to identifying measured data in the literature regarding model walk-in cooler/freezer refrigeration load profiles and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit. The various model load profiles found in the literature were analyzed and compared to the model walk-in box load profile given in the AHRI Load Spreadsheet. The model load profiles also served as a basis for the load profiles used in the *eQuest* simulations.

As a first step, an extensive computerized literature search was performed to identify available measured data from field sites and laboratory tests regarding walk-in refrigerator/freezer evaporator load and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit.

After an extensive literature review, only a few publications were found that contained model walk-in box refrigeration load profile data and/or performance data for walk-in coolers and/or freezers. The usefulness of the data given in these publications is somewhat limited due to short testing periods, typically on the order of several days or weeks, and/or due to the lack of detail provided in these publications.

Discussion of Pertinent Publications

The following publications were identified by the research team as being related to walk-in cooler or freezer load profiles and system performance:

- DOE. (2010b). Preliminary Technical Support Document (TSD): Energy Conservation Program for Certain Commercial and Industrial Equipment: Walk-In Coolers and Walk-In Freezers. Washington, D.C.: Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.
- Hwang, Yunho, Dae-Hyun Jin, and Reinhard Radermacher. (2007). Comparison of R-290 and two HFC blends for walk-in refrigeration systems. International Journal of Refrigeration 30 (4):633-641.
- Kimber, David J. (1998). Final Technical Progress Report. Incline Village, NV: Nevada Energy Control Systems, Inc.
- Nagaraju, J., K. Vikash, and M. V. Krishna Murthy. (2001). Photovoltaic-powered cold store and its performance. International Journal of Energy Research 25 (5):389-396.

- Sami, S. M., and P. J. Tulej. (1996). Drop-in-replacement blend HFC-23/HCFC-22/HFC-152A for air/refrigerant equipment. International Journal of Energy Research 20 (9):787-796.
- SCE. (2008). Preliminary CASE Report: Analysis of Standards Option for Walk-in Refrigerated Storage. Codes and Standards Enhancement Initiative (CASE). Sacramento, CA: Southern California Edison.
- Sekhar, S. J., and D. M. Lal. (2005). HFC134a/HC600a/HC290 mixture a retrofit for CFC12 systems. International Journal of Refrigeration 28 (5):735-743.
- Sekhar, S. Joseph, K. Senthil Kumar, and D. Mohan Lal. (2004). Ozone friendly HFC134a/HC mixture compatible with mineral oil in refrigeration system improves energy efficiency of a walk in cooler. Energy Conversion and Management 45 (7-8):1175-1186.
- Sezgen, Osman, and Jonathan G. Koomey. (1995). Technology Data Characterizing Refrigeration in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0. Berkeley, CA: Lawrence Berkeley National Laboratory.
- Sujau, M., J.E. Bronlund, I Merts, and D.J. Cleland. (2006). Effect of Defrost Frequency on Defrost Efficiency, Defrost Heat Load and Coolstore Performance. Innovative Equipment and Systems for Comfort and Food Preservation. Auckland, New Zealand, 16-18 February 2006.
- Wichman, Adam, and James E. Braun. (2009). Fault Detection and Diagnostics for Commercial Coolers and Freezers. HVAC&R Research 15 (1):77-99.

DOE. (2010b)

The DOE Preliminary Technical Support Document (TSD) (DOE 2010b) provides an overview of the preliminary analysis that DOE conducted in consideration of new energy conservation standards and test procedures for walk-in coolers and freezers. This document also summarizes key results from DOE's analyses and gives an 'energy use characterization' that discusses the assumptions used to calculate the refrigeration load for display and non-display walk-in coolers and freezers including the following:

- Product load
- Infiltration load
- Number and size of doors
- Number and duration of door openings
- Number and type of lighting fixtures
- Insulation type and thickness
- Evaporator coil capacity
- Condenser/evaporator fan type
- Compressor capacity
- Defrost type and duration

The report analyzes a diverse range of walk-in box options for each parameter listed above. Refrigeration load data and box details for a non-display walk-in with the baseline options are summarized in Table 2 for walk-in coolers and in Table 3 for walk-in freezers. Table 2 and Table 3 appear at the end of this chapter.

Hwang et al. (2007)

Hwang et al. (2007) compared the relative performance potential of HFCs (R-404A and R-410A) to R-290 for walk-in refrigeration systems. Experimental testing was performed in a psychrometric test facility, on two walk-in systems: one low temperature freezer system and one medium temperature cooler system. The low temperature refrigeration system had a capacity of 4 kW (13,650 Btu/hr) and provided a -29°C (-20.2°F) saturated evaporating temperature, while the medium temperature refrigeration system had a capacity of 11 kW (37,535 Btu/hr) and provided a saturated evaporating temperature ranging from -20°C to 0°C (-4 to 32°F). Results include refrigeration capacity, COP, average evaporating and condensing pressures, degrees of subcooling and superheating, compressor volumetric efficiency and compressor isentropic efficiency. However, no information is given concerning the walk-in cooler/freezer box details or refrigeration load.

Kimber. (1998)

Kimber (1998) conducted a refrigeration monitoring and testing project to validate the energy savings, safety and reliability of the Nevada Energy Control System, Inc. (NECSI) Evaporator Fan Controller. Commercial field site data was gathered from in-service walk-in coolers at the following sites:

- Safeway Store #309, Fremont, CA
- Trader Joe's Store #70, Sacramento, CA
- McDonald's Restaurant, Stockton, CA
- Walnut Creek School District, Walnut Creek, CA
- Cameron Park Liquors, Cameron Park, CA

This data included average daily energy consumption of the evaporator fans and the compressor, the number and duration of personnel door openings, the ambient temperature and humidity inside and outside of the walk-in box, and the compressor duty cycle data. Unfortunately, data fidelity varies for each site with the majority of sites not having the complete data set outlined above. Data gathered for the baseline case (No NECSI Evaporator Fan Controller) is summarized in Table 2 at the end of this chapter.

Nagaraju et al. (2001)

Nagaraju et al. (2001) reports performance data for a photovoltaic-powered walk-in freezer with an interior volume of 21 m^3 that was installed in Mangalore, India, for preserving 10 metric tons of frozen fish at -15°C. The measured data includes the ambient temperature outside of the walk-in box, the temperatures of the refrigerant at the condenser inlet and outlet and at the evaporator inlet and outlet. Power consumption was measured with Watt meters and the temperature inside the walk-in box versus time was measured as a function of heat load on the walk-in box. Pertinent information is summarized in Table 3 at the end of this chapter.

Sami and Tulej (1996)

Sami and Tulej (1996)analyzed HFC23/HCFC22/HFC152A as a substitute for CFC12, CFC502, and HCFC22. Items of interest include environmental impact, ozone depletion potential, global warming potential, flammability, toxicity, and performance. COP values and a ratio of average energy consumption to cooling capacity were compared for six walk-in units, including coolers and freezers. Unfortunately, no walk-in box details or refrigeration load details are described with the exception of the system type and the system capacity.

Sekhar et al. (2004)

Sekhar et al. (2004) analyzed the performance of an ozone friendly refrigerant mixture in a walk-in cooler similar in size to the small cooler analyzed in the AHRI Load Spreadsheet (AHRI 2009a). They benchmarked the HFC134a/HC600a/HC290 blend against a conventional CFC refrigerant (R-12) by analyzing no-load pull-down time, motor power, overall energy consumption, cycle time, temperature distribution along the coil, COP, and miscibility with mineral oil. Details are included in Table 2 at the end of this chapter.

Sekhar and Lal (2005)

Sekhar and Lal (2005) extended the work discussed in Sekhar et al. (2004). The 3.5 kW (11,943 Btu/hr) walk-in cooler utilized for the experiments is described in detail. This walk-in profile applies to both Sekhar et al. (2004) and Sekhar and Lal (2005). Details are included in Table 2 at the end of this chapter.

Southern California Edison (2008)

Southern California Edison (2008) utilized *eQuest*, a whole-building energy simulation tool, to model walk-in coolers and freezers in an effort to estimate the operational savings due to various options. Four different size walk-ins (250 ft^3, 500 ft^3, 1000 ft^3 and 2500 ft^3) were modeled using weather data for Baltimore, MD. The following options were analyzed:

- Floating head control
- Infiltration reduction with strip curtains or spring hinged doors
- High efficacy lighting or lighting controls
- Freezer floor insulation of at least R-28
- Compressor capable of 70°F condensing temperature
- Variable speed condenser fans
- Variable speed evaporator fans
- Temperature termination defrost controls
- Anti-sweat heater wattage limits and humidity responsive controls

In their simulations, SCE assumed that the product load was 70% of the box capacity and the lighting and infiltration loads were based on data presented in the ‘Heatcraft Engineering Manual’ (Heatcraft 2008). Details on the walk-in coolers and freezers analyzed are contained in Table 2 and Table 3, respectively, at the end of this chapter.

Sezgen and Koomey (1995)

Sezgen and Koomey (1995) discussed the use of the Electric Power Research Institute’s Commercial End-Use Planning System (COMMEND 4.0) to forecast refrigeration end uses in terms of specific technologies. In general, this article is a market summary of the commercial refrigeration sector detailing the system and market parameter assumptions of the forecasting software. Some items related to this investigation of model load profiles are the base refrigeration load and system electricity use values that are cited for walk-in coolers/freezers:

- Walk-in cooler: 70 Btu/h-ft^2, 17.5 kWh/ft^2-yr
- Walk-in freezer: 90 Btu/h-ft^2, 17.5 kWh/ft^2-yr

They also report typical installed sizes of walk-in coolers and freezers for grocery stores, restaurants, and refrigerated warehouses and estimate the energy and cost savings of walk-in refrigeration system efficiency measures.

Sujau et al. (2006)

Because the unit cooler of a walk-in operates below the freezing point of water, condensation on the outside of the coil freezes. Many factors influence frost's effect on system performance including coil design, operating conditions, and the inherent efficiency of the defrost system. Sujau et al. (2006) investigated a fourth factor, the effect of defrost frequency and duration on walk-in cooler performance. The experimentation was done on a 3.3 m (10.8 ft) × 4.4 m (14.4 ft) × 3.0 m (9.8 ft) box containing one 1.2 m (3.9 ft) x 2.4 m (7.9 ft) door fitted with a strip curtain. Two 2.3 kW electric defrost elements were used to analyze the effects of defrost intervals of 6 to 30 hrs. Walk-in box construction and load details are listed in Table 2 at the end of this chapter.

Wichman and Braun (2009)

Wichman and Braun (2009) discuss a diagnostic method utilizing parameters that are strongly influenced by individual faults and insensitive to ambient condition variation to allow multiple fault detection. In parallel, virtual sensors (empirically defined system parameters) are analyzed for effectiveness in simulating system conditions. The report demonstrates this diagnostic technique on a small, restaurant-style walk-in cooler and a small, restaurant-style walk-in freezer through experimentation with the following list of common faults:

- Refrigerant undercharge
- Refrigerant overcharge
- Liquid-line restriction
- Compressor valve leakage
- Condenser coil fouling
- Evaporator coil fouling

Virtual and measured values for evaporator and condenser pressures, temperatures and air flow rates, as well as compressor mass flow rates and power usage are compared against each other. In addition, virtual and estimated compressor shell heat losses are compared.

Discussion of Model Refrigeration Load Profiles for Walk-In Coolers and Freezers

The various components of the model refrigeration load profiles found in the literature for walk-in coolers and freezers are consolidated in Table 2 and Table 3, respectively, at the end of this chapter. The findings for each of these load components are discussed below and compared to the values given in the AHRI Load Spreadsheet (AHRI 2009a).

Walk-In Coolers

DOE (2010b), SCE (2008), Kimber (1998), Sekhar et al. (2004), Sekhar and Lal (2005), and Sujau et al. (2006) report model load profile data for walk-in coolers. Their findings are summarized in Table 2, at the end of this chapter, and discussed below.

Cooler: Site Conditions
The AHRI Load Spreadsheet (AHRI 2009a) specifies the most detailed site conditions of any of the reports found in the literature. AHRI specifies three outdoor ambient temperatures (80˚F, 95˚F, and 110˚F) compared to the value reported by Kimber (1998) of 59˚F.

The AHRI indoor (store) ambient temperature is consistent with DOE (2010b) at 75 ˚F. The ambient temperatures presented in the other five reports ranged from 54.7˚F to 89.6˚F with an average value of 64.8˚F. AHRI specified an indoor (store) ambient relative humidity of 50%. The relative humidity presented in three of the other reports ranged from 40% to 67.1% with an average value of 54.0%.

The AHRI ground temperature of 50˚F is consistent with SCE (2008). DOE used a value of 60˚F for ground temperature.

Cooler: Box Operating Conditions
AHRI (2009a) used a walk-in cooler box interior temperature of 35˚F and an interior relative humidity of 90%. The interior temperatures reported by the other five investigators ranged from 35˚F to 46.8˚F with an average value of 38.5˚F. The interior relative humidity was noted in three of the other reports and ranged from 60% to 82.3% with an average value of 73.6%.

Cooler: Box Construction Details
The AHRI Load Spreadsheet (AHRI 2009a) analyzed a small walk-in box with a 64 ft^2 plan area and a 512 ft^3 volume, and a large walk-in box with a 2500 ft^2 plan area and a 50,000 ft^3 volume. Kimber (1998) analyzed five box sizes, SCE (2008) analyzed four box sizes, DOE (2010b) analyzed three box sizes, while Sekhar (2004) and Sujau et al (2006) analyzed one box size each.

Kimber's box sizes ranged from a plan area of 108 ft^2 and a volume of 864 ft^3 to a volume of 5695 ft^3. The average plan area was 230.9 ft^2 (averaged over three box sizes) and the average volume was 2692.8 ft^3 (averaged over five box sizes). SCE's box sizes ranged from a plan area of 250 ft^2 to 2500 ft^2 with an average plan area of 1062.5 ft^2. No box volumes were cited by SCE.

DOE's box sizes ranged from a plan area of 80 ft^2 and volume of 608 ft^3 to a plan area of 750 ft^2 and a volume of 9000 ft^3. The average plan area was 356.7 ft^2 and the average volume was 3962.7 ft^3. Sekhar and Sujau analyzed plan areas of 57.8 ft^2 and 155.5 ft^2, respectively and volumes of 531.4 ft^3 and 1524.1 ft^3, respectively.

Considering all six reports cited from the literature, the plan area ranged from 57.8 ft^2 to 2500 ft^2 with an overall average value of 518.8 ft^2. Five of these six reports specified walk-in box volumes, ranging from 531.4 ft^3 to 9000 ft^3 with an average value of 2740.8 ft^3.

AHRI assumed ceiling, wall, and floor construction with an R-value of 25 h-ft^2-˚F/Btu. DOE used 4" of extruded polystyrene or polyurethane board with an associated R-value of approximately 24 h-ft^2-˚F/Btu for the ceiling and wall construction as its baseline option. The baseline floor analyzed by DOE was not insulated. Sekhar reports approximately 6" of mineral wool with an R-value of approximately 20 h-ft^2-˚F/Btu, while Sujau reports approximately 6" of polystyrene sandwich panel with an R-value of approximately 25 h-ft^2-˚F/Btu (Heatcraft 2008).

Total conduction heat load was reported by Sujau and floor heat load was reported by DOE. These values were calculated for the AHRI Load Spreadsheet for direct comparison. AHRI had an average total conduction load of 774.4 Btu/hr and 17,050 Btu/hr for the small and large walk-in coolers, respectively. Sujau estimated a conductive load of 648 Btu/hr. When compared on a per unit surface area basis, the total conduction load values for AHRI's small walk-in, AHRI's large walk-in, and Sujau's walk-in are 2.02, 1.89, and 0.81 Btu/hr-ft^2, respectively. AHRI had a floor heat load of 0.6 Btu/hr-ft^2 for the small and large walk-in coolers. The DOE baseline had values of 6.9, 4.4, and 2.97 Btu/hr-ft^2 for the small, medium, and large walk-in coolers, respectively. This discrepancy is due to no floor insulation for the DOE baseline walk-in box.

Cooler: Door Details

Passage, freight, and reach-in doors were noted in DOE (2010b), Kimber (1998), and Sujau et al (2006). AHRI (2009a) had one passage door for the small (64 ft^2 plan area and 512 ft^3 volume) and large (2500 ft^2 plan area and 50,000 ft^3 volume) walk-in coolers. All walk-in coolers of similar size to the AHRI small walk-in box also had only one passage door. One of Kimber's medium size boxes (315.9 ft^2 plan area and 2739 ft^3 volume) and the large DOE walk-in box (750 ft^2 plan area and 9000 ft^3 volume) had two passage doors.

AHRI assumed passage door dimensions of 4 ft x 7 ft for the small walk-in box and 6 ft x 10 ft for the large walk-in box. Three of the other reports cited passage door dimensions ranging from 3 ft x 7 ft to 3.9 ft x7.9 ft for walk-in boxes ranging from a small (80 ft^2 plan area and 608 ft^3 volume) to medium (750 ft^2 plan area and 9000 ft^3 volume) size.

DOE analyzed the effect of heat transfer through passage door windows. A glass area of 0.9 ft^2 was assumed for each passage door. DOE also used one freight door on their medium (240 ft^2 plan area and 2280 ft^3 volume) and large (750 ft^2 plan area and 9000 ft^3 volume) walk-in coolers. The medium-size walk-in cooler freight door had dimensions of 7 ft x 9 ft while the large walk-in cooler freight door had dimensions of 7 ft x 12 ft.

The total door area (passage and freight doors) was calculated for each report that specified door dimensions. The AHRI small and large walk-in coolers have total door areas of 28 and 60 ft^2, respectively. The AHRI small walk-in cooler value corresponds well with the DOE small walk-in cooler and Sujau's walk-in cooler (155.5 ft^2 plan area and 1524.1 ft^3 volume) which have total door areas of 21 ft^2 and 30.8 ft^2, respectively. The DOE medium-size and large walk-in coolers have much larger total door areas than AHRI at 84 and 126 ft^2, respectively.

When compared on a per wall surface area basis the total door areas are as follows:

- AHRI small walk-in cooler: 10.9 %
- AHRI large walk-in cooler: 1.5%
- DOE small walk-in cooler: 7.7%
- DOE medium-size walk-in cooler: 13.8%
- DOE large walk-in cooler: 9.5%
- Sujau walk-in cooler: 6.2%

Three of the coolers analyzed by Kimber had reach-in doors. Cameron Park (1880 ft^3 volume) had 13 reach-in doors, Trader Joe's (268.9 ft^2 plan area and 2286 ft^3 volume) had 9 reach-in doors, and Safeway (5695 ft^3 volume) had 13 reach-in doors.

Open door blockages were utilized in a number of analyzed walk-in coolers. AHRI applied a value of 85% for the open door blockage percentage. SCE assigned 75% for strip curtains and 95% for swing-type plastic hinged doors. The cooler analyzed by Sujau used a strip curtain. DOE did not assign any door infiltration reduction mechanisms for their baseline option, but did analyze strip curtains as a secondary option with an effectiveness value of 80%.

Cooler: Infiltration

The six cited references used multiple methods to estimate infiltration loading for walk-in coolers. AHRI (2009a) estimated door infiltration using the Gosney Olama Equation (Becker and Fricke 2005) for a door opening schedule of 30 openings per hour from 6 am to 7 am and 2 openings per hour from 7 am to 7 pm for the small cooler. Door opening duration was estimated at 30 seconds per door opening from 6 am to 7 am and 5 seconds per door opening from 7 am to 7 pm. The large walk-in cooler used a door opening schedule of 32 openings per hour from 6 am to 7 am and 4 openings per hour from 7 am to 7 pm with door opening durations of 30 seconds per door opening from 6 am to 7 pm. The AHRI total daily 'door-open' time is 17 minutes per day for the small cooler and 40 minutes per day for the large cooler.

DOE (2010b) also estimated door opening infiltration using the Gosney Olama Equation, assuming 60 openings per day for the passage and freight doors with a 'door-open' duration of 12 seconds per opening. In addition, the doors were open for a total of 15 minutes per day. This equates to a total daily 'door-open' time of 27 minutes per door for all sizes of walk-in coolers. In addition, DOE accounted for crack infiltration by assigning an infiltration value of 0.13 $ft^3/hr\text{-}ft^2$ of external surface.

SCE (2008) used the estimates for infiltration presented in the Heatcraft Refrigeration Manual (Heatcraft 2008). These values include both door opening and crack infiltration.

Actual door opening data was presented by Kimber (1998) for one site. For this medium size walk-in cooler (5695 ft^3 volume) there were 72.8 door openings per day on average. The total time that the door was open was tabulated at 6.4 hours per day (384 minutes per day). This walk-in cooler had 13 reach-in doors for customer access, explaining the higher usage.

Cooler: Product Loading

Two reports, in addition to the AHRI Load Spreadsheet (AHRI 2009a), analyzed product loading including DOE (2010b) and SCE (2008). AHRI used fruits and vegetables as the product with a product specific heat above freezing of 0.9 Btu/lb-˚F. This value agrees with that used by DOE.

AHRI defined the effective product loading as 775 lb/hr for the small walk-in cooler and 10,000 lb/hr for the large walk-in cooler for 8 hours from 6 am to 2 pm with a product pull-down temperature difference of 10˚F. DOE utilized the same product pull-down temperature difference, but defined the product loading in terms of the daily loading ratio. The small DOE walk-in cooler (80 ft^2 plan area and 608 ft^3 volume) had a daily loading ratio of 4 lb/ft^3-day. The medium-size DOE walk-in cooler (240 ft^2 plan area and 2280 ft^3 volume) and the large DOE walk-in cooler (750 ft^2 plan area and 9000 ft^3 volume) both had a daily loading ratio of 2 lb/ft^3-day. For direct comparison, these values were calculated for AHRI. The small AHRI walk-in cooler (64 ft^2 plan area and 512 ft^3 volume) had a daily loading ratio of 12.1 lb/ft^3-day while the large AHRI walk-in cooler (2500 ft^2 plan area and 50,000 ft^3 volume) had a daily loading ratio of 1.6 lb/ft^3-day.

The product loading reported by SCE is defined as 70% of capacity. Assuming that this capacity refers to walk-in box refrigeration capacity, values of 21,840 Btu/hr and 195,720 Btu/hr were calculated for the small SCE walk-in cooler (250 ft^2 plan area) and the large SCE walk-in cooler (2500 ft^2 plan area), respectively. The total product load for the AHRI small and large walk-in coolers are 55,800 Btu/day and 720,000 Btu/day, respectively.

Cooler: Lighting and Occupancy

AHRI (2009a) assumed one 100 W incandescent bulb for the small walk-in cooler (64 ft^2 plan area and 512 ft^3 volume) and 1 W/ft^2 (2500 W) of fluorescent lighting for the large walk-in cooler (2500 ft^2 plan area and 50,000 ft^3 volume). SCE (2008) used the Heatcraft Refrigeration Manual (Heatcraft 2008) to estimate lighting and reported the same values as reported by AHRI for the AHRI large walk-in cooler.

DOE (2010b) used compact fluorescent lighting (CFL) with 1 bulb for the small (80 ft^2 plan area and 608 ft^3 volume) and medium-sized (240 ft^2 plan area and 2280 ft^3 volume) walk-in coolers. Three CFLs were used for the DOE large walk-in cooler (750 ft^2 plan area and 9000 ft^3 volume). Each bulb and ballast used a total of 15 Watts of electrical energy that added to the heat load.

AHRI used an occupancy load of 1 person for the small walk-in cooler and 2 people for the large walk-in cooler. The person occupying the small walk-in cooler spent 60 minutes in the cooler from 6 am to 7 am and 2 minutes per hour from 7 am to 7 pm. The people occupying the large walk-in cooler also spent 60 minutes in the cooler from 6 am to 7 am, but 10 minutes per hour from 7 am to 7 pm. The lighting schedule utilized by AHRI corresponds to the AHRI occupancy schedule. Neither, DOE nor SCE explicitly defined their assumptions for lighting or occupancy schedules.

Cooler: Additional Loading

In addition to the model load details mentioned above, AHRI (2009a) includes a vehicle operating in the large walk-in cooler (2500 ft^2 plan area and 50,000 ft^3 volume). The vehicle is assumed to be adding 50 hp of heat to the space from 6 am to 7 am.

For the two groups of experiments performed, Sujau et al (2006) had miscellaneous heat loads of 3.1 kW sensible heat and 230 W latent heat, and 5.1 kW sensible and 340 W latent heat. Defrost loads using a 4.6 kW defrost system at intervals of 6, 8, 12, 18, 24, and 30 hours were also analyzed in the report by Sujau et al (2006).

Walk-in Cooler Summary

The AHRI Load Spreadsheet (AHRI 2009a) was compared to the reports by DOE (2010b), SCE (2008), Kimber (1998), Sekhar et al. (2004), Sekhar and Lal (2005), and Sujau et al. (2006). The AHRI 125/1251 model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) agrees with the findings reported by the other researchers for a majority of the box specifications and refrigeration load components. Exceptions include the walk-in cooler humidity, the large walk-in cooler door details, omission of crack infiltration, and the product loading for the small walk-in cooler.

The ambient conditions, ground temperature, and internal box temperature reported by AHRI are comparable to those found in the literature. However, AHRI reports a walk-in cooler relative humidity of 90% that exceeds the average value of 73.6% reported by the other researchers.

The AHRI small walk-in box size is appropriate at 64 ft^2 plan area and 512 ft^3 volume compared to the literature minimum of 57.8 ft^2 plan area and 531.4 ft^3 volume. The AHRI large walk-in box size is appropriate with a plan area equivalent to the literature maximum of 2500 ft^2. In addition, the R-value of the AHRI walk-in cooler construction at 25 h-ft^2-˚F/Btu is comparable to an average R-value of approximately 23 h-ft^2-˚F/Btu found in the cited literature.

The door details associated with the AHRI Load Spreadsheet are appropriate for the small walk-in cooler when analyzed on a total door area per wall surface area basis at 10.9% compared to a literature average of 9.3%. The AHRI large walk-in cooler had 1.5% of total door area per wall surface area. The AHRI passage door blockage factor agrees with the values found in the literature for various door infiltration reduction systems.

The AHRI Load Spreadsheet does not include infiltration due to crack leakage. The inputs used to calculate door opening infiltration are comparable to those used by DOE with a total door open time of 17 and 40 minutes per day for the AHRI small and large walk-in boxes, respectively compared to the DOE value of 27 minutes per day per door. This does not agree with the actual door opening data presented by Kimber, who reports a door open time of 384 minutes per day. However, this discrepancy can be explained by the fact that Kimber's test location had 13 reach-in doors for customer use.

For the small walk-in cooler, AHRI uses a daily product loading ratio that is 3 times larger than that reported by DOE. The AHRI large walk-in cooler product load is comparable to that reported by others. The lighting load utilized by AHRI agrees with SCE's analysis, but not DOE's. Occupancy loading and lighting schedule are not explicitly mentioned in the other six reports.

Walk-In Freezers

DOE (DOE 2010b), SCE (2008), Kimber (1998), and Nagaraju et al (2001) report model load profile data for walk-in freezers. Their findings are summarized in Table 3, at the end of this chapter, and discussed below.

Freezer: Site Conditions
The AHRI Load Spreadsheet (AHRI 2009a) specifies the most detailed site conditions of any of the reports found in the literature. AHRI specifies three outdoor ambient temperatures (80˚F, 95˚F, and 110˚F).

The AHRI indoor (store) ambient temperature is consistent with DOE (2010b) at 75 ˚F. The ambient temperatures presented in the other two reports were 54.7˚F and 86˚F with an average of 70.4 ˚F. AHRI specified an indoor (store) ambient relative humidity of 50%. The relative humidity presented in the DOE and SCE reports were 40% and 67.1% with an average value of 53.6%.

The AHRI ground temperature of 50˚F is consistent with SCE (2008). DOE used a value of 65˚F for ground temperature.

Freezer: Box Operating Conditions
AHRI (2009a) used a walk-in freezer box interior temperature of -10˚F and an interior relative humidity of 50%. The interior temperatures reported by the other three investigators ranged from -10˚F to 5˚F with an average value of 0˚F. The interior relative humidity reported by DOE was 60%.

Freezer: Box Construction Details
The AHRI Load Spreadsheet (AHRI 2009a) analyzed a small walk-in box with a 64 ft^2 plan area and a 512 ft^3 volume, and a large walk-in box with a 2500 ft^2 plan area and a 50,000 ft^3 volume. SCE (2008) analyzed four box sizes, DOE (2010b) analyzed three box sizes, and Nagaraju et al (2001) analyzed one box size.

SCE's box sizes ranged from a plan area of 250 ft^2 to 2500 ft^2 with an average plan area of 1062.5 ft^2. No box volumes were cited by SCE. DOE's box sizes ranged from a plan area of 48 ft^2 and a volume of 364.8 ft^3 to a plan area of 500 ft^2 and a volume of 6000 ft^3. The average DOE plan area was 242.7 ft^2 and the average volume was 2691.6 ft^3. Nagaraju et al (2001) analyzed a box with plan area of 106.4 ft^2 and volume of 750 ft^3.

Considering all three reports cited from the literature, the plan area ranged from 48 ft^2 to 2500 ft^2 with an average value of 635.6 ft^2. Two of these three reports specified walk-in box volumes, ranging from 364.8 ft^3 to 9000 ft^3 with an average value of 2206.2 ft^3.

AHRI assumed ceiling, wall, and floor construction with an R-value of 32 h-ft^2-˚F/Btu. DOE used 4" of extruded polystyrene or polyurethane board with an associated R-value of approximately 24 h-ft^2-˚F/Btu for the ceiling, wall, and floor construction as its baseline option. Nagaraju specified 6 inches of extruded polystyrene with plywood panels on each side for the ceiling and wall construction with an R-value of approximately 25 h-ft^2-˚F/Btu (Heatcraft 2008). The floor was insulated with 6 inches of extruded polystyrene as well. SCE noted a floor insulation of R-28 but did not note the insulation used for the ceiling or wall construction.

Floor heat load was reported by DOE. This value was calculated for the AHRI Load Spreadsheet for direct comparison. AHRI had a floor heat load of 1.88 Btu/hr-ft^2 for the small and large walk-in freezers. The DOE baseline had values of 3.11, 2.88, and 2.54 Btu/hr-ft^2 for the small, medium, and large walk-in freezers, respectively.

Freezer: Door Details

Passage and freight doors were noted by DOE (2010b). AHRI (2009a) had one passage door for the small (64 ft^2 plan area and 512 ft^3 volume) and large (2500 ft^2 plan area and 50,000 ft^3 volume) walk-in freezers. DOE's small (48 ft^2 plan area and 364.8 ft^3 volume) and medium-size (180 ft^2 plan area and 1710 ft^3 volume) walk-in freezers also had one passage door. The DOE large walk-in freezer (500 ft^2 plan area and 6000 ft^3 volume) had two passage doors.

AHRI assumed passage door dimensions of 4 ft x 7 ft for the small walk-in box and 6 ft x 10 ft for the large walk-in box. DOE used a passage door that was 3 ft x 7 ft.

DOE analyzed the effect of heat transfer through passage door windows. A glass area of 0.9 ft^2 was assumed for each passage door. DOE also used one freight door on their medium and large walk-in freezers. The medium-size walk-in freezer freight door had dimensions of 7 ft x 9 ft while the large walk-in freezer freight door had dimensions of 7 ft x 12 ft.

The total door area (passage and freight doors) was calculated for each report that specified door dimensions. The AHRI small and large walk-in freezers have total door areas of 28 and 60 ft^2, respectively. The AHRI small walk-in freezer value corresponds well with the DOE small walk-in which has a door area of 21 ft^2. The DOE medium-size and large walk-in freezers have much larger total door areas than the AHRI freezers at 84 and 126 ft^2, respectively.

When compared on a per wall surface area basis the total door areas are as follows:

- AHRI small walk-in freezer: 10.9 %
- AHRI large walk-in freezer: 1.5%
- DOE small walk-in freezer: 7.7%
- DOE medium-size walk-in freezer: 13.8%
- DOE large walk-in freezer: 9.5%

Open door blockages were utilized by a number of analyzed walk-in freezers. AHRI applied a value of 85% for the open door blockage percentage. SCE assigned 75% for strip curtains and 95% for swing-type plastic hinged doors. DOE did not assign any door infiltration reduction mechanisms for their baseline option, but did analyze strip curtains as a secondary option with an effectiveness value of 80%.

Freezer: Infiltration

The three cited references used multiple methods to estimate infiltration loading for walk-in freezers. AHRI (2009a) estimated door infiltration using the Gosney Olama Equation (Becker and Fricke 2005) for a door opening schedule of 8 openings per hour from 6 am to 7 am and 2 openings per hour from 7 am to 7 pm for the small freezer. Door opening duration was estimated at 30 seconds per door opening from 6 am to 7 am and 5 seconds per door opening from 7 am to 7 pm. The large walk-in freezer had a door opening schedule of 8 openings per hour from 6 am to 7 am and 4 openings per hour from 7 am to 7 pm with door opening durations of 30 seconds per door opening from 6 am to 7 pm. The total daily 'door-open' time was 6 minutes per day for the small freezer and 28 minutes per day for the large freezer.

DOE (2010b) also estimated door opening infiltration using the Gosney Olama Equation assuming 60 openings per day for the passage and freight doors with a 'door-open' duration of 12 seconds per opening. In addition, the doors were open for a total of 15 minutes per day. This equates to a total daily 'door-open' time of 27 minutes per door for all sizes of walk-in freezers. In addition, DOE accounted for crack infiltration by assigning an infiltration value of 0.13 $ft^3/hr\text{-}ft^2$ of external surface.

SCE (2008) used the estimates for infiltration presented in the Heatcraft Refrigeration Manual (Heatcraft 2008). Nagaraju et al (2001) estimated the air changes for the freezer that they analyzed at 0.5 air changes per hour. These values included both door opening and crack infiltration.

Freezer: Product Loading

AHRI used fruits and vegetables as the product with a product specific heat below freezing of 0.5 Btu/lb-˚F. This value is similar to the values used by DOE (2010b) and Nagaraju et al (2001) of 0.45 Btu/lb-˚F and 0.435 Btu/lb-˚F, respectively.

AHRI defined the effective product loading as 200 lb/hr for the small walk-in freezer and 2500 lb/hr for the large walk-in freezer for 8 hours from 6 am to 2 pm with a product pull-down temperature difference of 10˚F. DOE utilized the same product pull-down temperature difference, but defined the product loading in terms of the daily loading ratio. The small DOE walk-in freezer (48 ft^2 plan area and 364.8 ft^3 volume) had a daily loading ratio of 1 lb/ft^3-day. The medium-size DOE walk-in freezer (180 ft^2 plan area and 1710 ft^3 volume) and the large DOE walk-in freezer (500 ft^2 plan area and 6000 ft^3 volume) both had a daily loading ratio of 0.5 lb/ft^3-day. For direct comparison, these values were calculated for AHRI. The small AHRI walk-in freezer (64 ft^2 plan area and 512 ft^3 volume) had a daily loading ratio of 3.1 lb/ft^3-day while the large AHRI walk-in freezer (2500 ft^2 plan area and 50,000 ft^3 volume) had a daily loading ratio of 0.4 lb/ft^3-day.

The walk-in freezer analyzed by Nagaraju had a product loading of 22,046 lb of fish with a 0.9˚F pull down per hour. This corresponds to a heat load of 8631 Btu/hr. The product loading presented by SCE is defined as 70% of capacity. Assuming that this capacity refers to walk-in box refrigeration capacity, values of 57,120 Btu/hr and 633,360 Btu/hr were calculated for the small (250 ft^2 plan area) and the large (2500 ft^2 plan area) SCE walk-in freezers, respectively. The total product load for the AHRI small and large walk-in freezers are 8000 Btu/day and 100,000 Btu/day, respectively.

Freezer: Lighting and Occupancy

AHRI (2009a) assumed one 100 W incandescent bulb for the small walk-in freezer (64 ft^2 plan area and 512 ft^3 volume) and 1 W/ft^2 (2500 W) of fluorescent lighting for the large walk-in freezer (2500 ft^2 plan area and 50,000 ft^3 volume). SCE (2008) used the Heatcraft Refrigeration Manual (Heatcraft 2008) to estimate lighting and reported the same values as reported by AHRI for the AHRI large walk-in freezer.

DOE (2010b) used compact fluorescent lighting (CFL) with 1 bulb for both the small (48 ft^2 plan area and 364.8 ft^3 volume) and medium-size (180 ft^2 plan area and 1710 ft^3 volume) walk-in freezers. Three CFLs were used for the DOE large walk-in freezer (500 ft^2 plan area and 6000 ft^3 volume). Each bulb and ballast used a total of 15 Watts of electrical energy that added to the heat load.

AHRI used an occupancy load of 1 person for the small walk-in freezer and 2 people for the large walk-in freezer. The person occupying the small walk-in freezer spent 30 minutes in the freezer from 6 am to 7 am and 2 minutes per hour from 7 am to 7 pm. The people occupying the large walk-in freezer also spent 30 minutes in the freezer from 6 am to 7 am, but 10 minutes per hour from 7 am to 7 pm. The lighting schedule utilized by AHRI corresponds to the AHRI occupancy schedule. Neither, DOE nor SCE explicitly defined their assumptions for lighting or occupancy schedules.

Freezer: Additional Loading
In addition to the model load details mentioned above, AHRI (2009a) includes a vehicle operating in the large walk-in freezer. The vehicle is assumed to be adding 50 hp of heat to the space for 30 minutes during the day.

DOE (2010b) includes the energy added by a 2-way pressure relief valve and a passage door heater in their analysis. The relief valve operates at 23 Watts and the passage door heater operates at 8 W/ft. Both components operate 24 hours a day. DOE applied defrost systems that run for one hour a day operating at 1656 W for the DOE small walk-in freezer and 2756 W for the DOE large walk-in freezer. Nagaraju et al (2001) notes a miscellaneous load of 700 to 2350 Watts that was applied during their experiments.

Walk-in Freezer Summary
The AHRI Load Spreadsheet (AHRI 2009a) was compared to the reports by DOE (2010b), SCE (2008), Kimber (1998), and Nagaraju et al (2001). The AHRI model load profile given in the AHRI Load Spreadsheet (AHRI 2009a) agrees with the findings reported by the other researchers for a majority of the box specifications and refrigeration load components. Exceptions include the insulation R-value, the large walk-in freezer door details, omission of crack infiltration, and the product loading for the small walk-in freezer.

The ambient conditions, ground temperature, and internal box conditions reported by AHRI are comparable to those found in the literature.

The AHRI small walk-in box size is appropriate at 64 ft^2 plan area and 512 ft^3 volume compared to the literature minimum of 48 ft^2 plan area and 364.8 ft^3 volume. The AHRI large walk-in box size is appropriate with a plan area equivalent to the literature maximum of 2500 ft^2. The R-value of the AHRI walk-in freezer construction is 32 h-ft^2-°F/Btu and the average R-value found in the literature is approximately 26 h-ft^2-°F/Btu.

The door details associated with the AHRI Load Spreadsheet seem appropriate for the small walk-in freezer when analyzed on a total door area per wall surface area basis at 10.9%

compared to a literature average of 10.3%. The AHRI large walk-in freezer had 1.5% of total door area per wall surface area. The AHRI passage door blockage factor agrees with the values found in the literature for various door infiltration reduction systems.

The AHRI Load Spreadsheet does not include infiltration due to crack leakage. The inputs used to calculate door opening infiltration are comparable to those used by DOE for the AHRI large walk-in freezer with a total 'door-open' time of 28 minutes per day compared to the DOE value of 27 minutes per day per door. In contrast, the AHRI small walk-in freezer had a total door open value of 6 minutes per day.

For the small walk-in freezer, AHRI uses a daily product loading ratio that is 3 times larger than that reported by DOE. The AHRI large walk-in freezer product load is comparable to that reported by others. The lighting load utilized by AHRI agrees with SCE's analysis, but not DOE's. Occupancy loading and lighting schedule are not explicitly mentioned in the other three reports.

Summary

An extensive computerized literature search was performed to identify publications that contained model walk-in box refrigeration load profile data for walk-in coolers and/or freezers. The various components of the model refrigeration load profiles found in the literature for walk-in coolers and freezers are consolidated in Table 2 and Table 3, respectively, at the end of this chapter. The model load profiles found in the literature were analyzed and compared to the AHRI 1250/1251 model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a).

In summary, the AHRI 1250/1251 model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) agrees with the findings reported by the other researchers for a majority of the box specifications and refrigeration load components for both coolers and freezers. However, there are a few differences between the AHRI model load profile and the literature.

For both walk-in coolers and freezers, discrepancies between the AHRI model load profile and the literature include large walk-in box door size and number, absence of crack infiltration, and product loading for the small walk-in box. Although the AHRI 'door-open' time per door is comparable to that reported by DOE, when analyzed on a total door area per wall surface area basis, the AHRI large walk-in cooler/freezer had 1.5% of total door area per wall surface area compared to a literature average of 9.3% while the AHRI small walk-in cooler/freezer had 10.9%. Furthermore, the AHRI Load Spreadsheet does not include infiltration due to crack leakage. Finally, for the small walk-in cooler/freezer, AHRI uses a daily product loading ratio 3 times larger than that reported by DOE, while the AHRI large walk-in cooler/freezer product loading is comparable to that reported by other researchers.

In addition, for walk-in coolers, AHRI reports a walk-in cooler relative humidity of 90% that exceeds the average value of 73.6% reported by the other researchers. While for walk-in freezers, the R-value of the AHRI walk-in freezer construction is 32 h-ft^2-˚F/Btu which exceeds the average freezer R-value of approximately 26 h-ft^2-˚F/Btu found in the literature.

Table 1 presents an analysis of the load components that make up the total refrigeration load for the two AHRI Coolers and the two AHRI Freezers, where it can be seen that the product load of the small and large coolers is about seven times that of the small and large freezers. It is this large difference in product load that is responsible for the AHRI Cooler loads being significantly larger than the corresponding AHRI Freezer loads.

Table 1. Summary of AHRI 1250/1251 Model Load Profiles.

	SMALL COOLER (F)	LARGE COOLER (F)	SMALL FREEZER (F)	LARGE FREEZER (F)
CALCULATIONS				
CONDUCTION				
Conduction Heat Load (Btu/h-ft^2)	4.03032	2.34768	10.52475	6.25970625
INFILTRATION				
Infiltration Heat Load (Btu/h-ft^2)	3.882682954	0.632842305	2.195154725	0.79161131
PRODUCT LOAD				
Product Heat Load (Btu/h-ft^2)	36.328125	12	5.208333333	1.666666667
MISCELLANEOUS LOAD				
Miscellaneous Heat Load (Btu/h-ft^2)	0.979705143	2.569350383	0.964819922	1.471875
TOTAL HEAT LOAD				
Total Heat Load (Btu/h-ft^2)	45.2208331	17.54987269	18.89305798	10.18985923

Table 2. Model Load Profiles For Walk-In Coolers.

MODEL LOAD PROFILES FOR WALK-IN COOLERS						
	AHRI Load Spreadsheet (2009a)	DOE Non-Display Baseline (2010b)	SCE Proposed (2008)	Nevada Energy Control Systems (Kimber 1998)	Sekhar et al. (2004), Sekhar and Lal (2005)	Sujau et al (2006)
SITE CONDITIONS						
Outdoor Ambient Temperature (°F)	80, 95, 110			59.0 (Safeway)		
Sunlight directly on roof?	N – 8pm to 8am, Y – 8am to 8pm					
Roof Temperature (°F)	Roof T = Ambient T + 15°F if there is direct sunlight					
Indoor (Store) Ambient Temperature (°F)	75	75	Hourly weather for Baltimore, MD (54.7 average)	69.9 (Safeway) 57.7 (McDonald's) 61.3 (Walnut Creek) 61.7 (Cameron Park Liquor)	89.6	59
Indoor (Store) Ambient RH (%)	50	40 (weighted national average)	Hourly weather for Baltimore, MD (67.1 average)			55
Ground Temperature (°F)	50	60 (DOE Test Procedure)	50			
BOX OPERATING CONDITIONS						
Interior Temperature (°F)	35	35	35	39.4 (Safeway) 40.0 (McDonald's) 37.2 (Walnut Creek) 46.8 (Cameron Park Liquor)	38.9	35.1 (low load) 36.7 (high load)
Interior RH (typical) (%)	90	60		81.8 (Safeway) 76.3 (McDonald's)		82.3 (low load) 70.0 (high load)
BOX CONSTRUCTION						
Box Width (ft)	8 sm 50 lrg	8.0 sm 20 med 30 lrg		9.5 (Trader Joe's) 9.0 (McDonald's) 13.0 (Walnut Creek)	7.6	10.8
Box Length (ft)	8 sm 50 lrg	10 sm 12 med 25 lrg		28.3 (Trader Joe's) 12.0 (McDonald's) 24.3 (Walnut Creek)	7.6	14.4

MODEL LOAD PROFILES FOR WALK-IN COOLERS						
	AHRI Load Spreadsheet (2009a)	DOE Non-Display Baseline (2010b)	SCE Proposed (2008)	Nevada Energy Control Systems (Kimber 1998)	Sekhar et al. (2004), Sekhar and Lal (2005)	Sujau et al (2006)
Box Height (ft)	8 sm 20 lrg	7.6 sm 9.5 med 12 lrg		8.5 (Trader Joe's) 8.0 (McDonald's) 8.7 (Walnut Creek)	9.2	9.8
Box Floor Area (ft^2)	64 sm 2500 lrg	80 sm 240 med 750 lrg	250 sm 500 1000 2500 lrg	268.9 (Trader Joe's) 108.0 (McDonald's) 315.9 (Walnut Crrek)	57.8	155.5
Box Volume (ft^3)	512 sm 50000 lrg	608 sm 2280 med 9000 lrg		5,695 (Safeway) 2286 (Trader Joe's) 864 (McDonald's) 2,739 (Walnut Creek) 1,880 (Cameron Park Liquor)	531.4	1524.1
Ceiling R-value (h-ft^2-°F/Btu)	25	4" XPS or PU, R-24 (independent testing lab)			5.9 inches of mineral wool	5.9 inches of polystyrene sandwich panel
Wall R-value (h-ft^2-°F/Btu)	25	4" XPS or PU, R-24 (independent testing lab)			5.9 inches of mineral wool	5.9 inches of polystyrene sandwich panel
Floor R-value (h-ft^2-°F/Btu)	25	Uninsulated			5.9 inches of mineral wool	5.9 inches of polystyrene sandwich panel
External Equivalent Convective Film Coefficient (h-ft^2-°F/Btu)		0.68				
Internal Equivalent Convective Film Coefficient (h-ft^2-°F/Btu)		0.25				
Floor Equivalent Convective Film Coefficient (h-ft^2-°F/Btu)		0.87				
Total Conduction Load (Btu/hr)	211.2 sm 4950.0 lrg					648
Floor Heat Load (Btu/hr-ft^2)	0.6	6.9 sm 4.4 med 2.97 lrg (DOE finite element analysis)				

MODEL LOAD PROFILES FOR WALK-IN COOLERS						
	AHRI Load Spreadsheet (2009a)	DOE Non-Display Baseline (2010b)	SCE Proposed (2008)	Nevada Energy Control Systems (Kimber 1998)	Sekhar et al. (2004), Sekhar and Lal (2005)	Sujau et al (2006)
Door Info						
Number of Passage Doors	1 sm 1 lrg	1 sm 1 med 2 lrg		1 (Safeway) 1 (Trader Joe's) 1 (McDonald's) 2 (Walnut Creek) 1 (Cameron Park Liquor)		1
Height of Passage Door (ft)	7 sm 10 lrg	7				7.9
Width of Passage Door(ft)	4 sm 6 lrg	3		3 (McDonald's)		3.9
Passage Door Total Glass Area (ft^2)		0.9 sm 0.9 med 1.8 lrg				
Passage Door R-value (h-ft^2-°F/Btu)	25					
Number of Freight Doors		0 sm 1 med 1 lrg				
Height of Freight Door (ft)		9 med 12 lrg				
Width of Freight Door (ft)		7 med 7 lrg				
Number of Reach-In Doors				13 (Safeway) 9 (Trader Joe's) 13 (Cameron Park Liquor)		
Open Door Blockage Percentage (%)	85	None, 0%	75% for strip curtains 95% for swing-type plastic hinged doors			Strip curtain
INFILTRATION						
Air Density Factor	0.97					
Door Flow Factor		0.8 (ASHRAE Fundamentals)				
Infiltration Calculation	Gosney Olama Equation (ASHRAE Refrigeration Handbook)	Gosney Olama Equation (ASHRAE Refrigeration Handbook)	1.00 air changes per hour (sm) 0.68 ACH 0.46 ACH 0.25 ACH (lrg) (Heatcraft Refrigeration)			

MODEL LOAD PROFILES FOR WALK-IN COOLERS						
	AHRI Load Spreadsheet (2009a)	DOE Non-Display Baseline (2010b)	SCE Proposed (2008)	Nevada Energy Control Systems (Kimber 1998)	Sekhar et al. (2004), Sekhar and Lal (2005)	Sujau et al (2006)
Number of Door Openings	30 openings per hour – 6am to 7am; 2 openings per hour – 7am to 7pm (sm) 32 openings per hour – 6am to 7am; 4 openings per hour – 7am to 7pm (lrg)	60 openings per day for passage and freight doors (DOE Test Procedure)		72.8 openings per day (Safeway passage door)		
Duration of Door Openings	30 seconds per opening – 6am to 7am; 5 seconds per opening – 7am to 7pm (sm) 30 seconds per opening – 6am to 7pm (lrg)	12 seconds per opening for passage and freight doors. Passage and freight doors stand open an additional 15 minutes per day (DOE Test Procedure)		6.4 hours per day (Safeway passage door)		
Infiltration Between Insulated Panel Joints		0.13 ft^3/hr per ft^2 external surface (DOE research)				
PRODUCT LOAD						
Product Type	Fruits and Vegetables					
Product Pull-Down Temp. Difference (°F)	10	10				
Product Loading	6,200/8 lb per hour – 6am to 2pm (sm) 80,000/8 lb per hour – 6am to 2pm (lrg)		70% of capacity 21,840 Btu/hr (sm) 43,680 Btu/hr 86,520 Btu/hr 195,720 Btu/hr (lrg)			
Daily Loading Ratio (lbs of product per ft^3 of refrigerated space)	12.11 sm 1.60 lrg	4 sm 2 med 2 lrg				
Product Specific heat Above Freezing (Btu/lb-F)	0.90	0.90				
MISCELLANEOUS LOAD						
Lighting Power	100 W sm 2500 W lrg	1 CFL bulb, sm 1 CFL bulb, med 3 CFL bulbs, lrg 15 W/bulb, 55 L/W	1.0 W/ft^2 (Heatcraft Refrigeration)			448 W

MODEL LOAD PROFILES FOR WALK-IN COOLERS						
	AHRI Load Spreadsheet (2009a)	DOE Non-Display Baseline (2010b)	SCE Proposed (2008)	Nevada Energy Control Systems (Kimber 1998)	Sekhar et al. (2004), Sekhar and Lal (2005)	Sujau et al (2006)
Percentage of Light Power Converted to Heat	98% sm 85% lrg		High efficacy fluorescent lighting			
Lighting Schedule	30 minutes per hour – 6am to 7am; 2 minutes per hour – 7am to 7pm (sm) 60 minutes per hour – 6am to 7am; 10 minutes per hour – 7am to 7pm (lrg)					
Occupancy (Number of People)	1 person – 6am to 7pm (sm) 2 people – 6am to 7pm (lrg)					
Occupancy Time	60 minutes per hour – 6am to 7am; 2 minutes per hour – 7am to 7pm (sm) 60 minutes per hour – 6am to 7am; 10 minutes per hour – 7am to 7pm (lrg)					
Number of Vehicles	0 sm; 1 lrg					
Power per vehicle (hp)	0 sm; 50 lrg					
Vehicle operating time	N/A (sm) 60 minutes per hour – 6am to 7am (lrg)					
Miscellaneous Heat Load (W)						Varies: 3100 Sensible, 230 Latent to 5100 Sensible, 340 Latent
Defrost Power (kW)						4.6
Defrost Schedule						6, 8, 12, 18, 24, and 30 hr intervals

Table 3. Model Load Profiles For Walk-In Freezers

MODEL LOAD PROFILES FOR WALK-IN FREEZERS				
	AHRI Load Spreadsheet(2009a)	DOE Baseline (2010b)	SCE Proposed (2008)	Nagaraju et al (2001)
SITE CONDITIONS				
Outdoor Ambient Temperature (°F)	80, 95, 110			
Sunlight directly on roof?	N – 8pm to 8am, Y – 8am to 8pm			
Roof Temperature (°F)	Roof T = Ambient T + 15°F if there is direct sunlight			
Indoor (Store) Ambient Temperature (°F)	75	75	Hourly weather for Baltimore, MD (54.7 average)	86
Indoor (Store) Ambient RH (%)	50	40 (weighted national average)	Hourly weather for Baltimore, MD (67.1 average)	
Ground Temperature (°F)	50	65 (DOE Test Procedure)	50	
BOX OPERATING CONDITIONS				
Interior Temperature (°F)	-10	-10	5	5
Interior RH (typical) (%)	50	60		
BOX CONSTRUCTION				
Box Width (ft)	8.0 sm 50.0 lrg	6.0 sm 20.0 med 20.0 lrg		7.1
Box Length (ft)	8.0 sm 50.0 lrg	8.0 sm 9.0 med 25.0 lrg		15.1
Box Height (ft)	8.0 sm 20.0 lrg	7.6 sm 9.5 med 12.0 lrg		7.1
Box Floor Area (ft^2)	64 sm 2500 lrg	48 sm 180 med 500 lrg	250 sm 500 1000 2500 lrg	106.4
Box Volume (ft^3)	512 sm 50000 lrg	364.8 sm 1710.0 med 6000.0 lrg		750.0
Ceiling R-value (h-ft^2-°F/Btu)	32	4" XPS or PU, R-24 (independent testing lab)		6 inches of extruded polystyrene, plywood panels each side
Wall R-value (h-ft^2-°F/Btu)	32	4" XPS or PU, R-24 (independent testing lab)		6 inches of extruded polystyrene, plywood panels each side

MODEL LOAD PROFILES FOR WALK-IN FREEZERS				
	AHRI Load Spreadsheet(2009a)	DOE Baseline (2010b)	SCE Proposed (2008)	Nagaraju et al (2001)
Floor R-value (h-ft^2-°F/Btu)	32	4" XPS or PU, (R-22.42)	R-28 insulation (Energy Independence and Security Act), 6 inches of concrete at R-1.2 (ASHRAE 2005)	6 inches of extruded polystyrene
External Equivalent Convective Film Coefficient (h-ft^2-°F/Btu)		0.68		
Internal Equivalent Convective Film Coefficient (h-ft^2-°F/Btu)		0.25		
Floor Equivalent Convective Film Coefficient (h-ft^2-°F/Btu)		0.87	0.61 (ASHRAE 2005)	
Floor Heat Load (Btu/hr-ft^2)	1.88	3.11 sm 2.88 med 2.54 lrg (DOE finite element analysis)		
Door Info				
Number of Passage Doors	1 sm 1 lrg	1 sm 1 med 2 lrg		
Height of Passage Door (ft)	7 sm 10 lrg	7		
Width of Passage Door(ft)	4 sm 6 lrg	3		
Passage Door Total Glass Area (ft^2)		0.9 sm 0.9 med 1.8 lrg		
Passage Door R-value (h-ft^2-°F/Btu)	32			
Number of Freight Doors		0 sm 1 med 1 lrg		
Height of Freight Door (ft)		9 med 12 lrg		
Width of Freight Door (ft)		7 med 7 lrg		
Open Door Blockage Percentage (%)	85	None, 0%	75% for strip curtains 95% for swing-type plastic hinged doors	

MODEL LOAD PROFILES FOR WALK-IN FREEZERS				
	AHRI Load Spreadsheet(2009a)	DOE Baseline (2010b)	SCE Proposed (2008)	Nagaraju et al (2001)
INFILTRATION				
Air Density Factor	0.96			
Door Flow Factor		0.8 (ASHRAE Fundamentals)		
Infiltration Calculation	Gosney Olama Equation (ASHRAE Refrigeration Handbook)	Gosney Olama Equation (ASHRAE Refrigeration Handbook)	0.78 air changes per hour (sm) 0.53 air changes per hour 0.36 air changes per hour 0.21 air changes per hour (lrg) (Heatcraft Refrigeration)	0.5 air change per hour (247 W)
Number of Door Openings	8 openings per hour – 6am to 7am; 2 openings per hour – 7am to 7pm (sm) 8 openings per hour – 6am to 7am; 4 openings per hour – 7am to 7pm (lrg)	60 openings per day for passage and freight doors (DOE Test Procedure)		
Duration of Door Openings	30 seconds per opening – 6am to 7am; 5 seconds per opening – 7am to 7pm (sm) 30 seconds per opening – 6am to 7pm (lrg)	12 seconds per opening for passage and freight doors. Passage and freight doors stand open an additional 15 minutes per day (DOE Test Procedure)		
Infiltration Between Insulated Panel Joints		0.13 ft^3/hr per ft^2 external surface (DOE research)		
PRODUCT LOAD				
Product Type	Fruits and Vegetables			Fish
Product Pull-Down Temperature Difference (°F)	10	10		0.9°F per hour
Product Loading	1,600/8 lb per hour from 6:00am to 2:00pm (sm) 20,000/8 lb per hour from 6:00am to 2:00pm (lrg)		70% of capacity 57,120 Btu/hr (sm) 113,400 Btu/hr 226,800 Btu/hr 633,360 Btu/hr (lrg)	22,046 lb
Daily Loading Ratio (lbs of product per ft^3–day of refrigerated space)	3.1 sm 0.4 lrg	1 sm 0.5 med 0.5 lrg		
Specific Heat Below Freezing (Btu/lb-F)	0.50	0.45		0.435
MISCELLANEOUS LOAD				

MODEL LOAD PROFILES FOR WALK-IN FREEZERS				
	AHRI Load Spreadsheet(2009a)	DOE Baseline (2010b)	SCE Proposed (2008)	Nagaraju et al (2001)
Lighting Power	100 W sm 2500 W lrg	1 CFL bulb, sm 1 CFL bulb, med 3 CFL bulbs, lrg 15 W/bulb, 55 L/W	1.0 W/ft^2 (Heatcraft Refrigeration)	
Percentage of Light Power Converted to Heat	98% sm 85% lrg		High efficacy fluorescent lighting	
Lighting Schedule	30 minutes per hour – 6am to 7am; 2 minutes per hour – 7am to 7pm (sm) 30 minutes per hour – 6am to 7am; 10 minutes per hour – 7am to 7pm (lrg)			
Occupancy (number of people)	1 person – 6am to 7pm (sm) 2 people – 6am to 7pm (lrg)			
Occupancy time	30 minutes per hour – 6am to 7am; 2 minutes per hour – 7am to 7pm (sm) 30 minutes per hour – 6am to 7am; 10 minutes per hour – 7am to 7pm (lrg)			
Number of Vehicles	0 sm 1 lrg			
Power per Vehicle (hp)	0 sm 50 lrg			
Vehicle Operating Time	N/A (sm) 30 minutes per hour – 6am to 7am (lrg)			
2-way Pressure Relief Valve Heater (W)		23		
2-way Pressure Relief Valve Heater Operation (hr)		24		
Passage Door Heater Power (W / ft)		8		
Passage Door Heater Operation Time per Day (hr/day)		24		
Miscellaneous Heat Load (W)				Varies 700 to 2350
Defrost + Drain-down Heater Power (kW)		1.656 (sm) 2.756 (lrg)		
Defrost Schedule		1 hr / day runtime		

ANALYSIS OF MONITORED DATA FROM FIELD SITES

As a result of the industrial survey, the research team acquired detailed measured data for walk-in coolers and freezers from commercial field sites. These commercial field site data were analyzed to determine the operating characteristics and refrigeration load of in-service walk-in coolers and freezers. The load data from these field sites were compared to the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) that was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c)

Walk-In Cooler/Freezer Operating Data From National Resource Management, Inc.

The research team obtained access to measured data for numerous walk-in coolers and freezers from Emre Schveighoffer, president of National Resource Management, Inc (NRM). National Resource Management monitors walk-ins for various convenience stores, restaurants, supermarkets and institutions. The NRM software system provides access to the monitored data through a web-based interface.

Description of the Remote Site Manager (RSM) System

The Remote Site Manager (RSM) system available from National Resource Management allows users to remotely monitor, control and manage energy-consuming devices within a facility. Internet gateways are installed at the facility to provide the interface between sensors and controllers in the facility and the user. The gateways poll each connected device and send data to a server for storage and monitoring. Each gateway contains the following:

- 11 analog inputs for monitoring current transformers, pressure transducers, temperature sensors or other 4-20 mA signals
- 10 digital inputs for monitoring door status (open/closed), pulses from watt-hour meters, or other relay-type devices
- 10 digital outputs for controlling switch relays connected to loads such as lights and motors

The data available from a typical monitoring installation for a walk-in cooler or freezer consists of the following:

- Return air temperature at the evaporator
- Evaporator coil temperature
- Outside temperature
- Total current draw of the walk-in cooler or freezer refrigeration system
- Unit Cooler fan status (on/off)
- Refrigerant liquid line solenoid valve status (on/off)
- Defrost status (on/off)
- Door status (open/closed)

Figure 1 shows a Remote Site Manager summary web page for a typical facility. This web page provides the location of the facility, the current weather conditions at the facility, the current operating status of the refrigeration and HVAC equipment and the current alarm status.

Tedeschi West Bridgewater #110
397 West Center St., West Bridgewater MA 02379
Tel: 508-941-6842

Taunton, MA
Last Updated on Sep 13 2010, 2:52 pm EDT - Overcast
Temperature 65°F, Humidity 73%, Dewpoint 56°F

Log Out: bfricke
Help

Energy Trend

NRM CoolTrol			Temperature °F				Status								Starts 24 Hr.				% Run 24 Hr.				% Run 7 Days			
Description	Content	Status	Space	Evap	SP	24hr	Byp	Mode	Dfrst	Sol	Fan	Econ	Door	Amps	Econ	Sol	Comp	Fan	Econ	Sol	Comp	Fan	Econ	Sol	Comp	Fan
W.I.C.	Variety		37	31	38	38.9	Off	Run	Off	Off	On	Off	Closed	0.4	0	98	98	139	0	25.7	28.3	50.3	0	28.2	30.8	52.5

Door Heaters		Environmental			% Power		% Power 24 Hours		% Power 7 Days		Settings	
Description	Status	°F	% RH	Dew	Cooler	Freezer	Cooler	Freezer	Cooler	Freezer	Cooler	Freezer
CoolTrol 1		74	42	49	40	60	24	57.9	33.3	61.9	Normal Heat Output	High Heat Output

NRM Mini CoolTrol			Temperature °F				Status						Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	SP	24hr	Mode	Dfrst	Sol	Fan	Door	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Freezer	Ice Cream		-2	-23	-4	1	Run	Off	On	On		9.9	69	134	2	54.2	57	88.3	57.1	59.8	88.3
Product Cooler	Variety		30	40	28	32.5	Run	Off	On	On		6.4	126	126	0	35.4	43.3	100	40.3	47.3	100
W.I.C. Small	Variety		34	32	34	35.6	Run	Off	Off	Off	Closed	0.2	58	60	127	17.9	19	39.8	20.9	22.4	42.7
W.I.F. Small	Variety		-4	-13	-5	-1.4	Run	Off	On	On	Closed	8.8	102	112	104	43.9	47.7	57.5	48.7	52.2	61.3

IP Thermostat		Temperature °F					Status				Compressor			
Description	Status	Space	Supply	24hr	Sp Heat	Sp Cool	Unit Mode	Unit State	Fan Mode	Fan State	Amps	Starts 24 Hr.	% Run 24 Hr.	% Run Week
Hvac Deli		71.7	43.7	71.1	70	72	Auto	Cool	Auto	On	15.2	8	29	45.9
Hvac Store		71.3	75.3	70.2	70	72	Auto	Off	Auto	Off	0.6	1	0.2	4

Temperature Probes			Temperature °F	
Description	Content	Status	Space	24Hr
Deli Meat	Deli		31	31.1
Description	Content	Status	Space	24Hr
Deli Open Face	Deli		31	29.5
Description	Content	Status	Space	24Hr
Ice Chest	Ice		9	9

Schedules		Status			Statistics			Settings		
Description	Status	State	Output	Force Output	Starts 24 Hr.	% Run 24 Hr.	% Run Week	Photo Cell	Set Point	Differential
1: Signs		Active	Off	On Off Clear	2	31.6	28.2	354	425	30
2: Canopy		Active	Off	On Off Clear	2	31.9	28.9	354	415	30
3: Area		Active	Off	On Off Clear	2	32	29.3	354	405	30

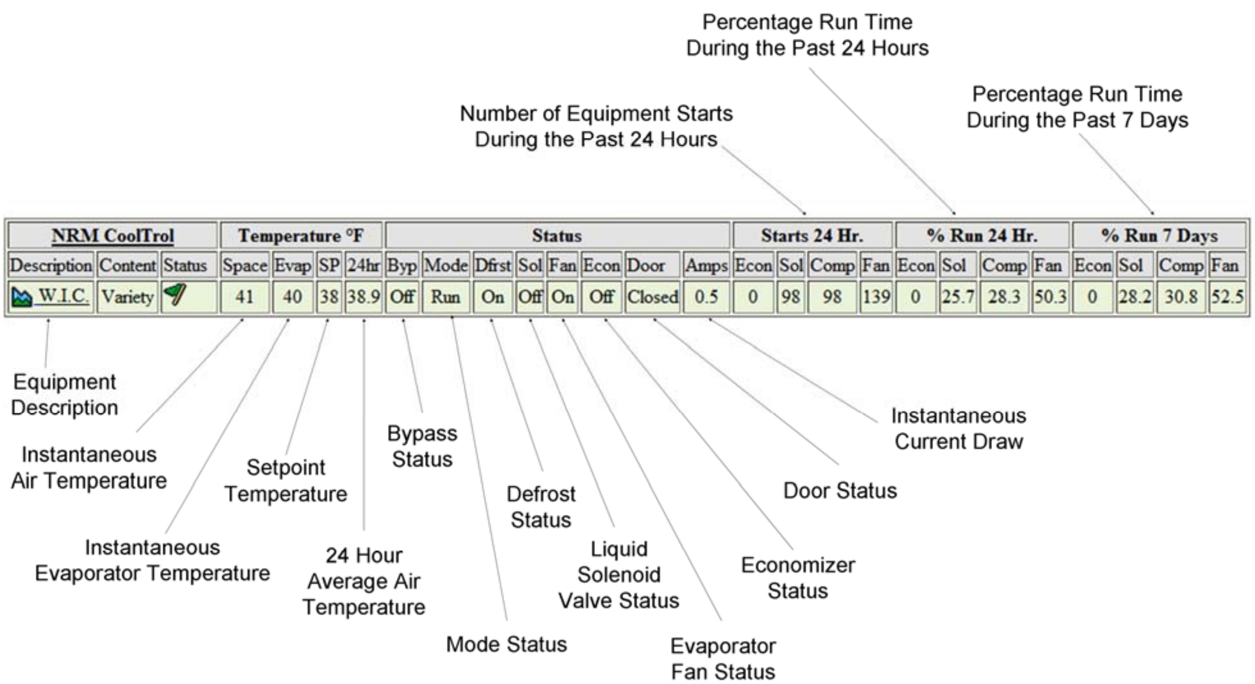
Alarms			
Start Time	End Time	Ack Time	Text

Comments

Figure 1. Remote Site Manager Summary Web Page

Figure 2 shows a sample table for a walk-in display cooler as it appears on the summary web page of the Remote Site Manager system. The following information is typically provided on each table:

- Equipment description: A descriptive name of the device being monitored
- Instantaneous air temperature: The instantaneous air temperature within the refrigerated space
- Instantaneous evaporator temperature: The instantaneous temperature of the evaporator in the refrigerated space
- Setpoint temperature: The thermostat setpoint temperature for the refrigerated space
- 24 hour average air temperature: The average air temperature within the refrigerated space during the past 24 hours
- Bypass status: Status of the 'Bypass Mode' which allows the user to bypass the refrigeration system control equipment installed by National Resource Management and revert to the original refrigeration system control equipment (On/Off)
- Mode status: Status of the monitoring and control system installed by National Resource Management (Run/Off)
- Defrost status: Status of the evaporator defrost heaters (On/Off)
- Liquid solenoid status: Status of the refrigerant liquid line solenoid valve (On/Off)



NRM CoolTrol			Temperature °F				Status								Starts 24 Hr.				% Run 24 Hr.				% Run 7 Days			
Description	Content	Status	Space	Evap	SP	24hr	Byp	Mode	Dfrst	Sol	Fan	Econ	Door	Amps	Econ	Sol	Comp	Fan	Econ	Sol	Comp	Fan	Econ	Sol	Comp	Fan
W.I.C.	Variety		41	40	38	38.9	Off	Run	On	Off	On	Off	Closed	0.5	0	98	98	139	0	25.7	28.3	50.3	0	28.2	30.8	52.5

Figure 2. Sample Status Table for a Walk-In Display Cooler from the Remote Site Manager Software (National Resource Management, Inc.).

- Unit Cooler fan status: Status of the evaporator fans (On/Off)
- Economizer status: Status of the economizer (On/Off)
- Door status: Status of the personnel access door of the walk-in cooler or freezer (Open/Closed)
- Instantaneous Current draw: Instantaneous current draw, in amperes, of the walk-in cooler or freezer refrigeration system
- Number of equipment starts during the past 24 hours: Number of times that the economizer, liquid solenoid, compressor, and evaporator fans have turned on during the past 24 hours
- Percentage run time during the past 24 hours: Percentage of time that the economizer, liquid solenoid, compressor, and evaporator fans have been on during the past 24 hours
- Percentage run time during the past 7 days: Percentage of time that the economizer, liquid solenoid, compressor, and evaporator fans have been on during the past 7 days

Figure 3 shows a sample Remote Site Manager trend chart that provides a time history of measured quantities for a walk-in display cooler. In the upper portion of the trend chart, the time history of the air temperature within the walk-in cooler (dark blue line), the temperature of the walk-in cooler evaporator (light blue line) and the thermostat setpoint (red line) are displayed. In the middle of the trend chart, the time history of the refrigeration system current draw (black line) is displayed. Finally, the lower portion of the trend chart shows the operational status of the following devices:

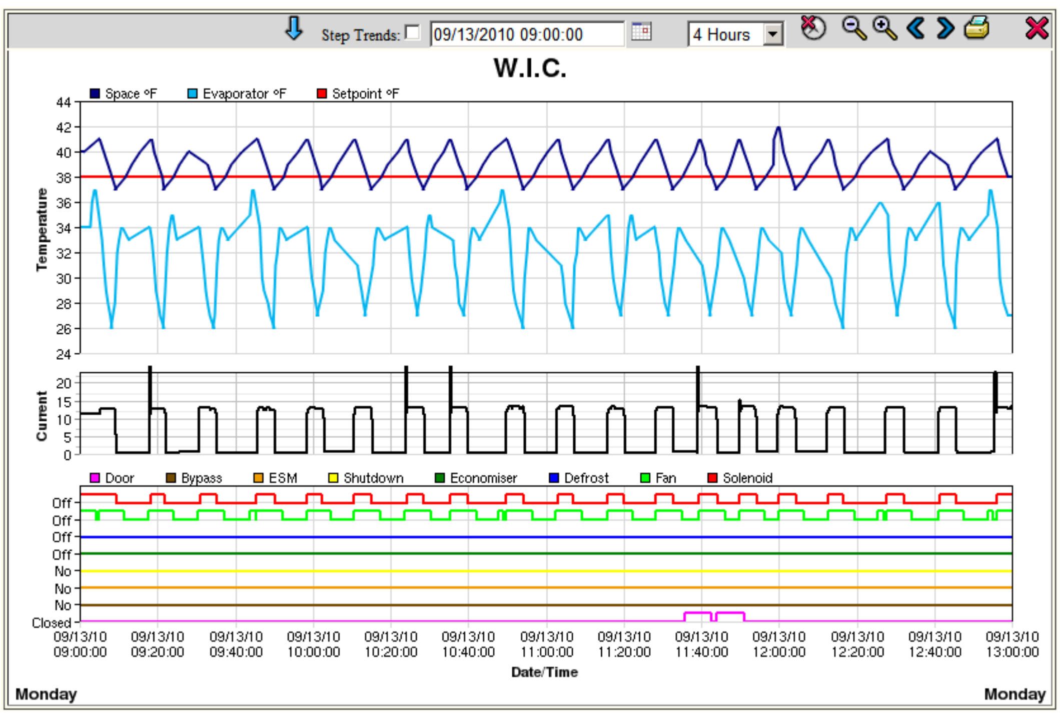


Figure 3. Sample Trend Chart for a Walk-In Display Cooler from Remote Site Manager (National Resource Management, Inc.).

- Solenoid (red line): On/Off status of the refrigerant liquid line solenoid valve
- Fan (light green line): On/Off status of the evaporator fans
- Defrost (blue line): On/Off status of the evaporator defrost heaters
- Economizer (dark green line): On/Off status of the economizer
- Shutdown (yellow line): Yes/No status of the refrigeration system 'Shutdown Button' which can be used to shut down the refrigeration system for 20 minutes; typically used during loading and unloading of the walk-in cooler or freezer
- ESM (orange line): Yes/No status of the 'Energy Savings Mode' which allows the temperature within the refrigerated space to drift (for example, at night); used with non-perishable goods only
- Bypass (brown line): Yes/No status of the 'Bypass Mode' which allows the user to bypass the refrigeration system control equipment installed by National Resource Management and revert to the original refrigeration system control equipment
- Door (magenta line): Open/Closed status of the personnel access door of the walk-in cooler or freezer

Description of Field Sites from National Resource Management

With the consent of National Resource Management, Inc., the research team was granted access to monitored data for the following two facilities:

- Tedeschi Food Shop (#110), Bridgewater, MA
- Chili's Restaurant (#1070), Lincoln, RI

Tedeschi Food Shop

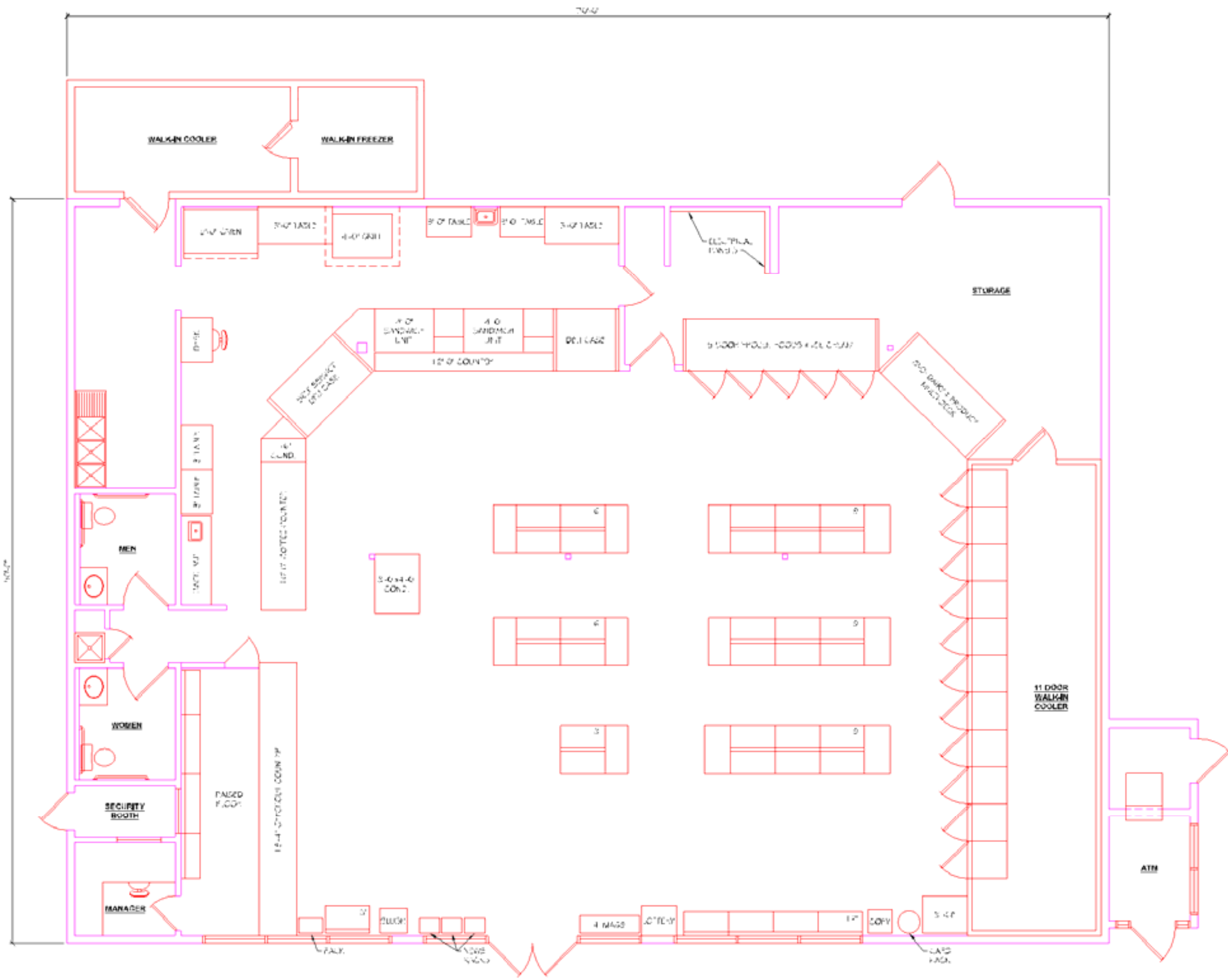
Figure 4 shows a floor plan for the Tedeschi Food shop in Bridgewater, MA. Monitored data from the 11-door display walk-in cooler, shown on the lower right side of the floor plan, was analyzed. This 11-door display walk-in cooler has a plan area of 32 ft x 9 ft with a personnel door located on one of the 9 ft wall sections. The refrigeration equipment for the 11-door display cooler consists of the following:

- Condensing Unit: Climate Control CZT045M6C (Located outdoors)
  R-404A, 39,760 Btu/hr @ 90°F ambient, 25°F SST, 4.5 hp
- Unit Coolers: Climate Control LSC160AJ (Quantity: 2)
  16,000 Btu/hr @ 25°F SST, 10°F TD, 2100 cfm, 171 W
  (Located along the 32 ft wall, opposite of the display doors)

The original unit cooler fan motors were replaced with electronically commutated motors (ECM).

Figure 5 shows a photograph of the exterior of the 11-door display walk-in cooler while Figures 6 and 7 show interior photographs of the 11-door display walk-in cooler. In Figure 6, the two evaporators of the display walk-in cooler can be seen along the back wall of the cooler, opposite of the 11 display doors.

During sufficiently cold weather conditions, the 11-door display walk-in cooler can be operated in economizer mode. In this mode, the refrigeration system is shut off and all cooling is provided by cold outside air which is drawn into the cooler. In Figures 6 and 7, the economizer duct can be seen, which runs along the ceiling in front of the evaporators. During economizer operation, cold air from outside the building is brought into the walk-in cooler through this economizer duct and discharged near the wall opposite of the personnel door. Air is discharged from the walk-in cooler through an opening located in the back wall, near the personnel door.



EXISTING CONDITIONS PLAN
SCALE: 1/4" = 1'-0"

Figure 4. Floor Plan of Tedeschi Food Shop (#110), Bridgewater, MA.

Figure 5. Photograph of the Exterior of the 11-Door Display Walk-In Cooler at Tedeschi Food Shop (#110), Bridgewater, MA.

Figure 6. Photograph of the Interior of the 11-Door Display Walk-In Cooler at Tedeschi Food Shop (#110), Bridgewater, MA, looking from the Personnel Door.

Figure 7. Photograph of the Interior of the 11-Door Display Walk-In Cooler at Tedeschi Food Shop (#110), Bridgewater, MA, looking from the Wall Opposite of the Personnel Door.

Chili's Restaurant

For the Chili's Restaurant (#1070), Lincoln, RI, monitored data from the beer cooler, food cooler and food freezer were analyzed. The beer cooler, which is maintained at 38°F, has a plan area of 6.25 ft x 7 ft with a height of 9 ft. A personnel door is located on the 7 ft wall. The refrigeration equipment for the beer cooler consists of the following:

- Condensing Unit: Cold Zone Model OR-H100H22-2T (Located outdoors)
  R-22, 9,550 Btu/hr @ 95°F ambient, 25°F SST, 1.0 hp
- Unit Cooler: Cold Zone HTA28-97B
  9,700 Btu/hr @ 25°F SST, 10°F TD, 1420 cfm, 70 W
  (Located along the 7 ft wall, opposite of the door)

The food cooler, which is maintained at 38°F, has a plan area of 17 ft x 7.5 ft with a height of 8.5 ft. A personnel door is located on the 7.5 ft wall. The refrigeration equipment for the food cooler consists of the following:

- Condensing Unit: Cold Zone Model OR-H151H22-2T (Located outdoors)
  R-22, 12,950 Btu/hr @ 95°F ambient, 25°F SST, 1.5 hp

- Unit Coolers: Cold Zone HTA18-66B (Quantity: 2)
  6,600 Btu/hr @ 25°F SST, 10°F TD, 740 cfm, 120 W
  (Located along the 7.5 ft wall, opposite of the door)

Finally, the freezer, which is maintained at 10°F, has a plan area of 10.25 ft x 7.25 ft with a height of 8.5 ft. A personnel door is located on the 7.25 ft wall. The refrigeration equipment for the freezer consists of the following:

- Condensing Unit: Cold Zone Model OR-H315L44-2T (Located outdoors)
  R-404A, 20,870 Btu/hr @ 95°F ambient, 0°F SST, 3.0 hp
- Unit Coolers: Cold Zone HTE26-92B (Quantity: 2)
  9,600 Btu/hr @ -10°F SST, 10°F TD, 1560 cfm, 70 W
  (Located along the 7.25 ft wall, opposite of the door

Analysis of Commercial Field Site Data from National Resource Management

The following information was collected from the National Resource Management web-based monitoring system for each of the four walk-ins described above:

- Thermostat set-point of the walk-in.
- Hourly percentage compressor run-time for each hour of each of the days: 1 July 2009, 1 October 2009, 1 January 2010 and 1 April 2010.
- Hourly outdoor ambient temperature for each hour of each of the days: 1 July 2009, 1 October 2009, 1 January 2010 and 1 April 2010.
- Door opening/closing times for each of the days: 1 July 2009, 1 October 2009, 1 January 2010 and 1 April 2010.
- Defrost initiation/termination times for each of the days: 1 July 2009, 1 October 2009, 1 January 2010 and 1 April 2010.

A sample plot showing the hourly percentage compressor run-times for the 11-door display walk-in cooler at the Tedeschi Food shop in Bridgewater, MA for 1 July 2009 is given in Figure 8 while the hourly outdoor ambient temperatures at this store for 1 July 2009 are shown in Figure 9. Run-time charts and trend charts for the four walk-ins, obtained directly from the National Resource Management web based monitoring system, are given in Appendix A.

For each of the days studied, the maximum, minimum and average of the hourly percentage compressor run-times were determined. The daily average of the hourly percentage compressor run-times was considered to be the dividing line between ‘low load’ operation and ‘high load’ operation. Then, for each day studied, an average ‘low load’ compressor run-time was calculated by averaging those hourly values of percentage run-time less than or equal to the daily average. Similarly, an average ‘high load’ compressor run-time was calculated by averaging those hourly values of percentage run-time greater than the daily average. Finally, the amount of time that the compressor operated at ‘low load’ and ‘high load’ was determined.

A summary of the run-time analysis of the four monitored walk-ins is provided in Table 4. It can be seen that the average hourly run-time during 'low load' operation for the three walk-in coolers was 16.6% while the average hourly run-time during 'high load' operation for the three walk-in coolers was 37.9%. On average, the three walk-in coolers operated 50.3% of the time at 'low load' conditions and 49.7% of the time at 'high load' conditions. It can also be seen that the average hourly run-time during 'low load' operation for the Chili's walk-in freezer was 33.3% while the average hourly run-time during 'high load' operation for the Chili's walk-in freezer was 60.4%. The Chili's walk-in freezer operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

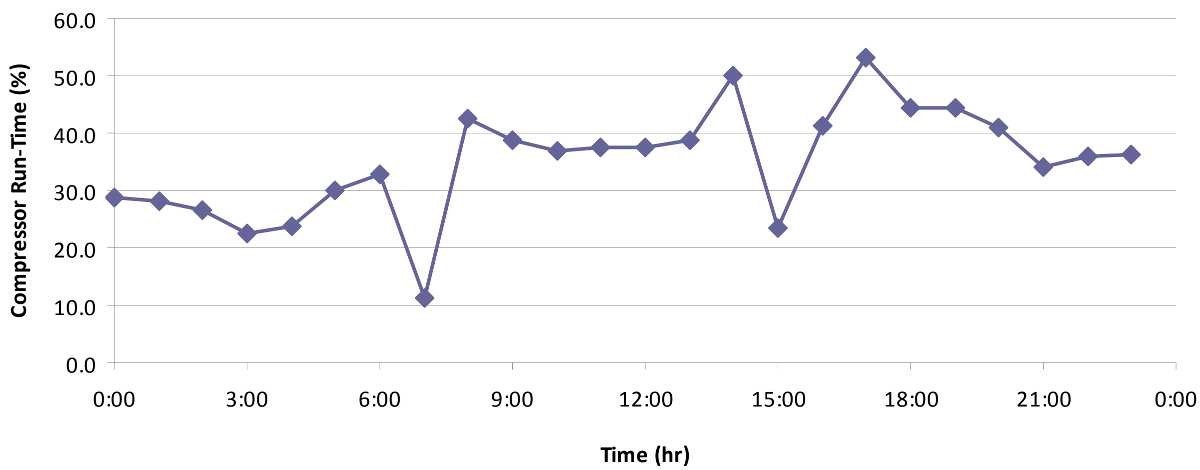


Figure 8. Hourly Compressor Run-Time for the 11-Door Display Walk-In Cooler at the Tedeschi Food shop in Bridgewater, MA (1 July 2009).

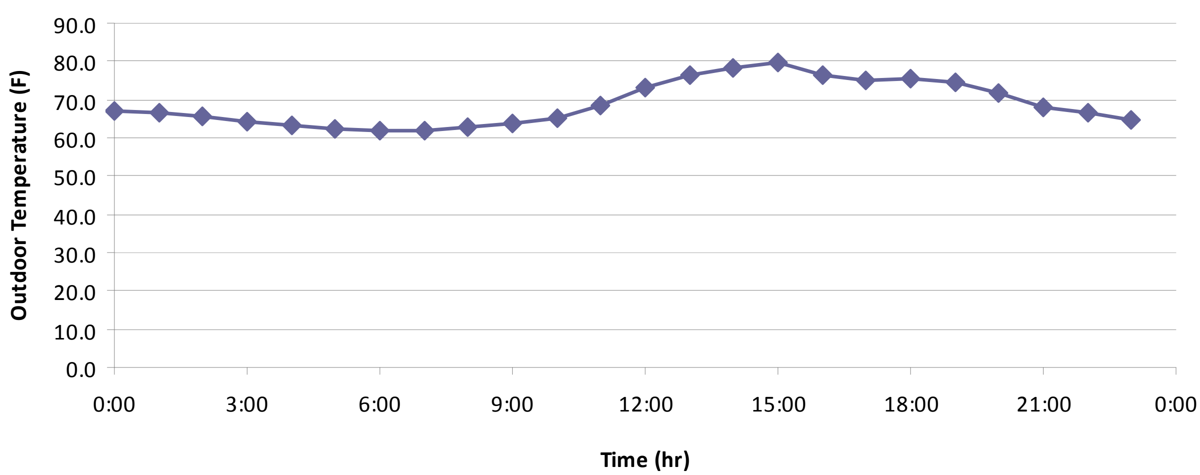


Figure 9. Outdoor Ambient Temperature at the Tedeschi Food shop in Bridgewater, MA (1 July 2009).

In AHRI Standard 1250/1251 (AHRI 2009b, 2009c), reference is made to the ‘box load low’ and the ‘box load high’, which are the refrigeration loads during the low load period of the day and the high load period of the day, respectively. In AHRI Standard 1250/1251, the ‘box load low’ for a walk-in cooler is considered to be 10% of the refrigeration capacity and the refrigeration system is considered to operate 67% of the time during a day at ‘box load low’. The ‘box load high’ for a walk-in cooler is considered to be 70% of the refrigeration capacity and the refrigeration system is considered to operate 33% of the time during a day at ‘box load high’.

Table 4. Run-Time Analysis of Walk-In Coolers and Freezers.

Statistic	Tedeschi 11-Door Cooler	Chili’s Beer Cooler	Chili’s Food Cooler	Cooler Average	AHRI 1250/1251 Cooler (AHRI 2009b, 2009c)	Chili’s Food Freezer	AHRI 1250/1251 Freezer (AHRI 2009b, 2009c)
Minimum Hourly Run-Time (%)	9.5	1.8	8.4	6.6		24.0	
Maximum Hourly Run-Time (%)	39.4	32.0	82.6	51.3		84.2	
Average Hourly Run-Time (%)	24.8	13.1	44.0	27.3		45.7	
Average ‘Low Load’ Run-Time (%)	16.4	7.7	25.8	16.6	BLL = 10	33.3	BLL = 40
Time at ‘Low Load’ (%)	45.8	55.2	50.0	50.3	67	54.2	67
Average ‘High Load’ Run-Time (%)	32.3	19.6	61.9	37.9	BLH = 70	60.4	BLH = 80
Time at ‘High Load’ (%)	54.2	44.8	50.0	49.7	33	45.8	33

Considering the three monitored walk-in coolers, the average ‘low load’ compressor run-time was 16.6%, as compared to the ‘box load low’ of 10% given in Standard 1250/1251, while the average ‘high load’ compressor run time for the three monitored walk-in coolers was 37.9%, as compared to the ‘box load high’ of 70% given in Standard 1250/1251.

On average, the three monitored walk-in coolers operated 50.3% of the time at ‘low load’ conditions, as compared to 67% of the time given in Standard 1250/1251, and 49.7% of the time at ‘high load’ conditions, as compared to 33% of the time given in Standard 1250/1251.

In AHRI Standard 1250/1251 (AHRI 2009b, 2009c), the ‘box load low’ for a walk-in freezer is considered to be 40% of the refrigeration capacity and the refrigeration system is considered to operate 67% of the time during a day at ‘box load low’. The ‘box load high’ for a walk-in freezer is considered to be 80% of the refrigeration capacity and the refrigeration system is considered to operate 33% of the time during a day at ‘box load high’.

In contrast, the average ‘low load’ compressor run time of the one monitored walk-in freezer was 33.3%, as compared to the ‘box load low’ of 40% given in Standard 1250/1251, while its average ‘high load’ compressor run time was 60.4%, as compared to the ‘box load high’ of 80% given in Standard 1250/1251.

The monitored walk-in freezer operated 54.2% of the time at ‘low load’ conditions, as compared to 67% of the time given in Standard 1250/1251, and 45.8% of the time at ‘high load’ conditions, as compared to 33% of the time given in Standard 1250/1251.

Therefore, the AHRI Standard 1250/1251 (AHRI 2009b, 2009c) assumes approximately a one-third to two-thirds split between the amount of time that the compressor operates at ‘high load’ and the amount of time that it operates at ‘low load’ for both coolers and freezers while the field data showed more like a 50-50 split. Also, the AHRI Standard 1250/1251 assumes a ‘low load’ for both coolers and freezers that is on the same order as that of the measured data. Furthermore, the AHRI Standard 1250/1251 assumes a ‘high load’ for coolers that is about twice that of the measured data and assumes a ‘high load’ for freezers that is about one-third higher than that of the measured data.

Table 5 shows a summary of the personnel door opening and closing events for the four walk-ins. The table gives the number of times the doors were opened during the four days studied, the average number of door openings per day and the average duration of the door openings. Data for the Chili’s Beer Cooler is missing because the door sensor was not functioning during the test period. The table shows considerable variation in the number and the duration of the door opening events for the three walk-ins whose door sensors were operational. It should also be noted that this data includes only the personnel door of the Tedeschi 11-door cooler and does not include the 11 display doors through which customers access the products. As shown in Table 5, the average number of door opening events for the three active walk-ins is 38.8 door opening events per day. The average duration of the door opening events for the three active walk-ins is 2.3 minutes per door opening event. The average size of these three walk-ins is 163.3 ft^2.

Table 5. Analysis of Walk-In Cooler and Freezer Door Opening and Closing Events.

Statistic	Tedeschi 11-Door Cooler	Chili’s Beer Cooler	Chili’s Food Cooler	Chili’s Food Freezer	Overall Average	AHRI Load Spreadsheet (2009a)
Number of door openings (during four days)	37	--	88	340		
Average number of door openings per day	9.3	--	22.0	85	38.8	55.5
Average duration of door openings (min)	4.8	--	1.0	1.2	2.3	0.41

The rating equations given in Standard 1250/1251 (AHRI 2009b, 2009c) are based upon the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a). This spreadsheet gives specifications for a small walk-in cooler/freezer (64 ft^2 plan area) and a large walk-in cooler/freezer (2500 ft^2 plan area). The small walk-in cooler has 30 door opening events that last 30 seconds each and 24 door openings events that last 5 seconds each, per day. The small walk-in freezer has 8 door openings at 30 seconds each and 24 door openings at 5 seconds each, per day. The large walk-in cooler has 80 door opening events per day that last 30 seconds each and the large walk-in freezer has 56 door opening events per day of 30 seconds each. As shown in Table 5, the average number of door opening events for the four walk-ins given in the AHRI Load Spreadsheet (AHRI 2009a) is 55.5 door openings per day, with an average duration of 24.6 seconds or 0.41 minutes per opening.

Therefore, the field data and the AHRI 1250/1251 Load Spreadsheet agree fairly well on the average number of door opening events per day: 38.8 door openings per day versus 55.5 door openings per day. However, the field data indicates that the average duration of a door opening event is 2.3 minutes while the average duration of the door opening events specified in the AHRI 1250/1251 Load Spreadsheet is only 0.41 minutes, an order of magnitude less. Thus, the AHRI 1250/1251 Load Spreadsheet greatly under estimates the average duration of the door opening events as compared to the measured data from the three in-service walk-in coolers/freezer.

Table 6 shows a summary of the defrost cycles for the four walk-ins. The table gives the total number of defrost cycles during the four days studied, the average number of defrost cycles per day and the average duration of the defrost cycles. It can be seen that, on average, during the four days studied, the three walk-in coolers experienced 2.42 defrost cycles per day with an average duration of 33.5 minutes per defrost cycle. It can also be seen that the Chili's walk-in freezer experienced 3 defrost cycles per day with an average duration of 37.8 minutes per defrost cycle.

Table 6. Analysis of Walk-In Cooler and Freezer Defrost Cycles.

Statistic	Tedeschi 11-Door Cooler	Chili's Beer Cooler	Chili's Food Cooler	Cooler Average	Chili's Food Freezer
Number of defrost cycles (during four days)	7	5	17	9.7	12
Average number of defrost cycles per day	1.75	1.25	4.25	2.42	3
Average duration of defrost cycles (min)	41.6	24.3	34.6	33.5	37.8

The Standard 1250/1251 rating equations are designed to include only the non-equipment related refrigeration loads. That is, the Annual Walk-in Energy Factor (AWEF) is defined as follows (AHRI 2009b, 2009c):

> *Annual Walk-in Energy Factor (AWEF).* A ratio of the total heat, not including the heat generated by the operation of refrigeration systems, removed, in Btu, from a walk-in box during one year period of usage for refrigeration to the total energy input of refrigeration systems, in watt-hours, during the same period.

Therefore, the refrigeration loads due to both the defrost cycles and the operation of the unit cooler fans are omitted from the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a). However, when calculating the AWEF, the electrical energy required to operate the defrost system and the unit cooler fans are both included in the total energy consumption of the refrigeration system.

A summary of the analysis of the refrigeration load per unit area of the three monitored walk-in coolers is provided in Table 7. For each of the coolers, the table gives the floor area, the set point temperature, the outdoor ambient temperature and the average refrigeration load per unit area during the four days studied.

Table 7. Analysis of Cooler Refrigeration Loads

Cooler	Floor Area (ft^2)	Set Point (˚F)	Outdoor Ambient (˚F)	Refrigeration Load per Unit Area (Btu / hr–ft^2)
Tedeschi 11-Door Cooler	288.0	37.5	48.8	32.9
Chili's Beer Cooler	43.8	38.0	48.8	28.5
Chili's Food Cooler	127.5	38.0	48.8	44.7
Average Cooler	153.1	37.8	48.8	35.4
AHRI 1250/1251 Small Cooler	64.0	37.8	48.8	45.2
AHRI 1250/1251 Large Cooler	2500.0	37.8	48.8	17.5
Average AHRI Cooler	1282.0	37.8	48.8	31.4

As shown in Table 7, the refrigeration loads for the three monitored walk-in coolers, during the four days studied, range from 28.5 Btu / hr–ft^2 to 44.7 Btu / hr–ft^2. The average refrigeration load per unit area for the three monitored walk-in coolers during the four days studied is 35.4 Btu / hr–ft^2.

The AHRI Load Spreadsheet (AHRI 2009a) calculates a refrigeration load for a small walk-in cooler (64 ft^2 plan area) and a large walk-in cooler (2500 ft^2 plan area). These refrigeration loads are 45.2 Btu / hr–ft^2 for the small cooler and 17.5 Btu / hr–ft^2 for the large cooler. Averaging these two loads gives 31.4 Btu / hr–ft^2 for an 'average' AHRI cooler.

Thus, the refrigeration load for the 'small AHRI cooler' correlates well with the measured data. However, the refrigeration load for the 'large AHRI cooler' is less than half that given by the measured data.

The analysis of the refrigeration load per unit area of the one monitored walk-in freezer is summarized in Table 8 along with the corresponding data for the 'small and large AHRI freezers' as calculated with the AHRI Load Spreadsheet (AHRI 2009a). Here it can be seen that there is a considerable discrepancy between the refrigeration loads calculated by the AHRI Load Spreadsheet and the measured refrigeration load of the Chili's food freezer. The refrigeration load of the 'small and large AHRI freezers' is only about one fifth that of the measured data.

Table 8. Analysis of Freezer Refrigeration Loads

Freezer	Floor Area (ft^2)	Set Point (˚F)	Outdoor Ambient (˚F)	Refrigeration Load per Unit Area (Btu / hr–ft^2)
Chili's Food Freezer	74.3	-1.5	48.8	95.2
AHRI 1250/1251 Small Freezer	64.0	-1.5	48.8	18.9
AHRI 1250/1251 Large Freezer	2500.0	-1.5	48.8	10.2
Average AHRI Freezer	1282.0	-1.5	48.8	14.6

Summary

An industrial survey was performed to acquire detailed measured data for walk-in coolers and freezers from commercial field sites. These commercial field site data were analyzed to determine the operating characteristics and refrigeration load of in-service walk-in coolers and freezers. The load data from these field sites were compared to the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) that was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c)

In summary, the AHRI Standard 1250/1251 (AHRI 2009b, 2009c) assumes 'low loads' for both coolers and freezers that correlates well with the measured 'low loads', however, the 'high loads' assumed in the AHRI Standard are higher than the measured 'high loads' for both coolers and freezers. In contrast, the AHRI Standard assumes that the refrigeration system of a cooler spends 33.2% more time in 'low load' operation as compared to the monitored data for the coolers. The AHRI Standard also assumes that the refrigeration system of a freezer spends 23.6% more time in 'low load' operation as compared to the monitored data for the freezer.

On the other hand, the AHRI 1250/1251 Load Spreadsheet (AHRI 2009a) agrees very closely with the field data on the average number of door opening events per day, however, the average duration of a door opening event in the field data is an order of magnitude greater than that specified in the AHRI 1250/1251 Load Spreadsheet.

The three monitored walk-in coolers averaged 2.42 defrosts per day with an average duration of 33.5 minutes per defrost while the monitored walk-in freezer experienced 3 defrost cycles per day averaging 37.8 minutes per defrost cycle. The AWEF, as defined in AHRI Standard 1250/1251, does not include the refrigeration loads due to both the defrost cycles and the operation of the unit cooler fans in the calculation of the AWEF. The Standard does include the electrical energy required to operate the defrost system and the unit cooler fans in the total energy consumption of the refrigeration system in the AWEF calculation.

Finally, the refrigeration load calculated by the AHRI 1250/1251 Load Spreadsheet (AHRI 2009a) for the ‘small AHRI cooler’ correlates well with the measured data while the load calculated for the ‘large AHRI cooler’ is less than half that given by the measured data. However, the refrigeration load calculated by the AHRI Load Spreadsheet for the ‘small and large AHRI freezers’ is only about 20% of the measured value.

REVIEW AND SELECTION OF MODELING TOOLS

The literature review revealed two computer modeling techniques that could be used to determine the energy efficiency of walk-in cooler and freezer refrigeration systems as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit. One technique involves the use of detailed refrigeration system modeling tools to determine the energy usage of the walk-in cooler/freezer refrigeration system. The other technique involves the use of whole building energy simulation programs that are capable of modeling the walk-in cooler/freezer envelope, internal and external loads, and the walk-in cooler/freezer refrigeration system.

Refrigeration System Modeling Tools

Refrigeration system modeling tools are based on models of the individual components of a refrigeration system (Ding 2007). However, these tools lack detailed information regarding the heat transfer to the evaporator and from the condenser. Typically, these modeling tools assume a constant evaporator load and they assume that the energy is rejected from the condenser at a single specified temperature. Thus, refrigeration system modeling tools make it difficult to account for the effects of variations in ambient dry-bulb and wet-bulb temperatures as well as variations in internal and external loads.

The literature review revealed several refrigeration system modeling tools which could potentially be used to model the energy usage of walk-in cooler and freezer refrigeration systems:

- *CoolPack* available from the Technical University of Denmark (Technical University of Denmark 1999)
- *Pack Calculation II* available from IPU(IPU 2010).
- *ORNL Heat Pump Design Model* (HPDM), Mark VI (DOE 2009)

The research team analyzed the capabilities of *CoolPack*, *Pack Calculation II* and the *ORNL Heat Pump Design Model* and a summary of the capabilities of these refrigeration system modeling tools is given below.

CoolPack is a collection of simulation models for refrigeration systems. Each of the models has a specific purpose including cycle analysis, dimensioning of main components, system simulation, energy analysis and life cycle cost. However, *CoolPack* is only capable of performing a static calculation for a single value of refrigeration load and a single ambient dry-bulb/wet-bulb condition at the condenser. Therefore *CoolPack* is not capable of simulating the performance of a refrigeration system whose load varies according to a daily schedule and it is not capable of accounting for condenser ambient conditions that vary with the weather.

Pack Calculation II is an application for calculating the yearly energy consumption of a refrigeration plant based upon its geographical location. *Pack Calculation II* contains models of 11 commonly used refrigeration cycles and more than 4000 commercially available compressors. It also has the capability of accounting for variations in condenser performance due to ambient dry-bulb and wet-bulb conditions that change according to detailed weather data. *Pack Calculation II* can model a user supplied time-dependent refrigeration load, however, it cannot model a temperature-dependent refrigeration load so the effects of weather data on refrigeration load (conduction and infiltration) are ignored.

The *ORNL Heat Pump Design Model* (HPDM) is a steady-state performance simulation and design tool for air-to-air heat pumps. The standard vapor-compression cycle is modeled with empirical representations for compressor performance and first-principle region-by-region modeling of the heat exchangers. The *ORNL Heat Pump Design Model* provides for a very detailed specification of the refrigeration system components including air-side fin patterns and heat transfer coefficients, refrigerant flow correlations and thermodynamic and transport properties of refrigerants and refrigerant line losses. It predicts EER, capacity, air- and refrigerant-side conditions for cooling operation with first-principles heat exchanger modeling; handles a variety of refrigerants; and will size flow control devices given heat exchanger design exit conditions. However, the *ORNL Heat Pump Design Model* is only capable of performing a static calculation for a single value of refrigeration load and a single ambient dry-bulb/wet-bulb condition at the condenser. Therefore the *ORNL Heat Pump Design Model* is not capable of simulating the performance of a refrigeration system whose load varies according to a daily schedule and it is not capable of accounting for condenser ambient conditions that vary with the weather.

Based on this analysis of refrigeration system modeling tools, it was determined that these type of models would not be suitable for validating AHRI Standard 1250/1251 due to their inability to perform annual hourly energy simulations using time varying refrigeration load schedules and detailed weather data.

Whole Building Energy Simulation Programs

Whole building energy simulation programs can simulate the hourly energy use of a building over a one-year period. These building energy simulation tools are capable of modeling the building envelope, heating and cooling loads and HVAC performance based on detailed weather data and building construction data. Two whole building energy simulation programs were identified that could potentially be used to model the energy usage of walk-in coolers and freezers:

- *EnergyPlus*, developed by the U.S. Department of Energy (DOE 2010a)
- *eQUEST*, supported by the Energy Design Resources program of the California Public Utilities Commission (James J. Hirsch and Associates 2009)

The refrigeration module of *eQUEST* makes use of a comprehensive set of input data concerning the design of a walk-in cooler/freezer and its associated refrigeration equipment, including:

- Walk-in box construction and building materials
- Walk-in box refrigeration load schedules including daily schedules of occupancy, lighting, infiltration, vehicles and product loading
- Annual weather data files for each climate zone in the United States
- Compressor performance curves and compressor capacity control
- Condenser type, capacity and fan flow rate and power

- Direct expansion evaporator, capacity and fan flow rate and power

eQuest is capable of simulating the annual energy consumption of a walk-in refrigeration system as well as its total cooling for each climatic zone in the United States (2004 International Energy Conservation Code (IECC) Climate Zones 1 through 7), for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box inside and condensing unit outside
- Walk-in box and condensing unit outside

eQuest is also capable of simulating the AHRI Standard 1250/1251 test method for rating the performance of walk-in coolers and freezers for the following two configurations:

- Condensing unit located inside
- Condensing unit outside

Furthermore, Southern California Edison used *eQuest*, to investigate the effects of floating head controls, variable speed evaporator fans and infiltration reduction devices upon walk-in refrigerator/freezer performance(SCE 2008).

Therefore, based upon the results of this literature review and analysis, *eQuest* (James J. Hirsch and Associates 2009), a state-of-the-art, publically available whole building energy model, was selected to estimate a walk-in refrigeration system's capacity and energy usage as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in box and the condensing unit.

VALIDATION OF *eQuest* MODEL

The ability of the *eQuest* whole building energy simulation tool to model a walk-in cooler or freezer was ascertained by comparing its calculated results to experimental data from an instrumented walk-in freezer. In addition, *eQuest* simulation results for a prototypical walk-in cooler were compared with results obtained from various load calculation methods.

Instrumented Walk-In Freezer at PG&E Food Service Technology Center

The research team acquired monitored data from a series of laboratory tests performed by the Pacific Gas & Electric Company (PG&E) on an instrumented walk-in freezer at the Food Service Technology Center (FSTC). These laboratory tests were simulated with *eQuest* and the *eQuest* results were compared to the measured data.

Appendix B gives the intended test protocol and description of the walk-in as provided to the research team by the FSTC. Appendix B also shows a sample of the monitored data provided by the FSTC.

Description of FSTC Walk-In Freezer

The specifications of the walk-in freezer tested by FSTC are given below:

- Interior Dimensions: 113 inches (L) × 89 inches (W) × 95 inches (H)
- Door Dimensions: 39 inches (W) × 80 inches (H)
- Box Construction: 3.5 inch thick urethane foam insulated panels
- Box Location: Indoors
- Refrigeration System: Remote split system with 2.5 horsepower condensing unit mounted directly on top of box, indoors.
- Electric defrost with 4 defrost cycles per day.
- Door Frame Heater: 90 W
- Lighting: 100 W
- Refrigerant: R404a
- Internal Box Temperature: 0°F (-18°C)

A photograph of the interior of the instrumented walk-in freezer at FSTC is shown in Figure 10.

The walk-in freezer contained a fixed product load consisting of miscellaneous bagged and boxed food products loaded to approximately 50% of the freezer's volume capacity.

The following quantities were monitored and recorded:

- Power consumption, which included the combined power of the condensing unit, the unit cooler, the 90 watt door frame heater, and the light.

- Internal walk-in freezer box temperature, measured at the center of the walk-in box floor plan at a height of 4 ft.
- Ambient temperature and relative humidity, measured 4 ft from the front of the walk-in freezer, at a height of 4 ft.
- Condensing unit ambient temperature measured at the front of the air intake to the condensing coil.

Three test trials were performed, during which time the quantities mentioned above were measured and recorded every 15 seconds for a period of four to six days.

Figure 10. Photograph of Walk-In Freezer Tested by FSTC.

Analysis of FSTC Walk-In Freezer Data

The measured data from the three test trials are analyzed in Appendix C. From this analysis, the following details were ascertained:

Trial 1: The test period for Trial 1 consisted of a total of four days. On Day 1, the door of the walk-in freezer was opened twice, once at 9:00am and again at 3:00pm. The door opening duration for each door opening event was 15 minutes. During each door opening event, two gallons of room-temperature water were introduced into the walk-in freezer to simulate product loading. During Days 2, 3, and 4 of Trial 1, the door of the walk-in freezer remained closed and no product loading or unloading occurred. During Trial 1, the ambient conditions near the condensing unit were maintained at 80°F (27°C), 41% RH.

Trial 2: The test period for Trial 2 consisted of a total of six days. During all days of Trial 2, the door of the walk-in freezer remained closed and no product loading or unloading occurred. During Trial 2, the ambient conditions near the condensing unit were maintained at 70°F (21°C), 34% RH.

Trial 3: The test period for Trial 3 consisted of a total of four days. On Day 1, the door of the walk-in freezer was opened twice, once at 3:20pm and again at 9:10pm. The door opening duration for each door opening event on Day 1 was 15 minutes. During each door opening event, two gallons of room-temperature water were introduced into the walk-in freezer to simulate product loading. During Day 2 of Trial 3, the door of the walk-in freezer remained closed and no product loading or unloading occurred. On Day 3, the door of the walk-in freezer was opened twice, once at 10:15am and again at 2:15pm. The door opening duration for each door opening event on Day 3 was 15 minutes. During each door opening event, two gallons of room-temperature water were introduced into the walk-in freezer to simulate product loading. On Day 4, the door of the walk-in freezer was opened twice, once at 10:15am and again at 4:15pm. The door opening duration for each door opening event on Day 4 was 15 minutes. During each door opening event, two gallons of room-temperature water were introduced into the walk-in freezer to simulate product loading. During Trial 3, the ambient conditions near the condensing unit were maintained at 75°F (24°C), 55% RH.

A summary of the FSTC walk-in freezer test trials is given in Table 9. In addition, plots of the experimental data collected by FSTC for the walk-in freezer are analyzed in Appendix C.

Table 9. Summary of FSTC Walk-In Freezer Test Trials.

	Trial 1: 80°F ambient near condenser	Trial 2: 70°F ambient near condenser	Trail 3: 75°F ambient near condenser
Day 1	Door opened twice (15 min. each time). Product loaded.	Door closed. No product loaded.	Door opened twice (15 min. each time). Product loaded.
Day 2	Door closed. No product loaded.	Door closed. No product loaded.	Door closed. No product loaded.
Day 3	Door closed. No product loaded.	Door closed. No product loaded.	Door opened twice (15 min. each time). Product loaded.
Day 4	Door closed. No product loaded.	Door closed. No product loaded.	Door opened twice (15 min. each time). Product loaded.
Day 5	--	Door closed. No product loaded.	--
Day 6	--	Door closed. No product loaded.	--

Furthermore, the experimental data collected by FSTC for Trail 2 were analyzed to determine the energy consumption of the various components of the refrigeration system and the walk-in freezer. The results of this analysis are summarized in Figure 11.

Analysis of Trial 2 Energy Consumption

Total Test Period for Trial 2: **144 hours**

Total Energy Consumption for Trial 2: **170.816 kWh**

Average Baseline (Evap Fans + Door Heater) Power: 0.397 kW
Period, Baseline: 144 hours
Baseline (Evap Fans + Door Heater) Energy Consumption: (0.397 kW)(144 hr) = **57.168 kWh**

Door Heater Power: 0.090 kW (assumed)
Period, Door Heater: 144 hours
Door Heater Energy Consumption: (0.090 kW)(144 hr) = **12.96 kWh**

Average Evaporator Fan Power: 0.397 kW – 0.090 kW = 0.307 kW
Period, Evaporator Fans: 144 hours
Evaporator Fan Power Consumption: (0.307 kW)(144 hr) = **44.208 kWh**

Average Baseline + Defrost Power: 1.639 kW
Average Defrost Power: 1.639 kW – 0.397 kW = 1.242 kW
Period, Defrost: 6.6167 hours
Defrost Energy Consumption: (1.242 kW)(6.6167 hr) = **8.218 kWh**

Condensing Unit Energy Consumption:
170.816 kWh – 8.218 kWh – 44.208 kWh – 12.96 kWh = **105.43 kWh**

Fractions of Total Energy Consumption:
- Door/Frame Heater: **12.96 kWh (7.6%)**
- Defrost Heater: **8.22 kWh (4.8%)**
- Evaporator Fans: 44.21 kWh (25.9%)
- Condensing Unit: 105.43 kWh (61.7%)

Figure 11. Summary of Trial 2 Energy Consumption.

The total energy consumption for Trial 2 was determined by integrating the power plots shown in Appendix C, Figures 79, 82, 85, 88, 91 and 94. The average baseline power consumption was determined by time averaging the low values shown on these same plots. The door heater power was determined from the FSTC test protocol and subtracted from the baseline power to arrive at the power used by the evaporator fans.

The defrost power was determined by subtracting the average baseline power from the average mid-level power shown in Figures 79, 82, 85, 88, 91 and 94.

Finally, the condensing unit power consumption was determined by subtracting all the other components from the total power consumed during the test.

***eQuest* Modeling of the FSTC Walk-In Freezer**

The energy consumption of the instrumented walk-in freezer tested by FSTC was simulated using the whole building simulation tool *eQuest.* Details of the *eQuest* input data for the walk-in freezer are described below, including specification of the refrigeration system and weather files as well as the estimation of the infiltration load, defrost load, lighting load and product load.

Simulation of the Actual PG&E FSTC Test Procedure

Although the FSTC test protocol shown in Appendix B called for two door openings per day, from the analysis of the FSTC data discussed in Appendix C, it can be seen that the actual test procedure deviated from the protocol. Table 9 (page 54) shows the actual test procedure as performed by the PG&E FSTC. The actual test procedure as shown in Table 9 was simulated using *eQuest*.

<u>*Refrigeration System*</u>

The only specification given by FSTC regarding the walk-in freezer refrigeration system was that the condensing unit was rated at 2.5 horsepower. Thus, a suitable 2.5 horsepower condensing unit and a unit cooler were chosen from a catalog (Climate Control) in the following manner. A condensing unit nominally rated for 2.5 horsepower was selected. The condensing unit had a specified capacity of 9,580 Btu/hr at 95°F ambient, -20°F SST. A unit cooler was then selected that had a similar rating of 9,000 Btu/hr at -20°F SST, 10°F TD. The corresponding component specifications were entered into the *eQuest* model.

The specifications of the selected 2.5 horsepower refrigeration system are as follows:

Condensing Unit (located indoors):

- Make: Climate Control
- Model Number: CZ*025L6
- Compressor: Copeland ZF08K4E
- Capacity: 9,580 Btu/hr at 95°F ambient, -20°F SST
- Fans: Two (2) 1/15 hp fans

Unit Cooler:

- Make: Climate Control
- Model Number: LSF090
- Capacity: 9,000 Btu/hr at -20°F SST, 10°F TD
- Fans: 2 shaded pole motors, 244 watts total power consumption

- Electric Defrost: 1,800 watts

A performance map for the ZF08K4E compressor was obtained from the manufacturer (Copeland) and input into *eQuest* to accurately model the performance of the condensing unit compressor.

Weather Files
Three weather data files in TMY2 format were created which consisted of constant dry-bulb and wet-bulb temperatures throughout the year, corresponding to the test conditions of Trials 1, 2, and 3:

- Weather Data File #1: Dry-bulb = 80.0°F, Wet-bulb= 63.4°F
- Weather Data File #2: Dry-bulb = 70.0°F, Wet-bulb= 54.0°F
- Weather Data File #3: Dry-bulb = 75.0°F, Wet-bulb= 63.9°F

In addition, to simulate the performance of the FSTC walk-in freezer which was located indoors, solar heat gain values of zero were specified in the TMY2 weather data files.

Infiltration Load
The infiltration rate through the door of the walk-in freezer was estimated with the Gosney Olama equation (Becker and Fricke 2005):

$$Q = 795.6A\left(1-\frac{\rho_i}{\rho_r}\right)^{0.5}(gH)^{0.5}F_m \tag{1}$$

where A is the doorway area (ft^2), ρ_i is the density of the infiltrating air (lb/ft^3), ρ_r is the density of the refrigerated air (lb/ft^3), g is the gravitational constant (g = 32.174 ft/s^2), H is the doorway height (ft) and F_m is a density factor defined as follows:

$$F_m = \left(\frac{2}{1+\left(\frac{\rho_r}{\rho_i}\right)^{1/3}}\right)^{1.5} \tag{2}$$

As discussed in Chapter 13 of the ASHRAE Handbook of Refrigeration, Gosney and Olama (1975) analytically developed their steady state air exchange equation for fully established flow based upon the refrigerated air temperature and the infiltrating air temperature with a coefficient that was determined by fitting experimental data. The Gosney and Olama (1975) equation was later verified in the work by A.M. Foster et al. (2003) using a 16 ft by 19 ft refrigerated walk-in. They report that the Gosney and Olama (1975) model was able to predict infiltration within experimental error. This was not what they expected because the assumption in the Gosney and Olama (1975) model is that the temperature difference between the cold store and ambient is constant, while their experiment showed that the temperature inside the cold store rose dramatically while the door was open. Nevertheless, the Gosney and Olama (1975) model predicted an infiltration rate that matched their experimental data.

Based on an average temperature of 75°F for the infiltrating air and a walk-in box temperature of 0°F, the infiltration rate through the walk-in freezer door was estimated to be 23 CFM/ft^2. To simulate the infiltration into the walk-in freezer during days in which the door was opened, the infiltration schedule in *eQuest* was set as follows: 15 minutes of infiltration at 10:00am at a rate of 23 CFM/ft^2 and 15 minutes of infiltration at 4:00pm at a rate of 23 CFM/ft^2. On days when the walk-in freezer door was not opened, the infiltration rate in *eQuest* was set to zero.

Defrost Load
In *eQuest*, the defrost heater schedule was specified as follows: 4 defrost cycles, each 20 minutes in length, occurring at midnight, 6:00am, noon, and 6:00pm. In the *eQuest* model, the electrical energy consumption of the defrost heater was set at 1200 watts to match the FSTC defrost load as determined from the analysis shown in Appendix C, Figure 66.

Door Heater
In *eQuest*, a continuous 90 W door/frame heater was specified to match the FSTC walk-in freezer door/frame heater.

Lighting Load
Incandescent lighting of 1.429 watt per square foot was specified in the *eQuest* model. Lighting was scheduled to be on for 15 minutes at 10:00am and on again for 15 minutes at 4:00pm to coincide with the door opening (infiltration) schedule.

Product Load
In the FSTC testing protocol, two gallons of water were introduced into the walk-in freezer to simulate product loading. The resulting heat load imposed on the walk-in freezer refrigeration system due to this product loading was calculated as follows.

$$q = mc_1\left(t_1 - t_f\right) + mh_{if} + mc_2\left(t_f - t_2\right) \tag{3}$$

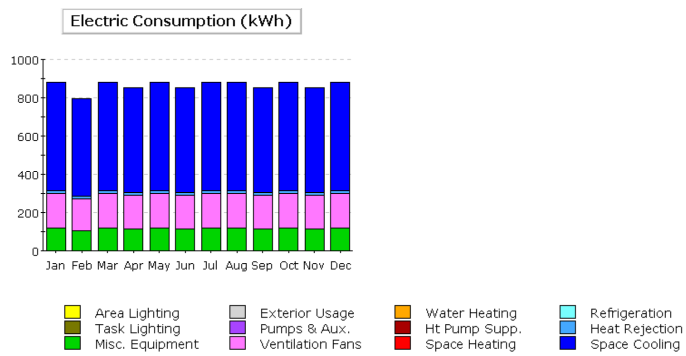
where q is the heat removed from the water, m is the mass of the water (2 gal = 16.62 lb) c_1 is the specific heat of water above freezing (1.0 Btu/lb·°F), t_1 is the initial temperature of the water above freezing (75°F), t_f is the freezing temperature of water (32°F), h_{if} is the latent heat of fusion of water (144 Btu/lb), c_2 is the specific heat of water below freezing (0.5 Btu/lb·°F) and t_2 is the final temperature of the water (0°F).

It was found that 3375 Btu of energy must be removed from two gallons of water in order to freeze the water and reduce its temperature from 75°F to 0°F. In the *eQuest* model, it was assumed that this energy was removed from the water in a 3 hour period. During days in which the walk-in freezer door was opened, the heat load schedule in *eQuest*, due to product loading, was set as follows: 1125 Btu to be removed every hour for 3 hours beginning at 10:00am and 1125 Btu to be removed every hour for 3 hours beginning at 4:00pm. On days when the walk-in freezer door was not opened, the heat load due to product loading was set to zero in *eQuest*.

Results

A sample output for one of the *eQuest* FSTC walk-in freezer simulations (Trial 2) is shown in Figure 12. This figure shows monthly energy consumption of the walk-in freezer in both tabular and bar graph format. The blue bars in the bar graph show the energy consumption of the condensing unit, where the dark blue bars represent the compressor energy consumption and the light blue bars represent the condenser fan energy consumption. The pink bars show the energy consumption of the evaporator fans and the green bars represent the energy consumption of the defrost heaters and the door heater. Not visible are the yellow bars which represent the energy consumption of the lighting. The numerical values corresponding to the individuals bars are given in the table below the bar graph shown in Figure 12.

The total annual energy consumption of the walk-in freezer is shown in the lower right corner of the table shown in Figure 12. The average daily energy consumption is then calculated by dividing this number by 365 days.



Electric Consumption (kWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	564	509	564	546	564	546	564	564	546	564	546	564	6,639
Heat Reject.	14	13	14	14	14	14	14	14	14	14	14	14	170
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	183	165	183	177	183	177	183	183	177	183	177	183	2,156
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	116	105	116	112	116	112	116	116	112	116	112	116	1,367
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2	1	2	1	2	1	2	2	1	2	1	2	18
Total	879	794	879	851	879	851	879	879	851	879	851	879	10,351

Figure 12. Sample *eQuest* Output for FSTC Walk-In Freezer Simulation (Trial 2).

The average daily electrical energy consumption of the walk-in freezer as measured by the FSTC is shown in Table 10 for each of the test trials. The calculated average daily energy consumption of the walk-in freezer as determined from the *eQuest* simulations is also shown in Table 10. It can be seen that *eQuest* accurately estimates the energy consumption of the walk-in freezer within 4.59%.

Table 10. Measured and Calculated Energy Consumption of the FSTC Walk-In Freezer.

Walk-In Freezer Test Trial	FSTC Data (kWh/day)	eQuest Results (kWh/day)	Difference (%)
Trial 1: 80°F, 2 door openings	33.6	34.9	-3.75

Trial 2: 70°F, no door openings	28.5	28.4	0.39
Trial 3: 75°F, 6 door openings	37.4	39.1	-4.59
Average	33.1	34.1	-2.88

As discussed above and summarized in Figure 11, the experimental data collected by FSTC for Trail 2 were analyzed to determine the energy consumption of the various components of the refrigeration system and the walk-in freezer. The energy consumption of these same components was also determined from the *eQuest* results for Trial 2. A comparison of the calculated and measured values is given in Table 11. It can be seen that *eQuest* accurately estimates the energy consumption of the various components of the refrigeration system and walk-in freezer.

Table 11. Summary of Trial 2 Energy Consumption.

	Energy Consumption (kWh)	Fraction of Total (%)
FSTC Data		
Door Heater	12.96	7.6
Defrost Heater	8.22	4.8
Evaporator Fans	44.21	25.9
Condensing Unit	105.43	61.7
eQuest Results		
Door Heater and Defrost Heater	22.47	13.2
Evaporator Fans	35.44	20.9
Condensing Unit	111.93	65.9

Comparison of *eQuest* to Various Load Calculation Methods

Specifications of a prototypical walk-in cooler were developed. The peak load of this prototypical walk-in cooler was determined using various load calculation methods. The peak load for the prototypical walk-in cooler was also determined from *eQuest* simulation results and the *eQuest* results were compared to the results obtained from the various load calculation methods.

Prototypical Walk-In Cooler

A prototypical walk-in cooler was designed based on information gathered from the following sources:

- AHRI. (2009a). Spreadsheet used to develop load profiles found in AHRI Standard 1250/1251.
- DOE. (2010b). Preliminary Technical Support Document (TSD): Energy Conservation Program for Certain Commercial and Industrial Equipment: Walk-In Coolers and Walk-In Freezers. Washington, D.C.: Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

- SCE. (2008). Preliminary CASE Report: Analysis of Standards Option for Walk-in Refrigerated Storage. Codes and Standards Enhancement Initiative (CASE). Sacramento, CA: Southern California Edison.

An abbreviated description of the prototypical walk-in cooler is given below while detailed specifications are given in Appendix D:

- Dimensions: 15.8 ft × 15.8 ft × 12 ft
- Single Door: 4 ft x 7 ft
- Construction: 6" polystyrene foam insulated panels (Perhaps a 4" wall thickness for the "Prototypical Walk-in Cooler" would have been more appropriate than the 6" wall thickness specified. However, since the same 6" wall thickness was used in all of the load calculation methods, the results of the validation exercise remain neutral with respect to the wall thickness. That is, the outcome of the validation exercise remains the same regardless of wall thickness.)
- Box location: Outdoors, Los Angeles, CA
- Internal Box Temperature: 35°F
- Refrigeration System
  - Compressor: Carlyle 5F20
  - Condenser: Bohn BRH023
  - Condenser Fans: Two (2) 1.5 hp fans
  - Evaporator: Krack KR66A-310 (air defrost)
  - Evaporator Fans: Six (6) fans, 444 W total
  - Refrigerant: R-22
- Infiltration: 0.4 air changes per hour
- Product Load: Fruit/Vegetable, Snap Beans @ 45°F (7.2°C), 6480 lb/day
- Occupancy:
  - One person in walk-in for 4.8 minutes per hour from 8:00am to 6:00pm, Monday thru Saturday
  - One person in walk-in for 2.4 minutes per hour from 10:00am to 6:00pm, Sunday
- Lighting: 1.0 W/ft^2
  - Lighting on for 4.8 minutes per hour from 8:00am to 6:00pm, Monday thru Saturday
  - Lighting on for 2.4 minutes per hour from 10:00am to 6:00pm, Sunday

Load Calculation Methods

The maximum cooling demand for the prototypical walk-in cooler was determined using the following load calculation methods:

- CoolPack (IPU, Denmark)
- Refrigeration Load Calculator (Emerson Climate Technologies)

- Calc-Rite Load Program (KeepRite Refrigeration)
- Heatcraft Load Estimate Form

Detailed results from these various load calculation methods are given in Appendix E.

Results

The *eQuest* load summary table for the prototypical walk-in cooler simulation is shown in Figure 13. As shown in this table, the maximum total refrigeration load was calculated by *eQuest* to be 20.113 kBtu/hr, nominally 20,100 Btu/hr.

Project 6 DOE-2.2-R47b 10/22/2010 16:04:01 BDL RUN 1

REPORT- SS-A System Loads Summary for EL1 Sys1 (PVVT) (G) WEATHER FILE- CZ06RV2 WYEC2

MONTH	- - - C O O L I N G - - - COOLING ENERGY (MBTU)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	- - - H E A T I N G - - - HEATING ENERGY (MBTU)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	- - - E L E C - - - ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	4.11589	22	5	55.F	55.F	18.152	-0.004	15	1	53.F	52.F	-4.042	384.	2.721
FEB	3.75264	5	5	51.F	48.F	17.744	-0.007	26	1	58.F	55.F	-6.733	351.	2.721
MAR	4.29107	12	5	52.F	50.F	17.725	0.000	31	24	52.F	51.F	0.000	392.	2.721
APR	4.27512	23	7	51.F	48.F	18.303	0.000	30	1	55.F	55.F	0.000	396.	2.721
MAY	4.69503	28	7	64.F	58.F	18.797	0.000	31	1	54.F	49.F	0.000	416.	2.721
JUN	4.78340	25	7	63.F	60.F	18.694	0.000	30	1	61.F	58.F	0.000	415.	2.721
JUL	5.02632	30	8	66.F	63.F	20.113	0.000	31	1	63.F	58.F	0.000	441.	2.721
AUG	4.90267	13	7	66.F	64.F	18.593	0.000	31	1	64.F	56.F	0.000	430.	2.721
SEP	4.59753	17	7	60.F	57.F	18.614	-0.005	24	2	64.F	60.F	-5.163	404.	2.721
OCT	4.74767	1	7	66.F	61.F	18.762	-0.030	22	2	61.F	56.F	-23.455	432.	2.721
NOV	4.24175	5	6	56.F	55.F	18.282	-0.006	5	1	58.F	57.F	-5.887	379.	2.721
DEC	3.88063	3	5	55.F	52.F	17.793	0.000	31	24	48.F	47.F	0.000	380.	2.721
TOTAL	53.310						-0.052						4821.	
MAX						20.113						-23.455		2.721

Figure 13. *eQuest* Load Summary for the Prototypical Walk-In Cooler.

The maximum cooling demand for the prototypical walk-in cooler as determined by the various load calculation methods and the *eQuest* simulation are summarized in Table 12. It can be seen that the maximum cooling demand determined by *eQuest* corresponds well with the demand determined by the various load calculation methods.

Table 12. Calculated Maximum Cooling Demand for the Prototypical Walk-In Cooler.

Calculation Method	Maximum Cooling Demand (Btu/hr)	Difference from *eQuest* (%)
CoolPack	19,000	-5.5
Refrigeration Load Calculator	19,700	-2.0
Calc-Rite Load Program	20,000	-0.50
Heatcraft Load Estimate Form	19,600	-2.5
eQuest	20,100	

eQUEST SIMULATIONS OF WALK-IN COOLER AND FREEZER PERFORMANCE

As previously discussed, a state-of-the-art, publically available whole building energy model, *eQuest* (James J. Hirsch and Associates 2009), was selected to simulate a walk-in refrigeration system's capacity and energy usage as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in box and the condensing unit.

Using this simulation tool, the total annual energy consumption of four typical walk-in refrigeration systems as well as their total annual cooling was determined for each climatic zone in the United States (2004 International Energy Conservation Code (IECC) Climate Zones 1 through 7), for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

For the configuration with both the walk-in box and the condensing unit located indoors, the ambient conditions surrounding both the walk-in box and the condensing unit were held constant at 80°F DB and 63°F WB to simulate the conditions found in the back room of a supermarket or restaurant.

For the two configurations with the condensing unit located outdoors, the ambient conditions surrounding the condensing unit were determined from hourly weather data for the seven cities shown in Table 13 that represent the seven climate zones in the continental United States.

Table 13. Climate Zones and Cities Used in *eQuest* Simulations.

Climate Zone	City	Annual Average Temperature (°F)
1	Miami, FL	76.9
2	San Antonio, TX	69.5
3	San Francisco, CA	58.0
4	Kansas City, MO	54.7
5	Omaha, NE	51.2
6	Billings, MT	48.2
7	International Falls, MN	38.2

The purpose of these climate zone simulations was to assess the field-site performance of walk-ins operating in the various regions of the United States. Walk-in performance was evaluated in terms of the Annual Walk-In Energy Factor (AWEF), defined as follows (AHRI 2009b, 2009c):

> *Annual Walk-In Energy Factor (AWEF):* A ratio of the total heat, not including the heat generated by the operation of refrigeration systems, removed, in Btu, from a walk-in box during one year period of usage for refrigeration to the total energy input of refrigeration systems, in watt-hours, during the same period.

These simulations make use of time dependent refrigeration load schedules including schedules for product loading, lighting, occupancy, infiltration, and vehicle usage. The condensing units and the unit coolers used in these simulations were sized, based on the walk-in box refrigeration load, according to industry standard practice using the 'Heatcraft Engineering Manual' (Heatcraft 2008). The condensing units and the unit coolers were then selected from manufacturers' websites.

For each of the seven cities, *eQuest* was used to determine the 'useful' refrigeration performed during an entire year, that is the total cooling performed during the year less the heat equivalent of the energy required to operate the unit cooler fans for the year. *eQuest* was also used to determine the total refrigeration system energy usage during the entire year.

Then for each simulated walk-in box and its refrigeration system, the AWEF for each of the seven cities was determined using the following equation:

$$AWEF = \frac{\text{Annual 'useful' refrigeration [Btu]}}{\text{Annual energy usage by the refrigeration system [Wh]}}$$

eQuest was also used to simulate the AHRI Standard 1250/1251 method-of-test for rating the performance of walk-in coolers and freezers for the following two configurations:

- Condensing unit located inside
- Condensing unit located outside

These AHRI 1250/1251 method-of-test simulations involve simulating the steady state performance of the walk-in's refrigeration system at the following 'Standard Rating Conditions.' For a cooler the internal temperature is held at 35 ºF DB, <50% RH and for a freezer the internal temperature is held at -10 ºF, <50% RH. For the condensing unit located indoors, the ambient temperature at the condenser is held at 90 ºF DB, 75 ºF WB. For the condensing unit located outdoors, simulations are required at three condenser ambient conditions:

- 95 ºF DB, 75 ºF WB
- 59 ºF DB, 54 ºF WB
- 35 ºF DB, 34 ºF WB.

Thus, in order to rate a walk-in's refrigeration system performance, four AHRI 1250/1251 method-of-test simulations are required, one at each of the four Standard Rating Conditions.

For each of the four Standard Rating Conditions, *eQuest* was used to determine the 'useful' refrigeration capacity, that is, the total cooling capacity less the heat equivalent of the energy required to operate the unit cooler fans. *eQuest* was also used to determine the total refrigeration system power input.

Then for each simulated walk-in box refrigeration system, the Standard 1250/1251 AWEF for the two configurations (condensing unit inside and condensing unit outside) was determined by using the calculation procedure described in Standard 1250/1251, based on the performance data obtained from the *eQuest* simulations at the Standard Rating Conditions. This calculation procedure involves applying the AHRI 1250/1251 Rating Equations. For the condensing unit located outdoors, the Annual Walk-in Energy Factor, AWEF, is calculated by weighting the system performance at individual bins with bin hours (number of hours for a given temperature that occurs over the year).

Also, for each simulated walk-in box refrigeration system, the annual compressor runtime, defined as the ratio of the box load to the refrigeration system capacity at each bin temperature, corresponding to the Standard 1250/1251 AWEF for the two configurations (condensing unit inside and condensing unit outside) was determined by using the calculation procedure derived in Appendix F.

eQuest Simulations of four walk-in systems were performed:

- Small single speed freezer
- Small single speed cooler
- Large single speed freezer
- Large single speed cooler

The specifications and the AWEF calculations for these four walk-in systems are given below. A summary and analysis of these simulations is given in the following chapter.

Small Single Speed Walk-In Freezer

The small single speed freezer is based on the instrumented walk-in freezer at the PG&E Food Service Technology Center that is discussed in the section **'Validation of *eQuest* Model.'** It has the same dimensions and the same unit cooler and condensing unit, however, the walk-in box construction details and the refrigeration load are different. The walk-in box construction details are those of a U.S. Cooler walk-in box (U.S. Cooler 2011).

The number of occupants and occupancy schedule, the lighting power and lighting schedule, and the product loading and product loading schedule were based on average values per square foot of plan area, for walk-in freezers, as determined from the review of model load profiles, discussed in the section **'Analysis of Model Load Profiles.'** The infiltration was determined, based on the walk-in box volume, from data for freezers given in the Heatcraft Engineering Manual (Heatcraft 2008).

Small Freezer: Walk-In Box Description

Dimensions: 9.42 ft x 7.42 ft x 7.92 ft (H)
Floor Area: 69.9 ft^2
Volume: 553.6 ft^3

Box Internal Air Temperature: -10°F

Wall/Roof Construction (Insulated Sandwich Panel)
- 26 gauge electro-galvanized steel (exterior surface)
- Extruded polystyrene (4" thick)
- 26 gauge electro-galvanized steel (interior surface)

Floor Construction (Insulated Sandwich Panel)
- 12 inches of soil (exterior surface)
- 6 inches of concrete
- 26 gauge electro-galvanized steel
- Extruded polystyrene (4" thick)
- 22 gauge stainless steel (interior surface)
- Heated Sub-Floor: 50˚F minimum (Heatcraft Manual and AHRI 1250/1251 Spreadsheet)

Doors:
- Number of Doors: 1
- Location of Doors: South Wall
- Size: 3.25 ft x 6.67 ft
- 26 gauge electro-galvanized steel (exterior surface)
- Extruded polystyrene (4" thick)
- 26 gauge electro-galvanized steel (interior surface)

Small Freezer: Refrigeration Load Components

Occupancy:

Number of People: 1
Heat Gain: 550 Btu/hr – person
Sensible: 275 Btu/hr – person
Latent: 275 Btu/hr – person (McQuiston)
Occupancy Schedule:
One person in walk-in for 6 minutes per hour from 8:00am to 6:00pm, Monday thru Sunday

Infiltration:

Method: Air Change
Air Changes per Hour: 0.789 (Heatcraft Manual)
Infiltration Schedule: (To simulate door openings during the work day)
0.757 air changes per hour from 6:00pm to 8:00am, Monday thru Sunday
0.833 air changes per hour from 8:00am to 6:00pm, Monday thru Sunday

Lighting:

Power Density: 1 W/ft^2 (Heatcraft Manual)
Total Power: 0.070 kW
Fraction of Light Heat: 1.0
Lighting Schedule:
Light on in walk-in for 6 minutes per hour from 8:00am to 6:00pm, Monday thru Sunday

Product Loading:

Total Product Heat Load: 267.9 Btu/hr continuous.
Product Type: Fruit / Vegetable
Product Loading (lb/hr): 57
Product Delta T: 10°F
Product Specific Heat Below Freezing (Btu/lb·°F): 0.47
Sensible Heat Ratio (Sensible heat transfer / Total heat transfer):
1.00 (Packaged product assumption)

Small Freezer: Equipment Specifications
Refrigerant: R-404A

Condensing Unit:
- Model: Climate Control CZ*025L6
- Nominal Power: 1 hp
- Type: Air Cooled
- No. Fans: 2
- Power / Fan (W): 50
- Air Flow / Fan (CFM): 650
- Capacity: 9580 Btu/hr @ 95°F ambient, -20°F SST

Compressor:
- Model: Copeland ZF08K4E-TF5
- Performance: Compressor Coefficients from Copeland
- Rated Performance: 167 lb/hr, 2.16 kW @ -20°F SST, 110°F SDT (Copeland)

Unit Cooler:
- Model: Climate Control LSF090
- Cooling Capacity: 9000 Btu/hr @ -20°F SST, 10°F TD
- Mimimum Supply Temperature: -15°F
- Cooling Control Range: 4°F
- Saturated Suction/Air Temperature Difference: 5°F
- Return Air Path: Direct
- Rated Supply Flow: 1300 CFM (Total for 2 Fans)
- No. Fans: 2
- Motor Type: Standard, Shaded Pole
- Total Fan Power: 244 W
- Fan Schedule: On Continuously

Small Freezer: Simulation Results

The *eQuest* simulation results for the small single speed walk-in freezer are given in Table 14 through Table 17 and Figure 14 through Figure 15. Table 14 and Table 15 show the AHRI 1250 AWEF calculations that are based on the *eQuest* simulations of the AHRI 1250 method-of-test for the condensing unit located inside and the condensing unit located outside, respectively. Table 16 shows the calculation of the annual compressor runtime corresponding to the Standard 1250 AWEF for the two configurations.

Table 17 shows the results of the *eQuest* simulations of the small freezer in the seven climate zones of the United States for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

The AWEF values calculated from the results of the *eQuest* simulations of the AHRI 1250 method-of-test and from the results of the climate zone simulations are plotted versus compressor runtime and average ambient temperature in Figure 14 and Figure 15, respectively.

Table 14. Small Freezer AHRI 1250 AWEF for Indoor Condenser.

AHRI 1250 AWEF Calculator: Small Freezer - Condenser Indoors		
Data from eQuest Simulation Results:		
Total Cooling Energy:	62.019	MBtu
Power Demand for Supply Fans:	0.244	kW
Total Electric Consumption:	36226.31	kWh
Miscellaneous Electric Consumption:	15943.2	kWh
Modified Data from eQuest Simulation Results:		
Total Cooling Rate: Q	7079.7945	Btu/hr
Energy Consumption: Ess	2315.4235	W
Evaporator Fan Power: Efc,off	244	W
Calculations According to AHRI 1250 Standard:		
Net Refrigeration Capacity: Qss	6247.2665	Btu/hr
Box Load High: BLH	4997.8132	Btu/hr
Box Load Low: BLL	2498.9066	Btu/hr
Load Factor High: LFH	0.8235184	
Load Factor Low: LFL	0.4705553	
AWEF:	2.2764103	

Average Runtime: 53.20%

Table 15. Small Freezer AHRI 1250 AWEF for Outdoor Condenser.

AHRI 1250 AWEF Calculator: Small Freezer - Condenser Outdoors

Data from eQuest Simulation Results:

Ambient Temperature (°F)	Total Cooling Energy (MBtu)	Total Electric Consumption (kWh)	Miscellaneous Electric Consumption (kWh)	Power Demand for Supply Fans (kW)
95	59.033	36301.01	15067.21	0.244
59	61.11	35966.59	15680.4	
35	61.556	36180.88	15811.8	

Modified Data from eQuest Simulation Results:

Ambient Temperature (°F)	qss (Btu/h)	Ess (W)	Power Demand for Supply Fans (W)
95	5906.398941	2423.949772	244
59	6143.499397	2315.775114	
35	6194.412639	2325.237443	

Calculations According to AHRI 1250 Standard:

Temp (°F)	Bin Hour (hr)	qss (Btu/h)	Ess (W)	BLH (Btu/h)	BLL (Btu/h)	LFH	LFL	WLH (Btu/h)	WLL (Btu/h)	BL (Btu)	E (W-h)
100.4	9	5871	2440	4801	2438	0.84	0.49	4934	2865	28963	14139.8412
95	74	5906	2424	4725	2363	0.82	0.47	4871	2800	232523	113203.0518
89.6	257	5942	2408	4649	2287	0.81	0.46	4808	2736	788030	382736.2545
84.2	416	5978	2391	4573	2211	0.79	0.45	4745	2671	1243975	602994.6784
78.8	630	6013	2375	4497	2135	0.78	0.43	4682	2606	1836063	888639.9911
73.4	898	6049	2359	4421	2059	0.76	0.42	4618	2542	2548925	1232355.781
68	737	6084	2343	4345	1983	0.75	0.41	4555	2477	2035968	983804.4903
62.6	943	6120	2327	4269	1907	0.73	0.39	4491	2411	2533433	1224163.229
57.2	628	6147	2316	4194	1831	0.72	0.38	4427	2346	1639475	795271.7298
51.8	590	6159	2319	4118	1755	0.71	0.37	4361	2279	1495466	733485.1643
46.4	677	6170	2321	4042	1679	0.70	0.36	4295	2213	1664573	825983.1457
41	576	6182	2323	3966	1603	0.68	0.35	4229	2147	1372499	689449.9529
35.6	646	6193	2325	3890	1527	0.67	0.34	4163	2080	1490238	758332.3125
30.2	534	6205	2327	3814	1451	0.66	0.32	4097	2014	1191317	614551.4982
24.8	322	6216	2329	3738	1375	0.65	0.31	4031	1947	693907	363161.5828
19.4	305	6228	2331	3662	1299	0.64	0.30	3964	1881	634111	336977.8433
14	246	6239	2334	3586	1223	0.62	0.29	3898	1814	492766	266144.5754
8.6	189	6250	2336	3510	1148	0.61	0.28	3832	1747	364236	200143.4879
3.2	78	6262	2338	3434	1072	0.60	0.27	3766	1681	144396	80812.71555
-2.2	5	6273	2340	3358	996	0.59	0.26	3700	1614	8876	5065.944936
	8760								Total	22439743	11111417
										AWEF	2.02

Average Runtime: 41.89%

Table 16. Small Freezer AHRI 1250 Run Time.

Calculation of Annual Compressor Runtime
Corresponding to AHRI 1250
Small Freezer

Condenser Indoors

Run %	53.20%

Condenser Outdoors

q_{ss} (95F)	5906.39894
q_{ss} (59F)	6143.4994
q_{ss} (35F)	6194.41264
Run %	41.89%

Temp [F]	Bin Hour [hr]	CR (t_j)	CR (t_j) * nj
100.4	9	0.55	4.93
95	74	0.53	39.37
89.6	257	0.52	132.62
84.2	416	0.50	208.11
78.8	630	0.48	305.34
73.4	898	0.47	421.40
68	737	0.45	334.63
62.6	943	0.44	413.97
57.2	628	0.42	266.70
51.8	590	0.41	242.82
46.4	677	0.40	269.77
41	576	0.39	222.03
35.6	646	0.37	240.63
30.2	534	0.36	192.01
24.8	322	0.35	111.63
19.4	305	0.33	101.82
14	246	0.32	78.98
8.6	189	0.31	58.27
3.2	78	0.30	23.06
-2.2	5	0.28	1.41
	8760		3669.52

Table 17. Small Freezer AWEF's for Climate Zones 1-7.

Small Freezer

Suction Temperature = -20°F

Box Location	Condenser Location	Climate Zone	Annual Average Temperature (°F)	Cooling Energy (MBtu)	Evaporator Fan Energy (kWh)	Cooling w/o Fan (MBtu)	Electrical Energy (kWh)	AWEF	Average Run Time (%)
OUT	OUT	1	76.9	32.531	2137.440	25.238	13278.04	1.90	54.57
OUT	OUT	2	69.5	30.408	2137.440	23.115	12449.60	1.86	50.88
OUT	OUT	3	58.0	27.157	2137.440	19.864	11167.37	1.78	44.93
OUT	OUT	4	54.7	27.075	2137.440	19.782	11181.61	1.77	44.76
OUT	OUT	5	51.2	26.139	2137.440	18.846	10777.23	1.75	43.10
OUT	OUT	6	48.2	25.610	2137.440	18.317	10534.88	1.74	41.83
OUT	OUT	7	38.2	22.469	2137.440	15.176	9272.83	1.64	35.99
Average				27.341				1.78	45.15
IN	OUT	1	76.9	32.378	2137.440	25.085	13209.24	1.90	54.41
IN	OUT	2	69.5	31.372	2137.440	24.079	13254.55	1.82	52.13
IN	OUT	3	58.0	30.125	2137.440	22.832	12154.80	1.88	49.65
IN	OUT	4	54.7	30.176	2137.440	22.883	12193.03	1.88	49.70
IN	OUT	5	51.2	29.780	2137.440	22.487	12016.96	1.87	49.02
IN	OUT	6	48.2	29.876	2137.440	22.583	11994.55	1.88	48.76
IN	OUT	7	38.2	28.342	2137.440	21.049	11390.58	1.85	46.49
Average				30.293				1.87	50.02
IN	IN	80°F		31.803	2137.440	24.510	13062.75	1.88	55.00

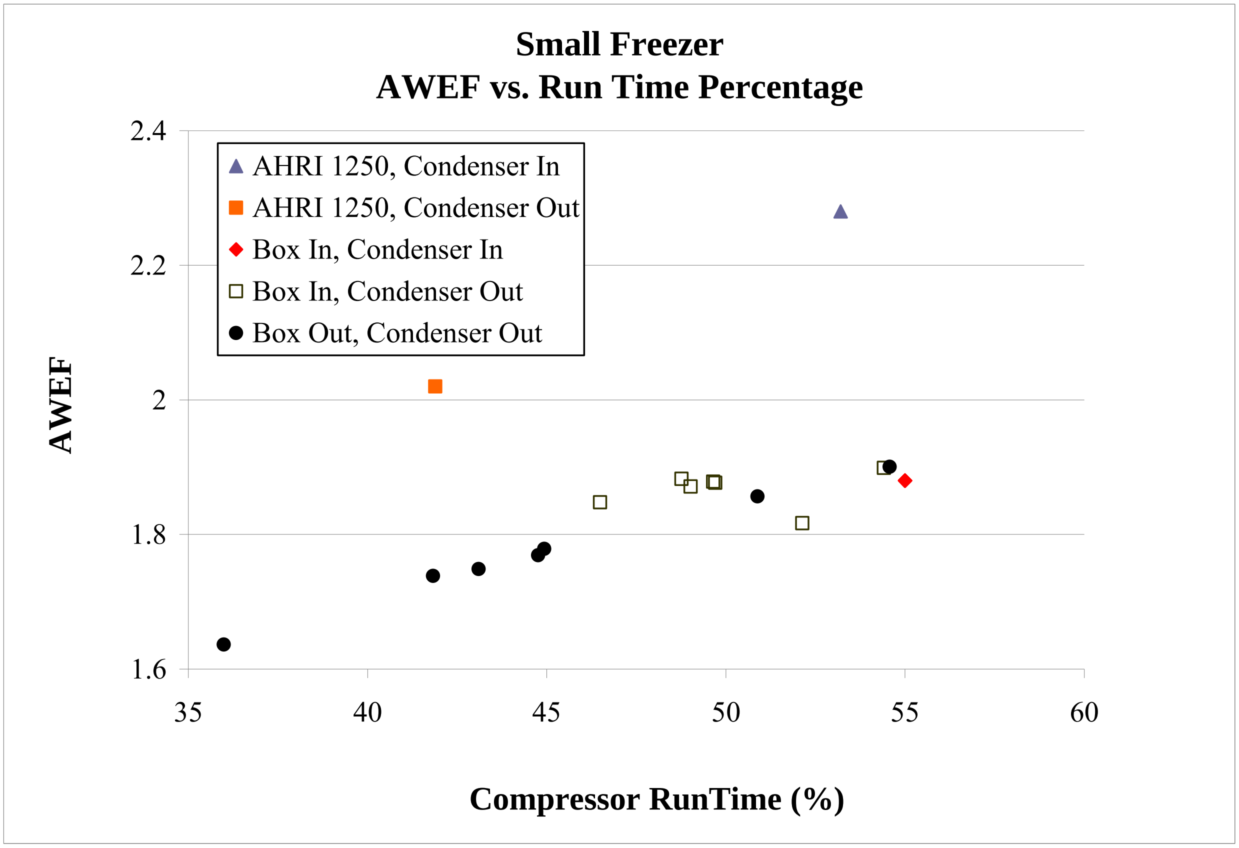


Figure 14. Small Freezer AWEF's versus Compressor Runtime for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

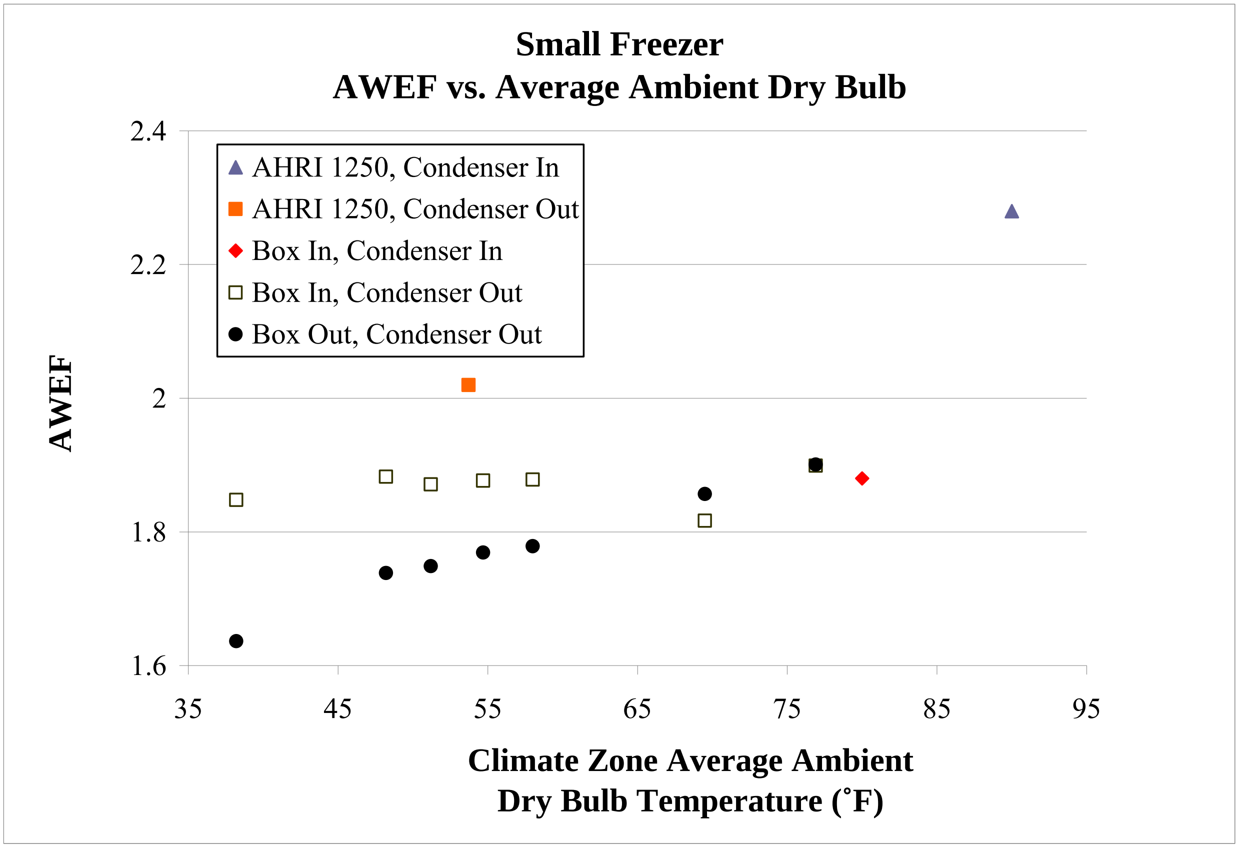


Figure 15. Small Freezer AWEF's versus Average Ambient Temperature for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

Small Single Speed Walk-In Cooler
The small single speed cooler is based on the instrumented walk-in freezer at the PG&E Food Service Technology Center that is discussed in the section **'Validation of *eQuest* Model.'** It has the same dimensions, however, the walk-in box construction details, internal air temperature and the refrigeration load are different. The walk-in box construction details are those of a U.S. Cooler walk-in box (U.S. Cooler 2011). The internal air temperature for the cooler is 35°F.

The number of occupants and occupancy schedule, the lighting power and lighting schedule, and the product loading and product loading schedule were based on average values per square foot of plan area, for walk-in coolers, as determined from the review of model load profiles, discussed in the section **'Analysis of Model Load Profiles.'** The infiltration was determined, based on the walk-in box volume, from data for coolers given in the Heatcraft Engineering Manual (Heatcraft 2008).

The condensing unit and the unit cooler used in this simulation were sized, based on the walk-in box refrigeration load, according to industry standard practice using the 'Heatcraft Engineering Manual' (Heatcraft 2008). The condensing unit and the unit cooler were then selected from manufacturers' websites.

Small Cooler: Walk-In Box Description
Dimensions: 9.42 ft x 7.42 ft x 7.92 ft (H)
Floor Area: 69.9 ft^2
Volume: 553.6 ft^3

Box Internal Air Temperature: 35°F

Wall/Roof Construction (Insulated Sandwich Panel)
  26 gauge electro-galvanized steel (exterior surface)
  Extruded polystyrene (4" thick)
  26 gauge electro-galvanized steel (interior surface)

Floor Construction (Insulated Sandwich Panel)
  12 inches of soil (exterior surface)
  6 inches of concrete
  26 gauge electro-galvanized steel
  Extruded polystyrene (4" thick)
  22 gauge stainless steel (interior surface)

Doors:
  Number of Doors: 1
  Location of Doors: South Wall
  Size: 3.25 ft x 6.67 ft
  26 gauge electro-galvanized steel (exterior surface)
  Extruded polystyrene (4" thick)
  26 gauge electro-galvanized steel (interior surface)

Small Cooler: Refrigeration Load Components

Occupancy:

Number of People: 1
Heat Gain: 550 Btu/hr – person
Sensible: 275 Btu/hr – person
Latent: 275 Btu/hr – person (McQuiston)
Occupancy Schedule:
One person in walk-in for 6 minutes per hour from 8:00am to 6:00pm, Monday thru Sunday

Infiltration:

Method: Air Change
Air Changes per Hour : 1.0 (Heatcraft Manual)
Infiltration Schedule: (To simulate door openings during the work day)
1.0 air changes per hour from 6:00pm to 8:00am, Monday thru Sunday
1.1 air changes per hour from 8:00am to 6:00pm, Monday thru Sunday

Lighting:

Power Density: 1 W/ft^2 (Heatcraft Manual)
Total Power: 0.070 kW
Fraction of Light Heat: 1.0
Lighting Schedule:
Light on in walk-in for 6 minutes per hour from 8:00am to 6:00pm, Monday thru Sunday

Product Loading:

Total Product Heat Load: 518.7 Btu/hr continuous.
Product Type: Fruit / Vegetable
Product Loading (lb/hr): 57
Product Delta T: 10°F
Product Specific Heat Above Freezing (Btu/lb·°F): 0.91
Sensible Heat Ratio (Sensible heat transfer / Total heat transfer):
1.00 (Packaged product assumption)

Small Cooler: Equipment Specifications
Refrigerant: R-404A

Condensing Unit:
- Model: Emerson M4FH-0050-CAA-109
- Nominal Power: 1 hp
- Type: Air Cooled
- No. Fans: 1
- Power / Fan (W): 48
- Air Flow / Fan (CFM): 300
- Capacity: 4380 Btu/hr @ 90°F ambient, 25°F SST

Compressor:
- Model: Copeland ASE32C3E-CAA
- Performance: Compressor Coefficients from Copeland
- Rated Performance: 91.86 lb/hr, 0.77769 kW @ 25°F SST, 117.1°F SDT (Copeland)

Unit Cooler:
- Model: Russell AA14-42B
- Cooling Capacity: 4200 Btu/hr @ 25°F SST, 10°F TD (Russell Coil)
- Mimimum Supply Temperature: 30°F
- Cooling Control Range: 4°F
- Saturated Suction/Air Temperature Difference: 5°F
- Return Air Path: Direct
- Rated Supply Flow: 830 CFM
- No. Fans: 1
- Motor Type: Standard, Shaded Pole
- Total Fan Power: 120 W
- Fan Schedule: On Continuously

Small Cooler: Simulation Results

The *eQuest* simulation results for the small single speed walk-in cooler are given in Table 18 through Table 21 and Figure 16 through Figure 17. Table 18 and Table 19 show the AHRI 1250 AWEF calculations that are based on the *eQuest* simulations of the AHRI 1250 method-of-test for the condensing unit located inside and the condensing unit located outside, respectively. Table 20 shows the calculation of the annual compressor runtime corresponding to the Standard 1250 AWEF for the two configurations.

Table 21 shows the results of the *eQuest* simulations of the small cooler in the seven climate zones of the United States for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

The AWEF values calculated from the results of the *eQuest* simulations of the AHRI 1250 method-of-test and from the results of the climate zone simulations are plotted versus compressor runtime and average ambient temperature in Figure 16 and Figure 17, respectively.

Table 18. Small Cooler AHRI 1250 AWEF for Indoor Condenser.

AHRI 1250 AWEF Calculator: Small Cooler - Condenser Indoors		
Data from eQuest Simulation Results:		
Total Cooling Energy:	35.52545	MBtu
Power Demand for Supply Fans:	0.12	kW
Total Electric Consumption:	17487.15	kWh
Miscellaneous Electric Consumption:	9274.65	kWh
Modified Data from eQuest Simulation Results:		
Total Cooling Rate: Q	4055.4167	Btu/hr
Energy Consumption: Ess	937.5	W
Evaporator Fan Power: Efc,off	120	W
Calculations According to AHRI 1250 Standard:		
Net Refrigeration Capacity: Qss	3645.9767	Btu/hr
Box Load High: BLH	2552.1837	Btu/hr
Box Load Low: BLL	364.59767	Btu/hr
Load Factor High: LFH	0.7302884	
Load Factor Low: LFL	0.1908651	
AWEF:	2.5773639	

Average Runtime: 29.80%

Table 19. Small Cooler AHRI 1250 AWEF for Outdoor Condenser.

AHRI 1250 AWEF Calculator: Small Cooler - Condenser Outdoors

Data from eQuest Simulation Results:

Ambient Temperature (°F)	Total Cooling Energy (MBtu)	Total Electric Consumption (kWh)	Miscellaneous Electric Consumption (kWh)	Power Demand for Supply Fans (kW)
95	33.35735	16921.4	8665.1	0.12
59	36.30655	17432.4	9530.15	
35	36.80295	17516.35	9698.05	

Modified Data from eQuest Simulation Results:

Ambient Temperature (°F)	qss (Btu/h)	Ess (W)	Power Demand for Supply Fans (W)
95	3398.476667	942.5	120
59	3735.143333	902.0833333	
35	3791.81	892.5	

Calculations According to AHRI 1250 Standard:

Temp (°F)	Bin Hour (hr)	qss (Btu/h)	Ess (W)	BLH (Btu/h)	BLL (Btu/h)	LFH	LFL	WLH (Btu/h)	WLL (Btu/h)	BL (Btu)	E (W-h)
100.4	9	3348	949	2394	361	0.75	0.21	2498	687	9289	3940.991039
95	74	3398	943	2379	340	0.73	0.20	2489	669	74943	31611.94539
89.6	257	3449	936	2364	318	0.72	0.19	2479	651	255292	107125.3156
84.2	416	3499	930	2348	297	0.71	0.18	2469	632	405168	169228.5453
78.8	630	3550	924	2333	276	0.69	0.17	2459	614	601380	250162.9244
73.4	898	3600	918	2318	254	0.68	0.17	2449	596	839791	348129.4279
68	737	3651	912	2302	233	0.67	0.16	2438	577	674935	278992.7906
62.6	943	3701	906	2287	211	0.66	0.15	2428	559	845301	348639.5504
57.2	628	3739	901	2272	190	0.65	0.14	2417	540	550759	227512.2202
51.8	590	3752	899	2257	169	0.64	0.14	2404	521	505991	210772.1311
46.4	677	3765	897	2241	147	0.64	0.13	2391	502	567475	238474.6141
41	576	3778	895	2226	126	0.63	0.13	2378	483	471645	200052.5675
35.6	646	3790	893	2211	104	0.62	0.12	2365	464	516436	221206.4548
30.2	534	3803	891	2195	83	0.62	0.12	2352	445	416544	180270.7446
24.8	322	3816	888	2180	62	0.61	0.11	2339	425	244931	107160.1419
19.4	305	3829	886	2165	40	0.61	0.11	2326	406	226085	100056.4193
14	246	3841	884	2150	19	0.60	0.10	2312	387	177580	79546.63698
8.6	189	3854	882	2134	-3	0.60	0.10	2299	368	132768	60237.03629
3.2	78	3867	880	2119	-24	0.59	0.09	2286	348	53281	24501.04033
-2.2	5	3880	878	2104	-46	0.59	0.08	2273	329	3318	1547.820816
	8760								Total	7572915	3189169
										AWEF	2.37

Average Runtime: 23.43%

Table 20. Small Cooler AHRI 1250 Run Time.

Calculation of Annual Compressor Runtime
Corresponding to AHRI 1250
Small Cooler

Condenser Indoors

Run %	29.80%

Condenser Outdoors

q_{ss} (95F)	3398.47667
q_{ss} (59F)	3735.14333
q_{ss} (35F)	3791.81
Run %	23.43%

Temp [F]	Bin Hour [hr]	CR (t_j)	CR (t_j) * nj
100.4	9	0.31	2.77
95	74	0.30	22.05
89.6	257	0.29	74.02
84.2	416	0.28	115.78
78.8	630	0.27	169.40
73.4	898	0.26	233.24
68	737	0.25	184.86
62.6	943	0.24	228.37
57.2	628	0.23	147.29
51.8	590	0.23	134.85
46.4	677	0.22	150.73
41	576	0.22	124.85
35.6	646	0.21	136.25
30.2	534	0.21	109.53
24.8	322	0.20	64.19
19.4	305	0.19	59.05
14	246	0.19	46.23
8.6	189	0.18	34.45
3.2	78	0.18	13.78
-2.2	5	0.17	0.86
	8760		2052.55

Table 21. Small Cooler AWEF's for Climate Zones 1-7.

Small Cooler

Suction Temperature = 25°F

Box Location	Condenser Location	Climate Zone	Annual Average Temperature (°F)	Cooling Energy (MBtu)	Evaporator Fan Energy (kWh)	Cooling w/o Fan (MBtu)	Electrical Energy (kWh)	AWEF	Average Run Time (%)
OUT	OUT	1	76.9	21.322	1051.200	17.735	4742.3	3.74	60.06
OUT	OUT	2	69.5	18.773	1051.200	15.186	4283.6	3.55	53.47
OUT	OUT	3	58.0	14.991	1051.200	11.404	3591.4	3.18	41.41
OUT	OUT	4	54.7	14.856	1051.200	11.269	3580.5	3.15	42.02
OUT	OUT	5	51.2	13.699	1051.200	10.112	3368.9	3.00	38.51
OUT	OUT	6	48.2	12.459	1051.200	8.872	3144.2	2.82	34.26
OUT	OUT	7	38.2	9.917	1051.200	6.330	2688.2	2.35	26.98
Average				15.145				3.11	42.39
IN	OUT	1	76.9	21.142	1051.200	17.555	4723.1	3.72	59.59
IN	OUT	2	69.5	19.657	1051.200	16.070	4436.3	3.62	55.13
IN	OUT	3	58.0	17.737	1051.200	14.150	4048.8	3.49	49.09
IN	OUT	4	54.7	17.716	1051.200	14.129	4057.3	3.48	48.95
IN	OUT	5	51.2	17.088	1051.200	13.501	3940.2	3.43	48.02
IN	OUT	6	48.2	16.449	1051.200	12.862	3815.6	3.37	45.17
IN	OUT	7	38.2	15.351	1051.200	11.764	3602.5	3.27	41.60
Average				17.877				3.48	49.65
IN	IN	80°F		19.753	1051.200	16.166	4518.0	3.58	55.00

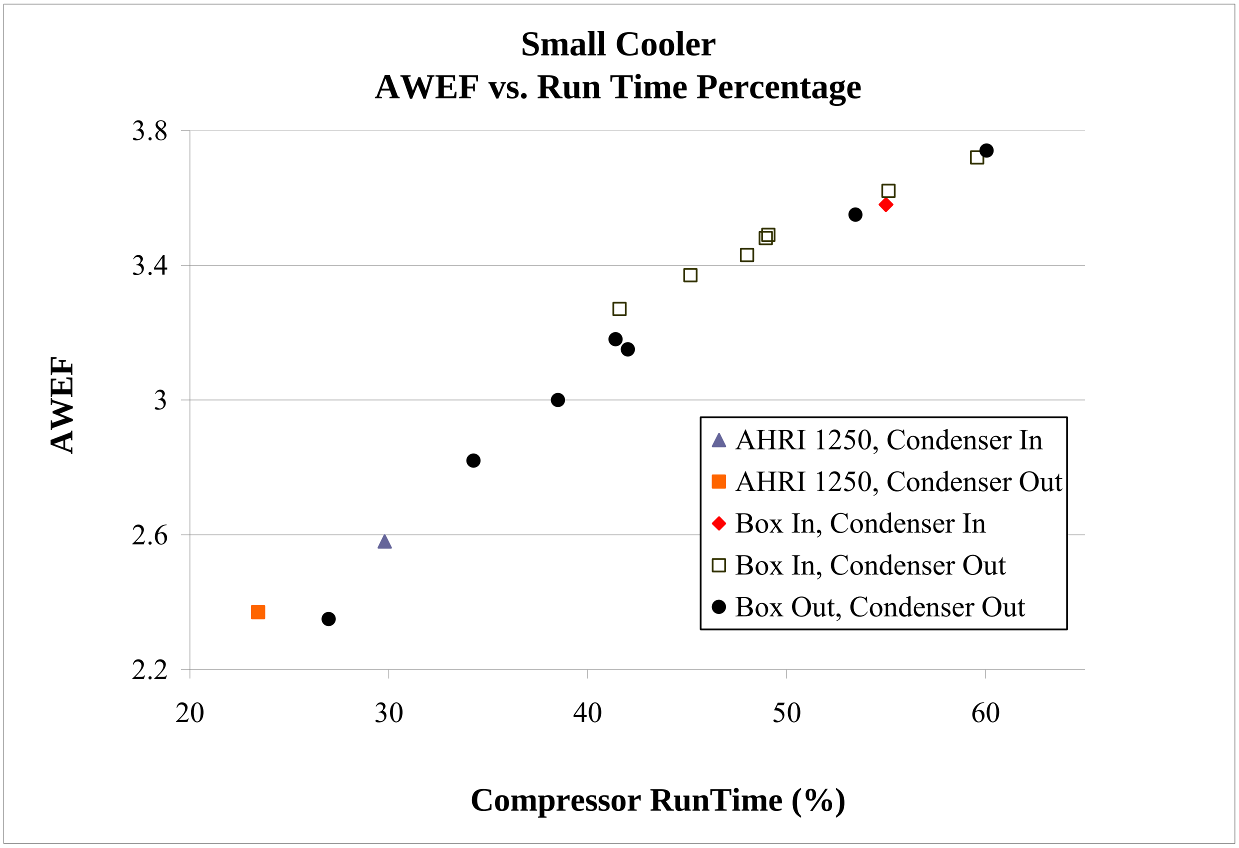


Figure 16. Small Cooler AWEF's versus Compressor Runtime for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

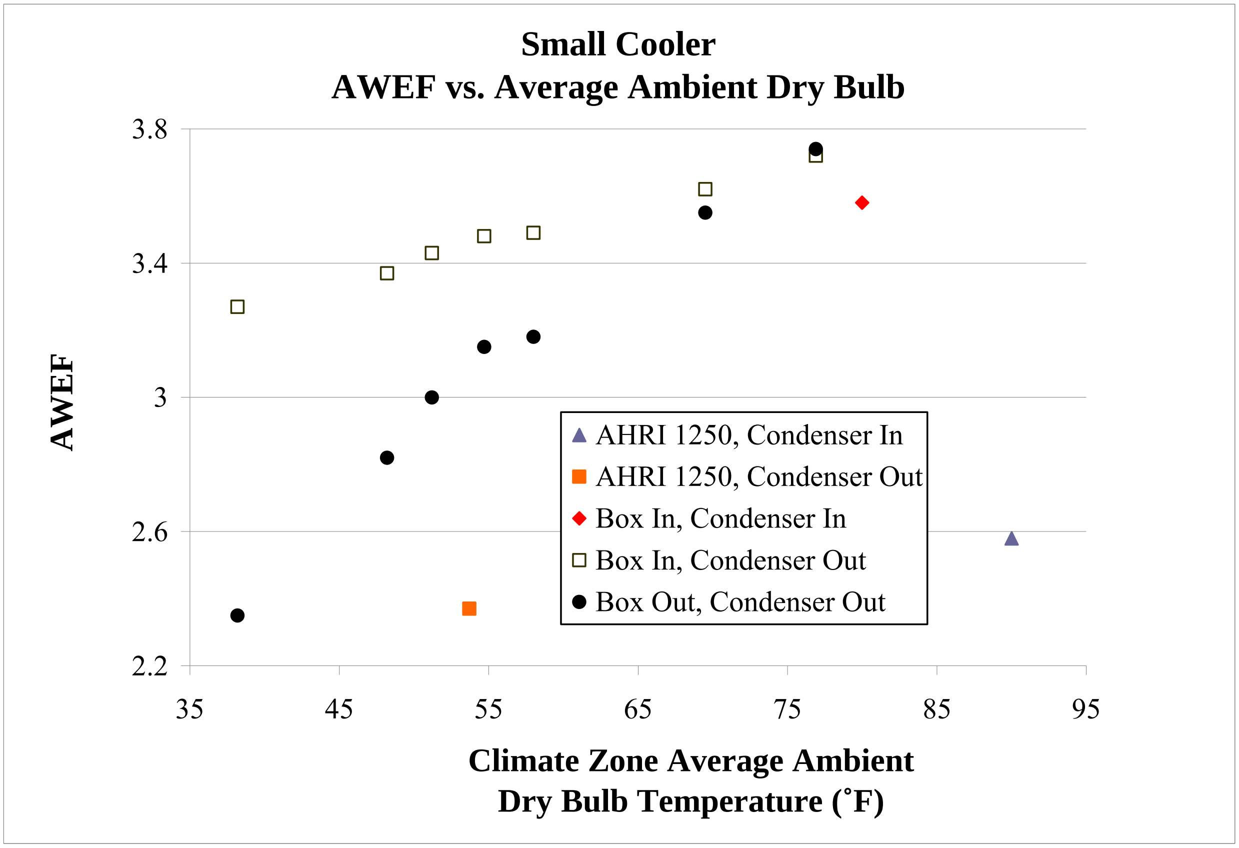


Figure 17 Small Cooler AWEF's versus Average Ambient Temperature for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

Large Single Speed Walk-In Freezer

The large single speed freezer is based on the 'Large Freezer' specified in the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) that was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c) The walk-in box dimensions and construction details are those specified in the AHRI Load Spreadsheet (AHRI 2009a).

The number of occupants and occupancy schedule, the lighting power and lighting schedule, and the product loading and product loading schedule were also based on the values given in the AHRI Load Spreadsheet (AHRI 2009a). The infiltration rate was determined, based on the walk-in box volume, from data for freezers given in the Heatcraft Engineering Manual (Heatcraft 2008). The infiltration schedule was designed to simulate the AHRI Large Freezer door opening schedule.

The condensing unit and the unit cooler used in this simulation was sized, based on the walk-in box refrigeration load, according to industry standard practice using the 'Heatcraft Engineering Manual' (Heatcraft 2008). The condensing unit and the unit cooler were then selected from manufacturers' websites.

Large Freezer: Walk-In Box Description

Dimensions: 50 ft x 50 ft x 20 ft (H)
Floor Area: 2500 ft^2
Volume: 50000 ft^3

Box Internal Air Temperature: -10°F

Wall/Roof Construction (Insulated Sandwich Panel)
R-Value: 32 h-ft^2-°F/Btu

Floor Construction (Insulated Sandwich Panel)
12 inches of soil (exterior surface)
6 inches of concrete
R-Value: 32 h-ft^2-°F/Btu
Heated Sub-Floor: 50˚F minimum (Heatcraft Manual and AHRI 1250/1251 Spreadsheet)

Doors:
Number of Doors: 1
Size: 6 ft x 10 ft
R-Value: 32 h-ft2-°F/Btu

Large Freezer: Refrigeration Load Components

Occupancy:

Number of People: 2

Heat Gain: 1410 Btu/hr – person (AHRI)

Use 1400 Btu/hr – person (Heatcraft Manual)

Occupancy Schedule:

Two people in walk-in for 30 minutes per hour from 6:00am to 7:00am (1 people-hr/day)

Two people in walk-in for 10 minutes per hour from 7:00am to 7:00pm (2 people-hr/day)

Vehicle Usage:

Number of Motorized Vehicles: 1

Vehicle Power: 50 hp (127250.0 Btu/hr; 37,284.95 W; 15 W / ft^2)

Vehicle Schedule:

One motorized vehicle for 30 minutes per hour from 6:00am to 7:00am

Infiltration:

Method: Air Change

Air Changes per Day: 1.6 (Heatcraft Manual)

Infiltration Schedule: (To simulate AHRI Large Freezer door opening schedule)

0.0491 Air changes per hour from 7:00pm to 6:00am

0.1093 Air changes per hour from 6:00am to 7:00am

0.0792 Air changes per hour from 7:00am to 7:00pm

Lighting:

Power Density: 1 W/ft^2 (2500 W total)

Lighting Schedule:

Lights on in walk-in for 30 minutes per hour from 6:00am to 7:00am

Lights on in walk-in for 10 minutes per hour from 7:00am to 7:00pm

Product Loading:

Product Schedule:

20,000 lbs per hour with a 8 hr pulldown delivered from 6:00am to 7:00am

Product Type: Fruit / Vegetable

Product Delta T: 10°F

Product Specific Heat Below Freezing (Btu/lb·°F):

0.50 (AHRI 1250/1251 Spreadsheet)

Use 0.47 (Heatcraft Manual)

Sensible Heat Ratio (Sensible heat transfer / Total heat transfer):

1.00 (Packaged product assumption)

Large Freezer: Equipment Specifications
Refrigerant: R-404A

Condensing Unit (2 units, where the following specification is referring to one unit):
- Model: Emerson CPDK-0900-TFC-001
- Nominal Power: 10.5 hp
- Type: Air Cooled
- No. Fans: 2
- Power / Fan (W): 425
- Air Flow / Fan (CFM): 3290
- Capacity (Btu/hr): 41,000 @ 90°F Ambient, -20°F SST
- Subcooling: 5°F

Compressor (2 units, where the following specification is referring to one unit):
- Model: Copeland 3DF3F40KE-TFC-100
- Performance: Compressor Coefficients from Copeland
- Rated Performance: 720 lb/hr, 7.6 kW @ -25°F SST, 105°F SDT (Copeland)
- Return Gas: 65°F

Unit Cooler (2 units, where the following specification is referring to one unit):
- Model: Larkin MLT6430
- Cooling Capacity: 43000 Btu/hr @ -20°F SST, 10°F TD
- Minimum Supply Temperature: 30°F
- Cooling Control Range: 4°F
- Saturated Suction/Air Temperature Difference: 5°F
- Return Air Path: Direct
- Rated Supply Flow: 8800 CFM (Total for 4 fans)
- No. Fans: 4
- Motor Type: Standard, 208-230/1/60
- Total Fan Power (W): 1100
- Fan Schedule: On Continuously

Large Freezer: Simulation Results
The *eQuest* simulation results for the large single speed walk-in freezer are given in Table 22 through Table 25 and Figure 18 through Figure 19. Table 22 and Table 23 show the AHRI 1250 AWEF calculations that are based on the *eQuest* simulations of the AHRI 1250 method-of-test for the condensing unit located inside and the condensing unit located outside, respectively. Table 24 shows the calculation of the annual compressor runtime corresponding to the Standard 1250 AWEF for the two configurations.

Table 25 shows the results of the *eQuest* simulations of the large freezer in the seven climate zones of the United States for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

The AWEF values calculated from the results of the *eQuest* simulations of the AHRI 1250 method-of-test and from the results of the climate zone simulations are plotted versus compressor runtime and average ambient temperature in Figure 18 and Figure 19, respectively.

Table 22. Large Freezer AHRI 1250 AWEF for Indoor Condenser.

AHRI 1250 AWEF Calculator: Large Freezer - Condenser Indoors		
Data from eQuest Simulation Results:		
Total Cooling Energy:	634.087	MBtu
Power Demand for Supply Fans:	2.2	kW
Total Electric Consumption:	339939.78	kWh
Miscellaneous Electric Consumption:	165651.56	kWh
Modified Data from eQuest Simulation Results:		
Total Cooling Rate: Q	72384.361	Btu/hr
Energy Consumption: Ess	19895.916	W
Evaporator Fan Power: Efc,off	2200	W
Calculations According to AHRI 1250 Standard:		
Net Refrigeration Capacity: Qss	64877.961	Btu/hr
Box Load High: BLH	51902.369	Btu/hr
Box Load Low: BLL	25951.184	Btu/hr
Load Factor High: LFH	0.8207404	
Load Factor Low: LFL	0.4622212	
AWEF:	2.7671711	

Average Runtime: 53.20%

Table 23. Large Freezer AHRI 1250 AWEF for Outdoor Condenser.

AHRI 1250 AWEF Calculator: Large Freezer - Condenser Outdoors

Data from eQuest Simulation Results:

Ambient Temperature (°F)	Total Cooling Energy (MBtu)	Total Electric Consumption (kWh)	Miscellaneous Electric Consumption (kWh)	Power Demand for Supply Fans (kW)
95	589.586	329715.97	152599.25	2.2
59	705.115	347897.72	186500.41	
35	743.922	355534.97	197888.44	

Modified Data from eQuest Simulation Results:

Ambient Temperature (°F)	qss (Btu/h)	Ess (W)	Power Demand for Supply Fans (W)
95	59797.9379	20218.80365	2200
59	72986.17991	18424.35046	
35	77416.20274	17996.17922	

Calculations According to AHRI 1250 Standard:

Temp (°F)	Bin Hour (hr)	qss (Btu/h)	Ess (W)	BLH (Btu/h)	BLL (Btu/h)	LFH	LFL	WLH (Btu/h)	WLL (Btu/h)	BL (Btu)	E (W-h)
100.4	9	57820	20488	48607	24688	0.86	0.49	49666	28495	293232	120802.6598
95	74	59798	20219	47838	23919	0.82	0.47	49172	27921	2354125	941761.5271
89.6	257	61776	19950	47070	23150	0.79	0.44	48663	27335	7978224	3103587.776
84.2	416	63754	19680	46301	22382	0.76	0.42	48139	26740	12594334	4770621.353
78.8	630	65733	19411	45532	21613	0.72	0.40	47602	26135	18588787	6865726.848
73.4	898	67711	19142	44763	20844	0.69	0.38	47053	25521	25805988	9306509.243
68	737	69689	18873	43994	20075	0.67	0.36	46493	24899	20612674	7268266.773
62.6	943	71667	18604	43225	19306	0.64	0.34	45922	24271	25649147	8855359.653
57.2	628	73318	18392	42457	18537	0.62	0.32	45323	23625	16598472	5651289.418
51.8	590	74315	18296	41688	17769	0.60	0.31	44681	22956	15140496	5147656.828
46.4	677	75312	18200	40919	17000	0.58	0.30	44036	22285	16852579	5726878.673
41	576	76309	18103	40150	16231	0.57	0.28	43388	21611	13895537	4724147.133
35.6	646	77305	18007	39381	15462	0.55	0.27	42738	20936	15087566	5136920.148
30.2	534	78302	17911	38612	14693	0.54	0.26	42084	20258	12061210	4116959.459
24.8	322	79299	17814	37844	13924	0.52	0.25	41428	19578	7025301	2406854.812
19.4	305	80296	17718	37075	13156	0.51	0.24	40770	18896	6419907	2210264.432
14	246	81292	17622	36306	12387	0.49	0.22	40109	18211	4988891	1728302.075
8.6	189	82289	17525	35537	11618	0.48	0.21	39445	17526	3687619	1287284.123
3.2	78	83286	17429	34768	10849	0.47	0.20	38780	16838	1461906	515016.7893
-2.2	5	84283	17333	33999	10080	0.45	0.19	38112	16148	89868	32003.34134
	8760								Total	227185863	79916213
										AWEF	2.84

Average Runtime: 36.16%

Table 24. Large Freezer AHRI 1250 Run Time.

Calculation of Annual Compressor Runtime
Corresponding to AHRI 1250
Large Freezer

Condenser Indoors	
Run %	53.20%
Condenser Outdoors	
q_{ss} (95F)	59797.9379
q_{ss} (59F)	72986.1799
q_{ss} (35F)	77416.2027
Run %	36.16%

Temp [F]	Bin Hour [hr]	CR (t_j)	CR (t_j) * nj
100.4	9	0.56	5.07
95	74	0.53	39.37
89.6	257	0.50	129.15
84.2	416	0.47	197.54
78.8	630	0.45	282.79
73.4	898	0.42	381.12
68	737	0.40	295.78
62.6	943	0.38	357.89
57.2	628	0.36	226.39
51.8	590	0.35	203.73
46.4	677	0.33	223.77
41	576	0.32	182.10
35.6	646	0.30	195.17
30.2	534	0.29	154.03
24.8	322	0.28	88.59
19.4	305	0.26	79.95
14	246	0.25	61.37
8.6	189	0.24	44.81
3.2	78	0.23	17.55
-2.2	5	0.21	1.07
	8760		3167.26

Table 25. Large Freezer AWEF's for Climate Zones 1-7.

Large Freezer Suction Temperature = -20°F									
Box Location	Condenser Location	Climate Zone	Annual Average Temperature (°F)	Cooling Energy (MBtu)	Evaporator Fan Energy (kWh)	Cooling w/o Fan (MBtu)	Electrical Energy (kWh)	AWEF	Average Run Time (%)
OUT	OUT	1	76.9	413.347	19272.000	347.588	118779.30	2.93	61.48
OUT	OUT	2	69.5	386.901	19272.000	321.142	110863.29	2.90	56.79
OUT	OUT	3	58.0	347.443	19272.000	281.684	95415.36	2.95	49.52
OUT	OUT	4	54.7	346.584	19272.000	280.825	97173.41	2.89	49.08
OUT	OUT	5	51.2	336.160	19272.000	270.401	93541.82	2.89	47.20
OUT	OUT	6	48.2	327.728	19272.000	261.969	90249.37	2.90	45.39
OUT	OUT	7	38.2	295.059	19272.000	229.300	80762.60	2.84	39.83
Average				350.460				2.90	49.90
IN	OUT	1	76.9	399.508	19272.000	333.749	114757.29	2.91	59.16
IN	OUT	2	69.5	385.591	19272.000	319.832	109230.87	2.93	56.70
IN	OUT	3	58.0	369.018	19272.000	303.259	99551.70	3.05	52.55
IN	OUT	4	54.7	370.505	19272.000	304.746	101167.36	3.01	51.89
IN	OUT	5	51.2	365.987	19272.000	300.228	98939.42	3.03	51.63
IN	OUT	6	48.2	365.152	19272.000	299.393	97230.55	3.08	50.55
IN	OUT	7	38.2	350.768	19272.000	285.009	91543.07	3.11	47.44
Average				372.361				3.02	52.85
IN	IN	80°F		384.897	19272.000	319.138	112217.27	2.84	55.98

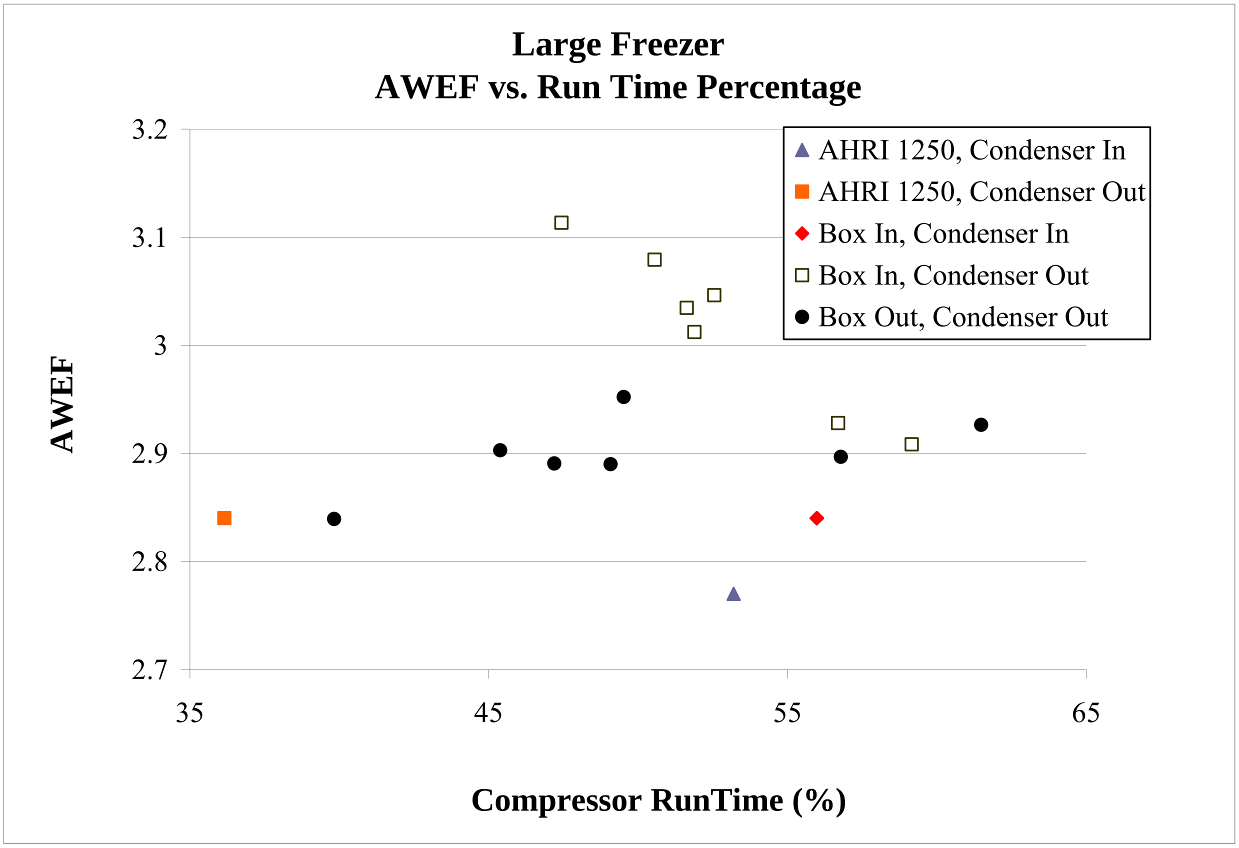


Figure 18. Large Freezer AWEF's versus Compressor Runtime for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

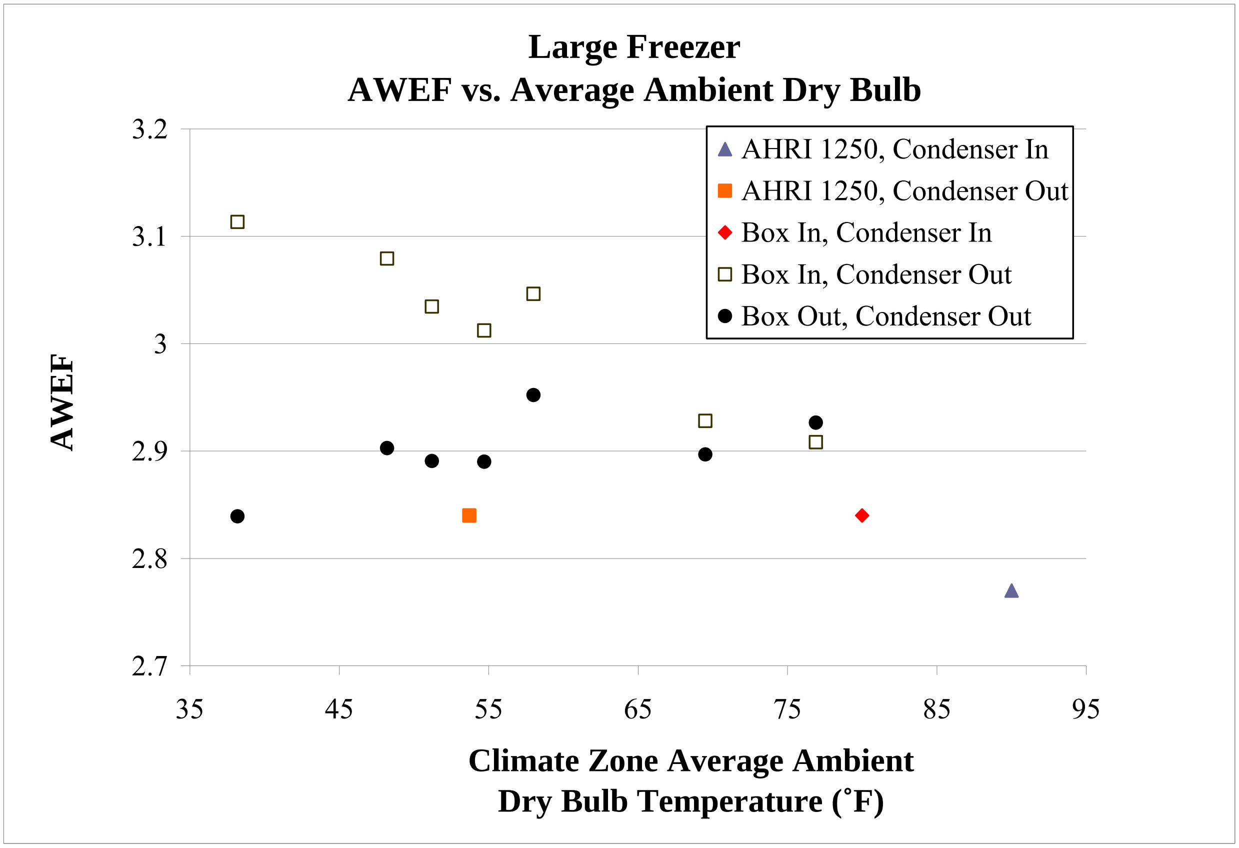


Figure 19. Large Freezer AWEF's versus Average Ambient Temperature for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

Large Single Speed Walk-In Cooler
The large single speed cooler is based on the 'Large Cooler' specified in the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) that was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c) The walk-in box dimensions and construction details are those specified in the AHRI Load Spreadsheet (AHRI 2009a).

The number of occupants and occupancy schedule, the lighting power and lighting schedule, and the product loading and product loading schedule were also based on the values given in the AHRI Load Spreadsheet (AHRI 2009a). The infiltration rate was determined, based on the walk-in box volume, from data for coolers given in the Heatcraft Engineering Manual (Heatcraft 2008). The infiltration schedule was designed to simulate the AHRI Large Cooler door opening schedule.

The condensing unit and the unit cooler used in this simulation was sized, based on the walk-in box refrigeration load, according to industry standard practice using the 'Heatcraft Engineering Manual' (Heatcraft 2008). The condensing unit and the unit cooler were then selected from manufacturers' websites.

Large Cooler: Walk-In Box Description
Dimensions: 50 ft x 50 ft x 20 ft (H)
Floor Area: 2500 ft^2
Volume: 50000 ft^3

Box Internal Air Temperature: 35°F

Wall/Roof Construction (Insulated Sandwich Panel)
R-Value: 25 h-ft^2-°F/Btu

Floor Construction (Insulated Sandwich Panel)
12 inches of soil (exterior surface)
6 inches of concrete
R-Value: 25 h-ft^2-°F/Btu

Doors:
Number of Doors: 1
Size: 6 ft x 10 ft
R-Value: 25 h-ft2-°F/Btu

Large Cooler: Refrigeration Load Components

Occupancy:

Number of People: 2

Heat Gain: 892.5 Btu/hr – person (AHRI)

Use 895 Btu/hr – person (Heatcraft Manual)

Occupancy Schedule:

Two people in walk-in for 60 minutes per hour from 6:00am to 7:00am (2 hr/day)

Two people in walk-in for 10 minutes per hour from 7:00am to 7:00pm (4 hr/day)

Vehicle Usage:

Number of Motorized Vehicles: 1

Vehicle Power: 50 hp (127250.0 Btu/hr; 37,284.95 W; 15 W / ft^2)

Vehicle Schedule:

One motorized vehicle for 60 minutes per hour from 6:00am to 7:00am

Infiltration:

Method: Air Change

Air Changes per Day: 2.0 (Heatcraft Manual)

Infiltration Schedule: (To simulate AHRI Large Cooler door opening schedule)

0.0617 Air changes per hour from 7:00pm to 6:00am

0.2696 Air changes per hour from 6:00am to 7:00am

0.0877 Air changes per hour from 7:00am to 7:00pm

Lighting:

Power Density: 1 W/ft^2 (2500 W total)

Lighting Schedule:

Lights on in walk-in for 60 minutes per hour from 6:00am to 7:00am

Lights on in walk-in for 10 minutes per hour from 7:00am to 7:00pm

Product Loading:

Product Schedule:

80,000lbs per hour with a 8 hr pulldown delivered from 6:00am to 7:00am

Product Type: Fruit / Vegetable

Product Delta T: 10°F

Product Specific Heat Above Freezing (Btu/lb·°F): 0.90

Sensible Heat Ratio (Sensible heat transfer / Total heat transfer):

1.00 (Packaged product assumption)

Large Cooler: Equipment Specifications

Refrigerant: R-404A

Condensing Unit (2 units, where the following specification is referring to one unit):

Model: Emerson FJAM-075Z-TSC-010
Nominal Power: 12 hp
Type: Air Cooled
No. Fans: 2
Power / Fan (W): 510
Air Flow / Fan (CFM): 2650
Capacity: 64,520 Btu/hr @ 90°F ambient, 25°F SST
Subcooling: 5°F

Compressor (2 units, where the following specification is referring to one unit):

Model: Copeland ZS56K4E-TWC
Performance: Compressor Coefficients from Copeland
Rated Performance: 1120 lb/hr, 7.6 kW @ 20°F SST, 120°F SDT (Copeland)
Return Gas: 65°F

Unit Cooler (2 units, where the following specification is referring to one unit):

Model: Larkin LHA6 630
Cooling Capacity: 63000 Btu/hr @ 25°F SST, 10°F TD
Mimimum Supply Temperature: 30°F
Cooling Control Range: 4°F
Saturated Suction/Air Temperature Difference: 5°F
Return Air Path: Direct
Rated Supply Flow: 9000 CFM (Total for 2 fans)
No. Fans: 2
Motor Type: Standard, 208-230/3/60
Total Fan Power (W): 1119
Fan Schedule: On Continuously

Large Cooler: Simulation Results

The *eQuest* simulation results for the large single speed walk-in cooler are given in Table 26 through Table 29 and Figure 20 through Figure 21. Table 26 and Table 27 show the AHRI 1250 AWEF calculations that are based on the *eQuest* simulations of the AHRI 1250 method-of-test for the condensing unit located inside and the condensing unit located outside, respectively. Table 28 shows the calculation of the annual compressor runtime corresponding to the Standard 1250 AWEF for the two configurations.

Table 29 shows the results of the *eQuest* simulations of the large cooler in the seven climate zones of the United States for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

The AWEF values calculated from the results of the *eQuest* simulations of the AHRI 1250 method-of-test and from the results of the climate zone simulations are plotted versus compressor runtime and average ambient temperature in Figure 20 and Figure 21, respectively.

Table 26. Large Cooler AHRI 1250 AWEF for Indoor Condenser.

AHRI 1250 AWEF Calculator: Large Cooler - Condenser Indoors		
Data from eQuest Simulation Results:		
Total Cooling Energy:	1041.671	MBtu
Power Demand for Supply Fans:	2.238	kW
Total Electric Consumption:	447171	kWh
Miscellaneous Electric Consumption:	284786	kWh
Modified Data from eQuest Simulation Results:		
Total Cooling Rate: Q	118912.21	Btu/hr
Energy Consumption: Ess	18537.1	W
Evaporator Fan Power: Efc,off	2238	W
Calculations According to AHRI 1250 Standard:		
Net Refrigeration Capacity: Qss	111276.16	Btu/hr
Box Load High: BLH	77893.311	Btu/hr
Box Load Low: BLL	11127.616	Btu/hr
Load Factor High: LFH	0.7192648	
Load Factor Low: LFL	0.1577943	
AWEF:	4.2350917	

Average Runtime: 29.80%

Table 27. Large Cooler AHRI 1250 AWEF for Outdoor Condenser.

AHRI 1250 AWEF Calculator: Large Cooler - Condenser Outdoors

Data from eQuest Simulation Results:

Ambient Temperature (°F)	Total Cooling Energy (MBtu)	Total Electric Consumption (kWh)	Miscellaneous Electric Consumption (kWh)	Power Demand for Supply Fans (kW)
95	983.212	433823	266512	2.238
59	1055.801	443779	290089	
35	1095.355	453421	300556	

Modified Data from eQuest Simulation Results:

Ambient Temperature (°F)	qss (Btu/h)	Ess (W)	Power Demand for Supply Fans (W)
95	104602.7568	19099.42922	2238
59	112889.1723	17544.52055	
35	117404.4691	17450.34247	

Calculations According to AHRI 1250 Standard:

Temp (°F)	Bin Hour (hr)	qss (Btu/h)	Ess (W)	BLH (Btu/h)	BLL (Btu/h)	LFH	LFL	WLH (Btu/h)	WLL (Btu/h)	BL (Btu)	E (W-h)
100.4	9	103360	19333	73693	11119	0.73	0.17	75734	17465	285916	74760.86178
95	74	104603	19099	73222	10460	0.72	0.16	75357	16865	2306700	597032.4149
89.6	257	105846	18866	72751	9801	0.71	0.15	74978	16264	7857713	2014091.633
84.2	416	107089	18633	72281	9142	0.70	0.15	74597	15662	12470804	3167129.941
78.8	630	108332	18400	71810	8483	0.69	0.14	74215	15058	18510050	4660014.673
73.4	898	109575	18166	71339	7824	0.67	0.13	73830	14453	25848183	6454258.447
68	737	110818	17933	70868	7165	0.66	0.12	73444	13847	20774044	5147678.504
62.6	943	112061	17700	70398	6506	0.65	0.12	73056	13240	26017786	6401501.842
57.2	628	113228	17537	69927	5847	0.64	0.11	72663	12631	16951967	4158342.568
51.8	590	114244	17516	69456	5188	0.63	0.11	72262	12021	15574062	3837468.743
46.4	677	115260	17495	68986	4529	0.62	0.10	71861	11409	17466499	4325319.516
41	576	116276	17474	68515	3870	0.61	0.09	71458	10797	14516921	3614866.845
35.6	646	117292	17453	68044	3211	0.61	0.09	71054	10184	15895557	3982404.658
30.2	534	118308	17432	67573	2552	0.60	0.08	70649	9571	12820946	3233695.153
24.8	322	119323	17410	67103	1893	0.59	0.08	70244	8956	7538792	1915400.923
19.4	305	120339	17389	66632	1234	0.58	0.07	69837	8341	6958738	1782173.033
14	246	121355	17368	66161	575	0.57	0.06	69429	7725	5465793	1411987.02
8.6	189	122371	17347	65691	-84	0.56	0.06	69020	7109	4086522	1065617.851
3.2	78	123387	17326	65220	-743	0.56	0.05	68610	6492	1639946	431992.3385
-2.2	5	124403	17304	64749	-1402	0.55	0.05	68199	5874	102140	27201.32345
	8760								Total	233089080	58302938
										AWEF	4.00

Average Runtime: 23.54%

Table 28. Large Cooler AHRI 1250 Run Time.

Calculation of Annual Compressor Runtime
Corresponding to AHRI 1250
Large Cooler

Condenser Indoors

Run %	29.80%

Condenser Outdoors

q_{ss} (95F)	104602.757
q_{ss} (59F)	112889.172
q_{ss} (35F)	117404.469
Run %	23.54%

Temp [F]	Bin Hour [hr]	CR (t_j)	CR (t_j) * nj
100.4	9	0.31	2.77
95	74	0.30	22.05
89.6	257	0.29	74.24
84.2	416	0.28	116.45
78.8	630	0.27	170.86
73.4	898	0.26	235.90
68	737	0.25	187.46
62.6	943	0.25	232.18
57.2	628	0.24	149.72
51.8	590	0.23	136.32
46.4	677	0.22	151.54
41	576	0.22	124.85
35.6	646	0.21	135.52
30.2	534	0.20	108.37
24.8	322	0.20	63.18
19.4	305	0.19	57.83
14	246	0.18	45.04
8.6	189	0.18	33.39
3.2	78	0.17	13.29
-2.2	5	0.16	0.82
	8760		2061.78

Table 29. Large Cooler AWEF's for Climate Zones 1-7.

Large Cooler

Suction Temperature = 25°F

Box Location	Condenser Location	Climate Zone	Annual Average Temperature (°F)	Cooling Energy (MBtu)	Evaporator Fan Energy (kWh)	Cooling w/o Fan (MBtu)	Electrical Energy (kWh)	AWEF	Average Run Time (%)
OUT	OUT	1	76.9	573.258	19604.880	506.363	101648	4.98	54.12
OUT	OUT	2	69.5	537.462	19604.880	470.567	97459	4.83	50.98
OUT	OUT	3	58.0	488.591	19604.880	421.696	87861	4.80	45.30
OUT	OUT	4	54.7	485.982	19604.880	419.087	87365	4.80	45.04
OUT	OUT	5	51.2	472.294	19604.880	405.399	84804	4.78	43.48
OUT	OUT	6	48.2	458.146	19604.880	391.251	82348	4.75	41.86
OUT	OUT	7	38.2	417.185	19604.880	350.290	75667	4.63	37.64
Average				490.417				4.80	45.49
IN	OUT	1	76.9	557.290	19604.880	490.395	99708	4.92	52.72
IN	OUT	2	69.5	537.503	19604.880	470.608	97428	4.83	50.62
IN	OUT	3	58.0	515.935	19604.880	449.040	91783	4.89	48.33
IN	OUT	4	54.7	517.126	19604.880	450.231	91957	4.90	48.04
IN	OUT	5	51.2	510.364	19604.880	443.469	90411	4.91	47.17
IN	OUT	6	48.2	505.866	19604.880	438.971	89300	4.92	46.49
IN	OUT	7	38.2	487.849	19604.880	420.954	85142	4.94	44.08
Average				518.848				4.90	48.21
IN	IN	80°F		535.099	19604.880	468.204	98373	4.76	51.15

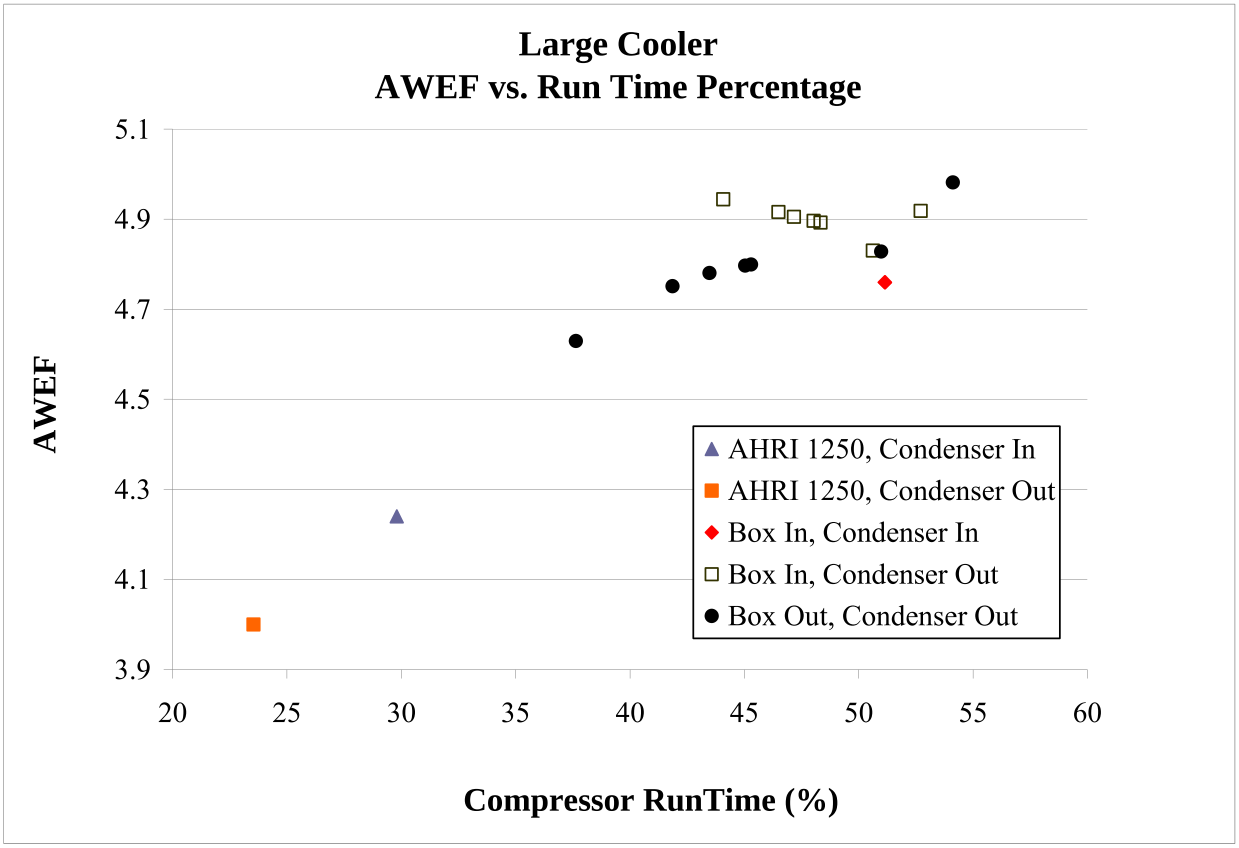


Figure 20. Large Cooler AWEF's versus Compressor Runtime for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

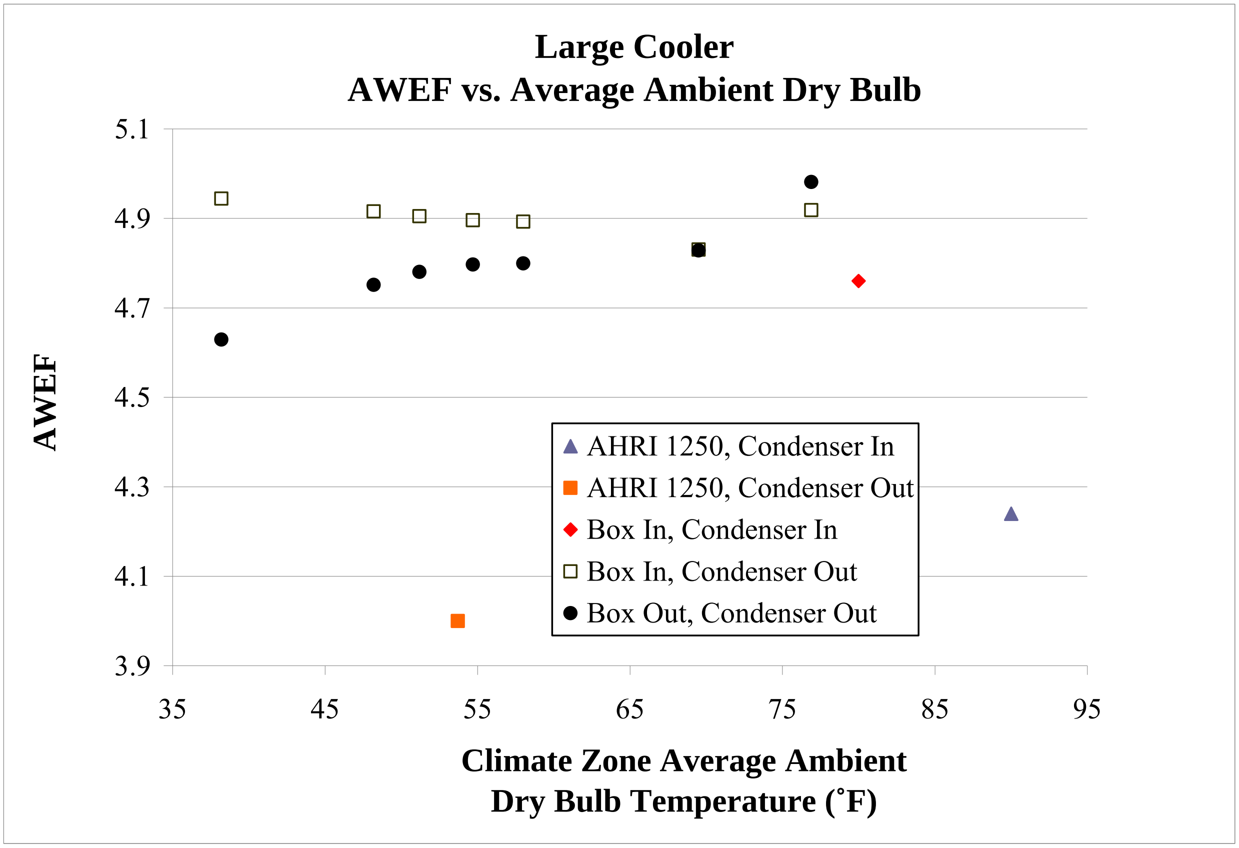


Figure 21. Large Cooler Field AWEF's versus Average Ambient Temperature for the AHRI 1250 Method-of-Test and Climate Zones 1-7.

ANALYSIS OF SIMULATION RESULTS

Table 30 through Table 33 summarize the AWEF results for the four walk-in systems that were simulated. These four tables plus Table 14 through Table 29 and Figure 14 through Figure 21 show two distinct trends in the AWEF. First, the AWEF generally increases with increasing compressor run time. Second, the AWEF generally increases with decreasing annual average ambient temperature.

Table 30. Summary: Small Freezer AWEF's.

AHRI 1250 -or- Climate Zone	Box In, Condenser In		Box In, Condenser Out		Box Out, Condenser Out	
	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)
AHRI 1250	2.28	53.20	2.02	41.89	2.02	41.89
1 (76.9°F)	1.88	55.00	1.90	54.41	1.90	54.57
2 (69.5°F)	1.88	55.00	1.82	52.13	1.86	50.88
3 (58.0°F)	1.88	55.00	1.88	49.65	1.78	44.93
4 (54.7°F)	1.88	55.00	1.88	49.70	1.77	44.76
5 (51.2°F)	1.88	55.00	1.87	49.02	1.75	43.10
6 (48.2°F)	1.88	55.00	1.88	48.76	1.74	41.83
7 (38.2°F)	1.88	55.00	1.85	46.49	1.64	35.99
Zone Average	1.88	55.00	1.87	50.02	1.78	45.15

Table 31. Summary: Small Cooler AWEF's.

AHRI 1250 -or- Climate Zone	Box In, Condenser In		Box In, Condenser Out		Box Out, Condenser Out	
	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)
AHRI 1250	2.58	29.80	2.37	23.43	2.37	23.43
1 (76.9°F)	3.58	55.00	3.72	59.59	3.74	60.06
2 (69.5°F)	3.58	55.00	3.62	55.13	3.55	53.47
3 (58.0°F)	3.58	55.00	3.49	49.09	3.18	41.41
4 (54.7°F)	3.58	55.00	3.48	48.95	3.15	42.02
5 (51.2°F)	3.58	55.00	3.43	48.02	3.00	38.51
6 (48.2°F)	3.58	55.00	3.37	45.17	2.82	34.26
7 (38.2°F)	3.58	55.00	3.27	41.60	2.35	26.98
Zone Average	3.58	55.00	3.48	49.65	3.11	42.39

Table 32. Summary: Large Freezer AWEF's.

AHRI 1250 -or- Climate Zone	Box In, Condenser In		Box In, Condenser Out		Box Out, Condenser Out	
	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)
AHRI 1250	2.77	53.20	2.84	36.16	2.84	36.16
1 (76.9°F)	2.84	55.98	2.91	59.16	2.93	61.48
2 (69.5°F)	2.84	55.98	2.93	56.70	2.90	56.79
3 (58.0°F)	2.84	55.98	3.05	52.55	2.95	49.52
4 (54.7°F)	2.84	55.98	3.01	51.89	2.89	49.08
5 (51.2°F)	2.84	55.98	3.03	51.63	2.89	47.20
6 (48.2°F)	2.84	55.98	3.08	50.55	2.90	45.39
7 (38.2°F)	2.84	55.98	3.11	47.44	2.84	39.83
Zone Average	2.84	55.98	3.02	52.85	2.90	49.90

Table 33. Summary: Large Cooler AWEF's.

AHRI 1250 -or- Climate Zone	Box In, Condenser In		Box In, Condenser Out		Box Out, Condenser Out	
	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)	AWEF	Average Run Time (%)
AHRI 1250	4.24	29.80	4.00	23.54	4.00	23.54
1 (76.9°F)	4.76	51.15	4.92	52.72	4.98	54.12
2 (69.5°F)	4.76	51.15	4.83	50.62	4.83	50.98
3 (58.0°F)	4.76	51.15	4.89	48.33	4.80	45.30
4 (54.7°F)	4.76	51.15	4.90	48.04	4.80	45.04
5 (51.2°F)	4.76	51.15	4.91	47.17	4.78	43.48
6 (48.2°F)	4.76	51.15	4.92	46.49	4.75	41.86
7 (38.2°F)	4.76	51.15	4.94	44.08	4.63	37.64
Zone Average	4.76	51.15	4.90	48.21	4.80	45.49

The first trend, that the AWEF increases with increasing compressor run time, occurs because according to the definition of the AWEF, the heat equivalent of the unit cooler fan power is subtracted from the refrigeration load, resulting in a smaller AWEF numerator while the unit cooler fan power is included in the total energy usage of the refrigeration system, resulting in a larger AWEF denominator. Since the unit cooler fans are always operating, when the condensing unit is not operating, the unit cooler fans add heat to the box that is not included as 'useful' refrigeration and their power requirement adds to the total energy usage of the refrigeration system. The net effect is a reduction in the AWEF.

When the condensing unit is operating, the heat equivalent of the unit cooler fan power is removed simultaneously by the refrigeration system, resulting in a reduced instantaneous refrigeration capacity. Whereas, the heat that is added to the box by the unit cooler fans when the compressor is not operating is 'stored' in the box and must be removed by the refrigeration system at a later time. However, this portion of the refrigeration load is not included in the 'useful' refrigeration load used to calculate the AWEF.

Thus, if the refrigeration system is considerably oversized relative to the box load, the condensing unit will not be operating for long periods of time during the day, that is, the compressor run time will be smaller and the AWEF will be reduced.

The second trend, that the AWEF increases with decreasing annual average ambient temperature, occurs because as the ambient temperature surrounding the condenser is reduced, the difference between the saturated condensing temperature and the ambient increases. This increased temperature difference results in a higher heat rejection rate per unit mass of refrigerant and a lower compressor discharge pressure. Hence, the compressor work and energy usage will be decreased and thus the AWEF will be increased with decreasing ambient temperature. However, this effect is somewhat offset because the 'useful' refrigeration and the compressor run time also decrease with decreasing ambient temperature.

In summary, the AWEF generally increases with increasing compressor run time and with decreasing average ambient temperature. However, the behavior of a walk-in system is further complicated because a reduced average ambient temperature usually results in a reduced compressor run time. So these two general trends tend to compete against each other and the combined effect on the AWEF of a walk-in refrigeration system depends upon the walk-in refrigeration system's operating characteristics.

Walk-in Box and Condensing Unit Inside

For the configuration with both the walk-in box and the condensing unit located indoors, the ambient conditions surrounding both the walk-in box and the condensing unit were held constant at 80°F DB and 63°F WB to simulate the conditions found in the back room of a supermarket or restaurant.

Thus, the ambient conditions surrounding both the box and the condenser were held constant for all seven climate zones resulting in a constant AWEF value for this configuration across all seven climate zones. Therefore, the 'Box In, Condenser In' configuration appears as a single point in Figure 14 through Figure 21.

These climate zone simulation results for the 'Box In, Condenser In' configuration should be compared to the results from the AHRI 1250/1251 method-of-test simulation for the condensing unit located indoors in which the ambient conditions surrounding the condensing unit were held constant at 90°F DB, 75°F WB. These 'AHRI 1250, Condenser In' results also appear as a single point in Figure 14 through Figure 21.

Therefore, different ambient temperatures are used in the climate zone simulations versus the AHRI 1250/1251 method-of-test simulations. The ambient temperature used the AHRI 1250/1251 method-of-test simulations is specified according to the 'Standard Rating Conditions' given in AHRI 1250/1251. The ambient temperature used in the climate zone simulations was chosen by the researchers to represent the conditions found in the back room of a supermarket or restaurant. It has been the experience of the researchers that 80°F DB and 63°F WB are a more typical back room condition than the 90 ºF DB, 75 ºF WB specified in the AHRI 1250/1251 method of test.

As shown in Table 30 through Table 33, the AWEF values for the climate zone simulations of 'Box In, Condenser In' were 1.88 and 2.84 for the small and large freezers and 3.58 and 4.76 for the small and large coolers, respectively, while the compressor run times ranged from 51.15% to 55.98%. The AHRI 1250/1251 method-of-test simulations had AWEF values of 2.28 and 2.77 for the small and large freezers and 2.58 and 4.24 for the small and large coolers, respectively, with compressor run times of 53.20% for the freezers and 29.80% for the coolers. These results are shown graphically in Figure 22 where the percentage difference in AWEF is plotted versus percentage difference in compressor run times.

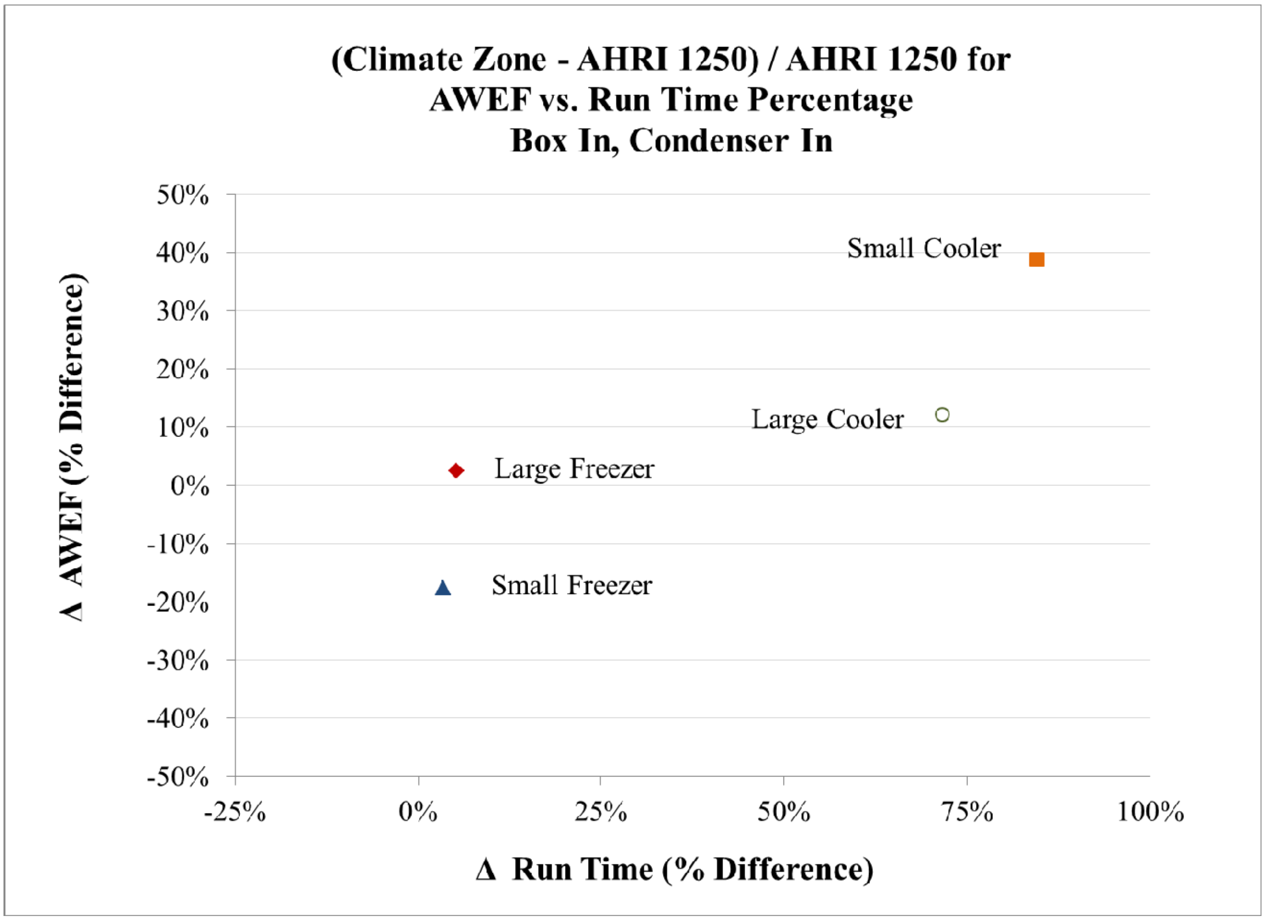


Figure 22. Percentage Difference in AWEF versus Percentage Difference in Compressor Runtime for the Walk-in Box and Condensing Unit Located Inside.

From these results, it can be seen that the simulated climate zone AWEF's compare relatively well to the simulated 1250/1251 method-of-test AWEF's for the freezers and for the large cooler, but not so well for the small cooler. The simulated climate zone AWEF's are 17.5% smaller and 2.5% larger than the simulated 1250/1251 method-of-test AWEF's for the small and large freezers, respectively. The compressor run times for the climate zone simulations are about 4.3% larger than the values determined from the simulated 1250/1251 method-of-test for the freezers. The simulated climate zone AWEF’s are 38.8% and 12.3% larger than the simulated 1250/1251 method-of-test AWEF’s for the small and large coolers respectively. The compressor run times for the climate zone simulations are about 78% larger than the values determined from the simulated 1250/1251 method-of-test for the coolers.

Walk-in Box Inside and Condensing Unit Outside

For the configuration with the walk-in box located indoors and the condensing unit located outdoors, the ambient conditions surrounding the walk-in box were held constant at 80°F DB and 63°F WB to simulate the back room of a supermarket or restaurant. The ambient conditions surrounding the condensing unit were those of the hourly weather data for the seven cities shown in Table 13 that represent the seven climate zones in the continental United States.

Since the ambient conditions surrounding the walk-in box were held constant for all seven climate zones and since the schedules for occupancy, infiltration, lighting and product loading did not vary with climate zone, the refrigeration load schedule for the ‘Box In, Condenser Out’ configuration remained constant across all seven climate zones. However, since refrigeration systems generally become more efficient as the annual average ambient temperature surrounding the condenser is reduced, the AWEF generally increased somewhat as the average ambient temperature decreased across the climate zones. This behavior is clearly demonstrated in Figure 15, Figure 17, Figure 19, and Figure 21 for the ‘Box In, Condenser Out’ configuration, especially so for the large freezer and the large cooler, Figure 19, and Figure 21, respectively.

These climate zone simulations for the ‘Box In, Condenser Out’ configuration should be compared to the results from the AHRI 1250/1251 method-of-test simulation for the condensing unit located outdoors. These ‘AHRI 1250, Condenser Out’ results appear as a single point in Figure 14 through Figure 21.

As shown in Table 30 through Table 33, the AWEF values for the climate zone simulations of ‘Box In, Condenser Out’ ranged from 1.82 to 4.94 with an average value of 3.32 and the compressor run times ranged from 41.60% to 59.59% with an average value of 50.18%. These results are shown graphically in Figure 23 where the percentage difference in AWEF is plotted versus the annual average ambient temperature of the seven climate zones for the configuration with the walk-in box located indoors and the condensing unit located outdoors.

From these results, it can be seen that the simulated climate zone AWEF’s compare relatively well to the simulated 1250/1251 method-of-test AWEF’s for the freezers but not as well for the coolers, especially the small cooler. For the freezers, the simulated climate zone AWEF’s are within 9.9% and 9.5% of the simulated 1250/1251 method-of-test AWEF’s for the small and large freezers, respectively, across all seven climate zones. The compressor run times for the climate zone simulations of the freezers are on average 19.4% larger and 46.2% larger than the values determined from the simulated 1250/1251 method-of-test for the small and large freezers, respectively, across all seven climate zones. For the large cooler, the simulated climate zone AWEF’s across all seven climate zones are within 23.5% of the simulated 1250/1251 method-of-test AWEF. However, the simulated climate zone AWEF’s for the small cooler range from 38.0% larger to 57.0% larger than the simulated 1250/1251 method-of-test AWEF’s with the closest agreement in Climate Zone 7 and least agreement in Climate Zone 1. The compressor run times for the climate zone simulations of the coolers are on average 111.9% larger and 104.8% larger than the values determined from the simulated 1250/1251 method-of-test for the small and large coolers, respectively, across all seven climate zones.

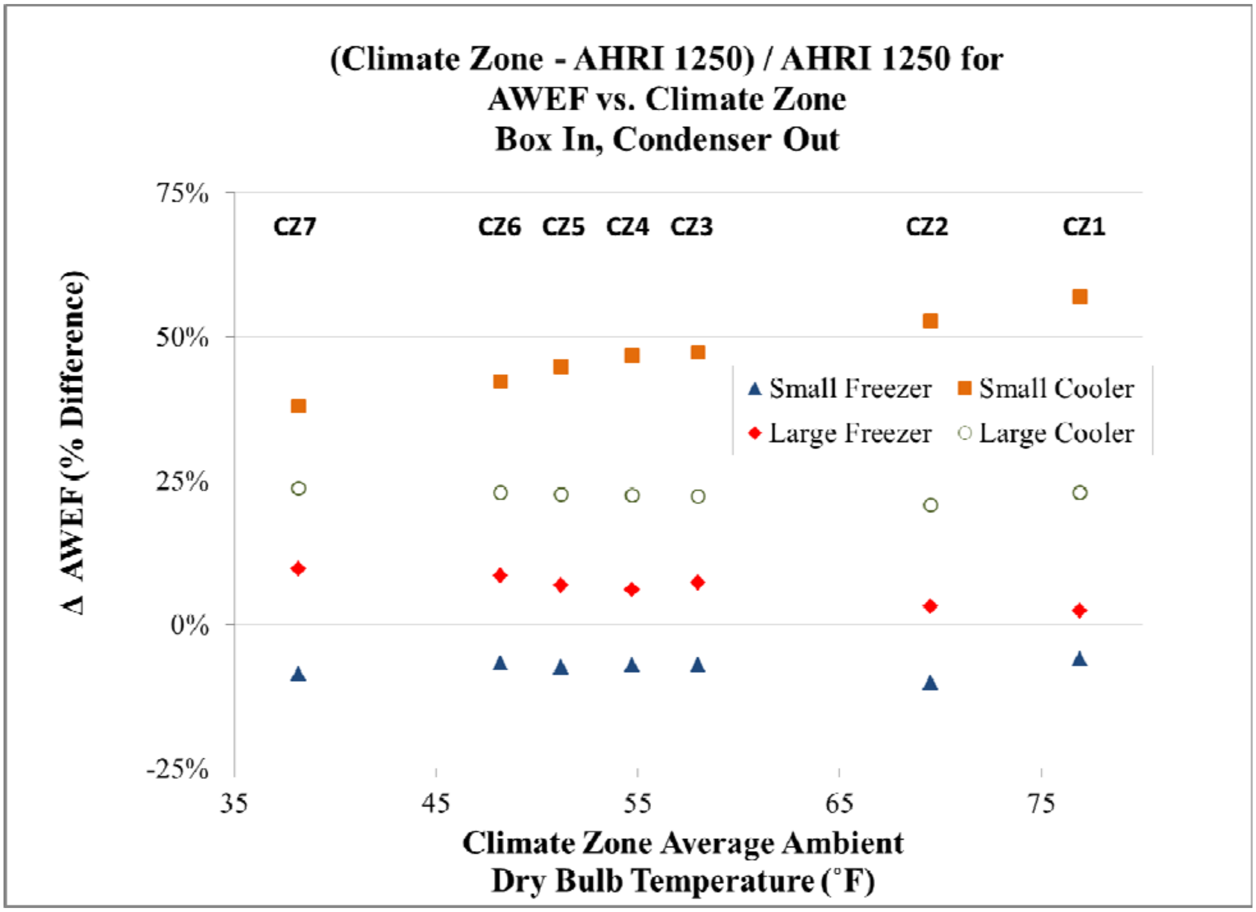


Figure 23. Percentage Difference in AWEF's versus Annual Average Ambient Temperature of Climate Zones 1-7 for the Configuration with The Walk-In Box Located Indoors and the Condensing Unit Located Outdoors.

Walk-in Box and Condensing Unit Outside

For the configuration with both the walk-in box and the condensing unit located outdoors, the ambient conditions surrounding both the walk-in box and the condensing unit were those of the hourly weather data for the seven cities shown in Table 13 that represent the seven climate zones in the continental United States.

Since the ambient conditions surrounding the walk-in box were those of the hourly weather data for the seven climate zones, the refrigeration load for the 'Box Out, Condenser Out' configuration increased as the annual average ambient temperature surrounding the box increased across the climate zones. This increase in refrigeration load results from an increase in infiltration load and an increase in heat load through the walls, roof and floor of the box as the outdoor ambient temperature increases even though the schedules for occupancy, infiltration, lighting and product loading did not vary with climate zone.

As shown in Table 13, the average annual ambient temperature of the climate zones decreases monotonically with increasing climate zone number, so that Climate Zone 1 is the warmest (76.9°F) and Climate Zone 7 is the coldest (38.2°F). Thus, as discussed above, the refrigeration load for the 'Box Out, Condenser Out' configuration also decreases monotonically with increasing climate zone number.

Furthermore, as shown in Table 30 through Table 33, the AWEF values and the compressor run time values for the climate zone simulations of 'Box Out, Condenser Out' generally decreased with increasing climate zone number. The relationship of the AWEF value to the average annual ambient temperature of Climate Zones 1 through 7 for the 'Box Out, Condenser Out' configuration is shown in Figure 24, while Figure 25 depicts the relationship of compressor runtime to the average annual ambient temperature of Climate Zones 1 through 7 for the 'Box Out, Condenser Out' configuration.

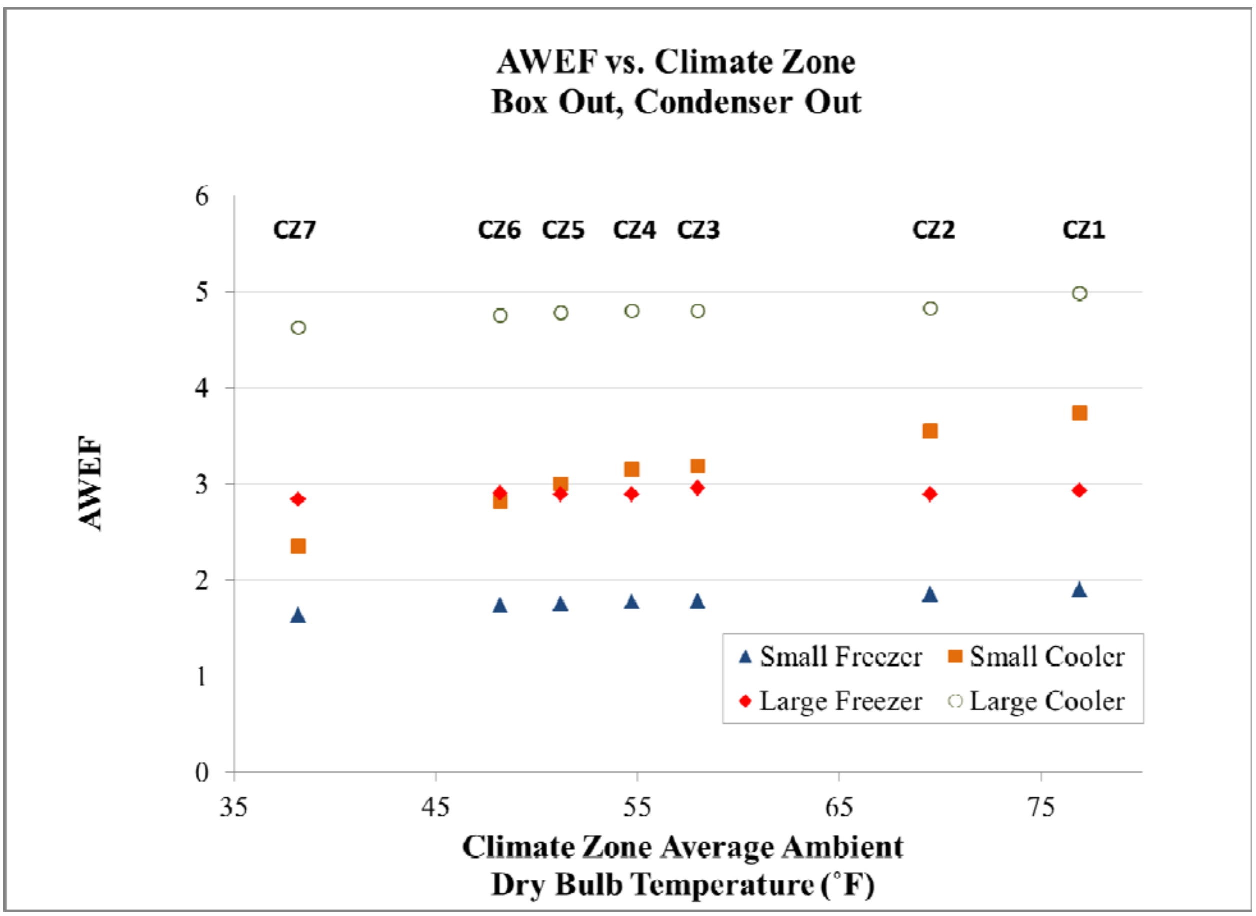


Figure 24. AWEF versus Annual Average Ambient Temperature of Climate Zones 1-7 for the Configuration with The Walk-In Box Located Outdoors and the Condensing Unit Located Outdoors.

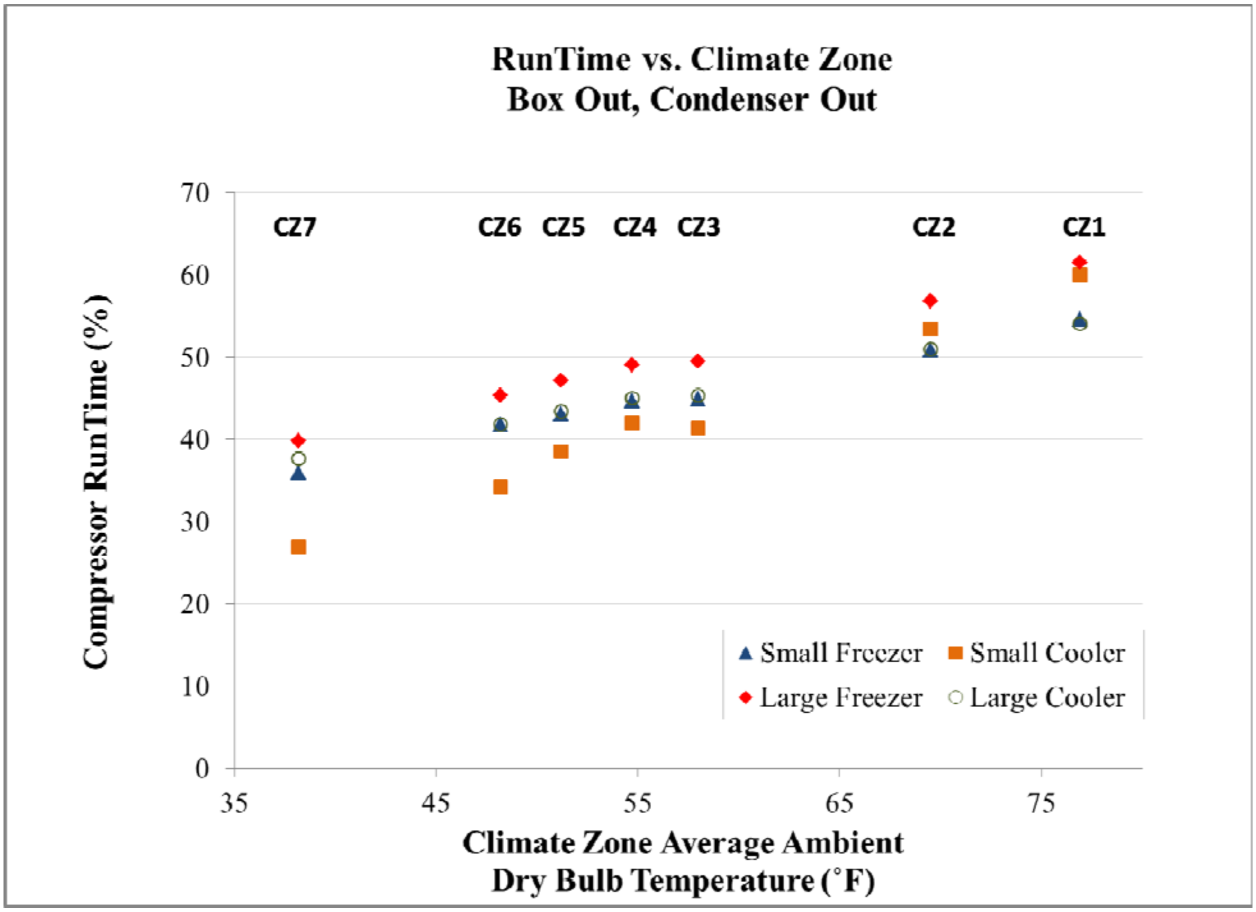


Figure 25. Compressor Runtime versus Annual Average Ambient Temperature of Climate Zones 1-7 for the Configuration with The Walk-In Box Located Outdoors and the Condensing Unit Located Outdoors.

From these results, it can be deduced that the AWEF value increases with increasing compressor run time. This behavior is clearly demonstrated in Figure 14, Figure 16, Figure 18, and Figure 20 wherein the AWEF values are plotted versus the compressor run time values for the 'Box Out, Condenser Out' configuration.

These climate zone simulations for the 'Box Out, Condenser Out' configuration should be compared to the results from the AHRI 1250/1251 method-of-test simulation for the condensing unit located outdoors. These 'AHRI 1250, Condenser Out' results appear as a single point in Figure 14 through Figure 21.

As shown in Table 30 through Table 33, the AWEF values for the climate zone simulations of 'Box Out, Condenser Out' ranged from 1.64 to 4.98 with an average value of 3.15 and the compressor run times ranged from 26.98% to 61.48% with an average value of 45.73%. These results are shown graphically in Figure 26 where the percentage difference in AWEF is plotted versus the annual average ambient temperature of the seven climate zones for the configuration with the walk-in box located outdoors and the condensing unit located outdoors.

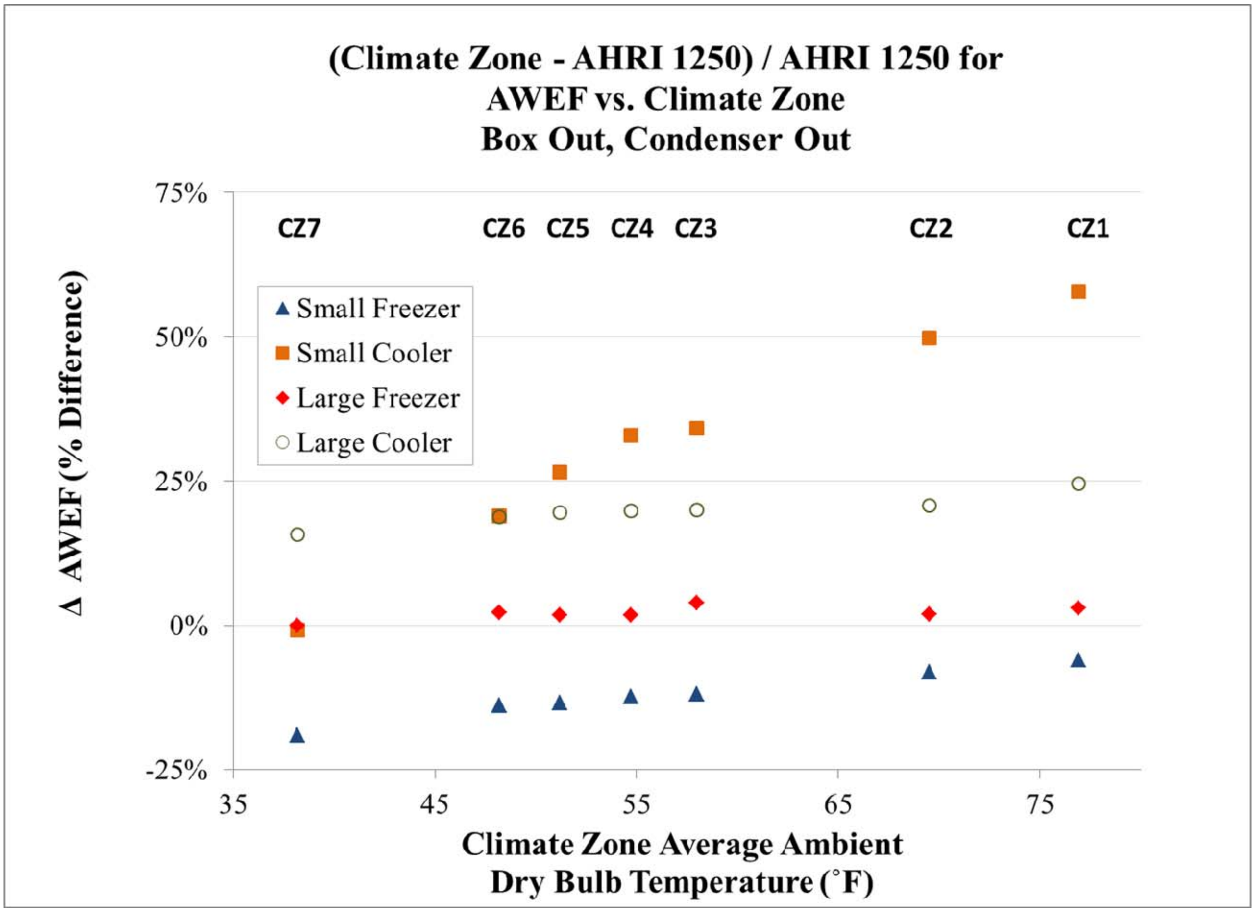


Figure 26. Percentage Difference in AWEF's versus Annual Average Ambient Temperature of Climate Zones 1-7 for the Configuration with The Walk-In Box Located Outdoors and the Condensing Unit Located Outdoors.

From these results, it can be seen that the simulated climate zone AWEF's compare relatively well to the simulated 1250/1251 method-of-test AWEF's for the freezers but not as well for the coolers, especially the small cooler. For the freezers, the simulated climate zone AWEF's are within 18.8% and 3.9% of the simulated 1250/1251 method-of-test AWEF's for the small and large freezers, respectively, across all seven climate zones. The compressor run times for the climate zone simulations of the freezers are on average 7.8% larger and 38.0% larger than the values determined from the simulated 1250/1251 method-of-test for the small and large freezers, respectively, across all seven climate zones. For the large cooler, the simulated climate zone AWEF's across all seven climate zones are within 24.5% of the simulated 1250/1251 method-of-test AWEF. However, the simulated climate zone AWEF's for the small cooler range from 0.8% smaller to 57.8% larger than the simulated 1250/1251 method-of-test AWEF's with the closest agreement in Climate Zone 7 and least agreement in Climate Zone 1. The compressor run times for the climate zone simulations of the coolers are on average 80.9% larger and 93.2% larger than the values determined from the simulated 1250/1251 method-of-test for the small and large coolers, respectively, across all seven climate zones.

AHRI 1250/1251 AWEF versus Average Climate Zone AWEF

Table 30 through Table 33 give average values of the simulated climate zone AWEF's for each of the three configurations of the four walk-in systems that were simulated. As previously discussed these tables also give the results of the AHRI 1250/1251 method-of-test simulations for these four walk-in systems.

The simulated AHRI 1250/1251 method-of-test AWEF's are compared to the average value of the simulated climate zone AWEF's for each of the three configurations of these four walk-in systems. When making this comparison, one must keep in mind that the AWEF's calculated from the climate zone simulations are based on 8760 hour-by-hour calculations of refrigeration capacity at varying ambient conditions determined from hour-by-hour weather data. The AWEF's calculated from the AHRI 1250/1251 method-of-test simulations are based on four steady state calculations of refrigeration capacity at four Standard Rating Conditions.

The bin analysis used to calculate the AHRI 1250/1251 method-of-test AWEF does not include the interaction between the time-of-day occurrences of the various load components, for example, door openings during the hottest hours of the day, while eQuest accounts for these interactions in the climate zone simulations and corresponding AWEF.

Furthermore, the bin analysis used to calculate the AHRI 1250/1251 method-of-test AWEF approximates system performance with three data points while eQuest makes use of the compressor map and other system details to determine system performance in the climate zone simulations and corresponding AWEF.

Figure 27 shows the simulated AHRI 1250/1251 method-of-test AWEF for the condensing unit located indoors, plotted versus the average simulated climate zone AWEF for the configuration with the walk-in box located indoors and the condensing unit located indoors, for each of the four walk-in systems, averaged over the seven climate zones.

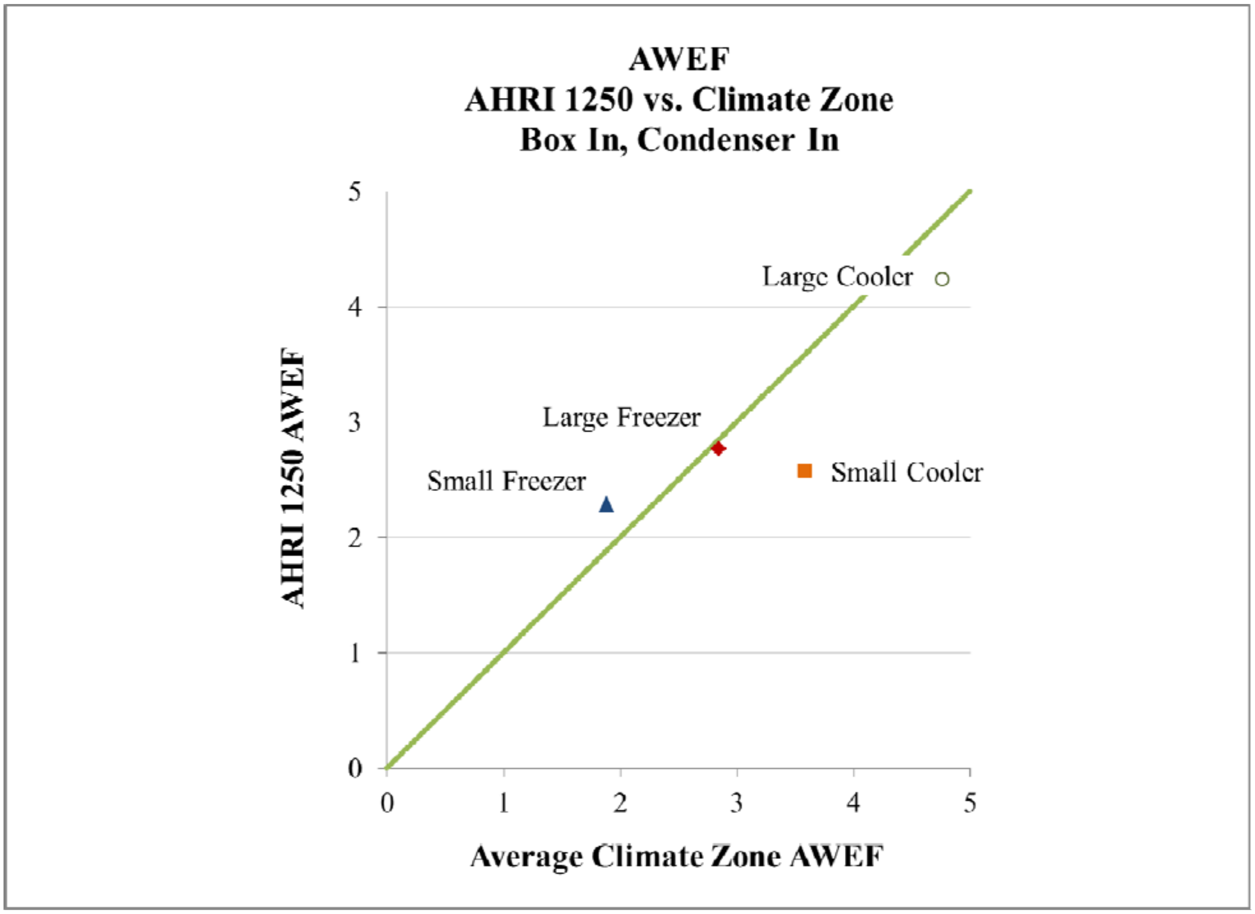


Figure 27. AHRI 1250 AWEF versus Average Climate Zone AWEF for the Configuration with the Walk-In Box Located Indoors and the Condensing Unit Located Indoors.

This plot indicates that the AHRI 1250/1251 method-of-test AWEF for the condensing unit located indoors is a good predictor of the 'field' AWEF for the 'Box In, Condenser In' configuration of a walk-in freezer system, but not as good for a walk-in cooler system. This plot also shows that the 'field' AWEF's for the coolers exceeded the value of the AHRI 1250/1251 method-of-test AWEF's.

Figure 28 shows the simulated AHRI 1250/1251 method-of-test AWEF for the condensing unit located outdoors, plotted versus the average simulated climate zone AWEF for the configuration with the walk-in box located indoors and the condensing unit located outdoors, for each of the four walk-in systems, averaged over the seven climate zones.

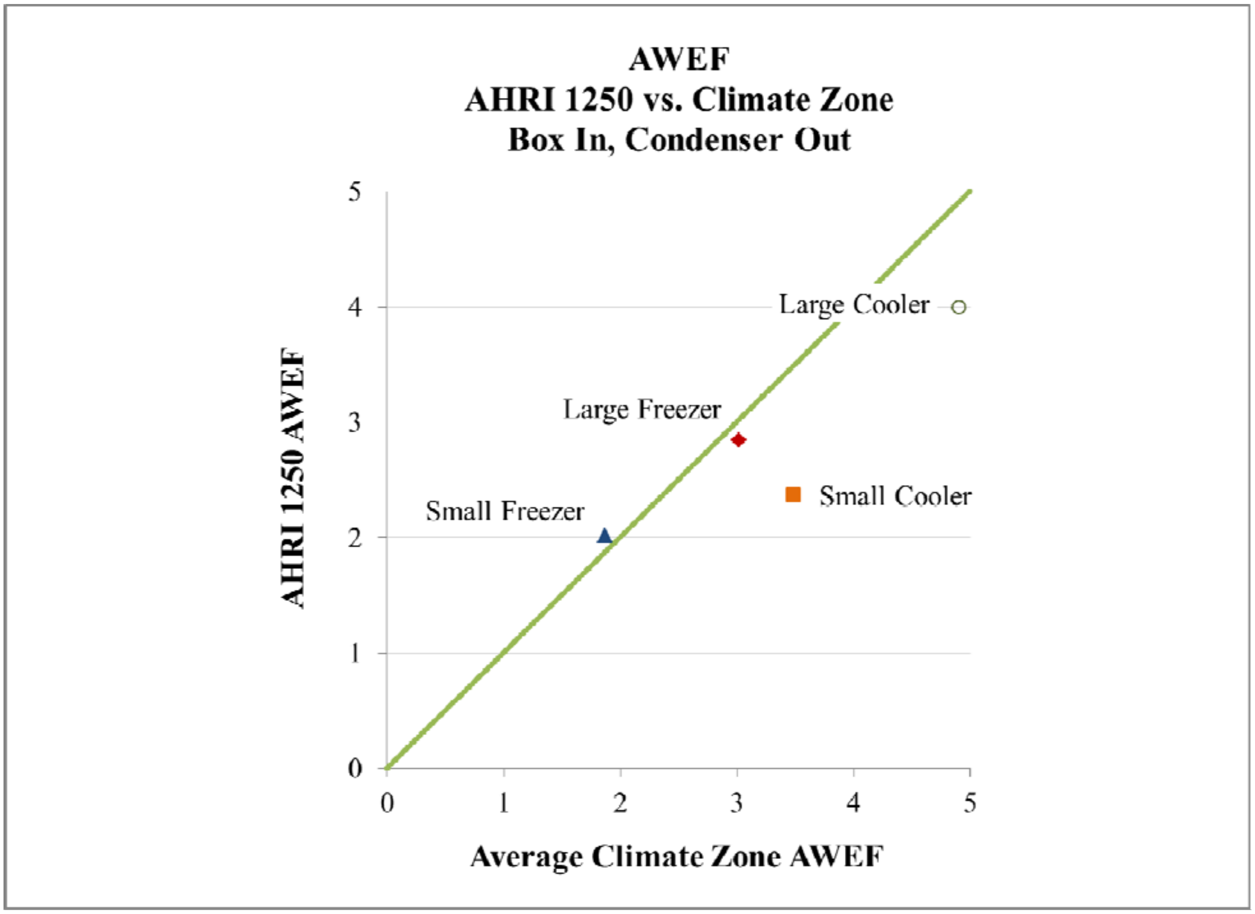


Figure 28. AHRI 1250 AWEF versus Average Climate Zone AWEF for the Configuration with the Walk-In Box Located Indoors and the Condensing Unit Located Outdoors.

This plot indicates that the AHRI 1250/1251 method-of-test AWEF for the condensing unit located outdoors is a good predictor of the 'field' AWEF for the 'Box In, Condenser Out' configuration of a walk-in freezer system, but not as good for a walk-in cooler system. This plot also shows that the 'field' AWEF's for the coolers exceeded the value of the AHRI 1250/1251 method-of-test AWEF's.

Figure 29 shows the simulated AHRI 1250/1251 method-of-test AWEF for the condensing unit located outdoors, plotted versus the average simulated climate zone AWEF for the configuration with the walk-in box located outdoors and the condensing unit located outdoors, for each of the four walk-in systems, averaged over the seven climate zones.

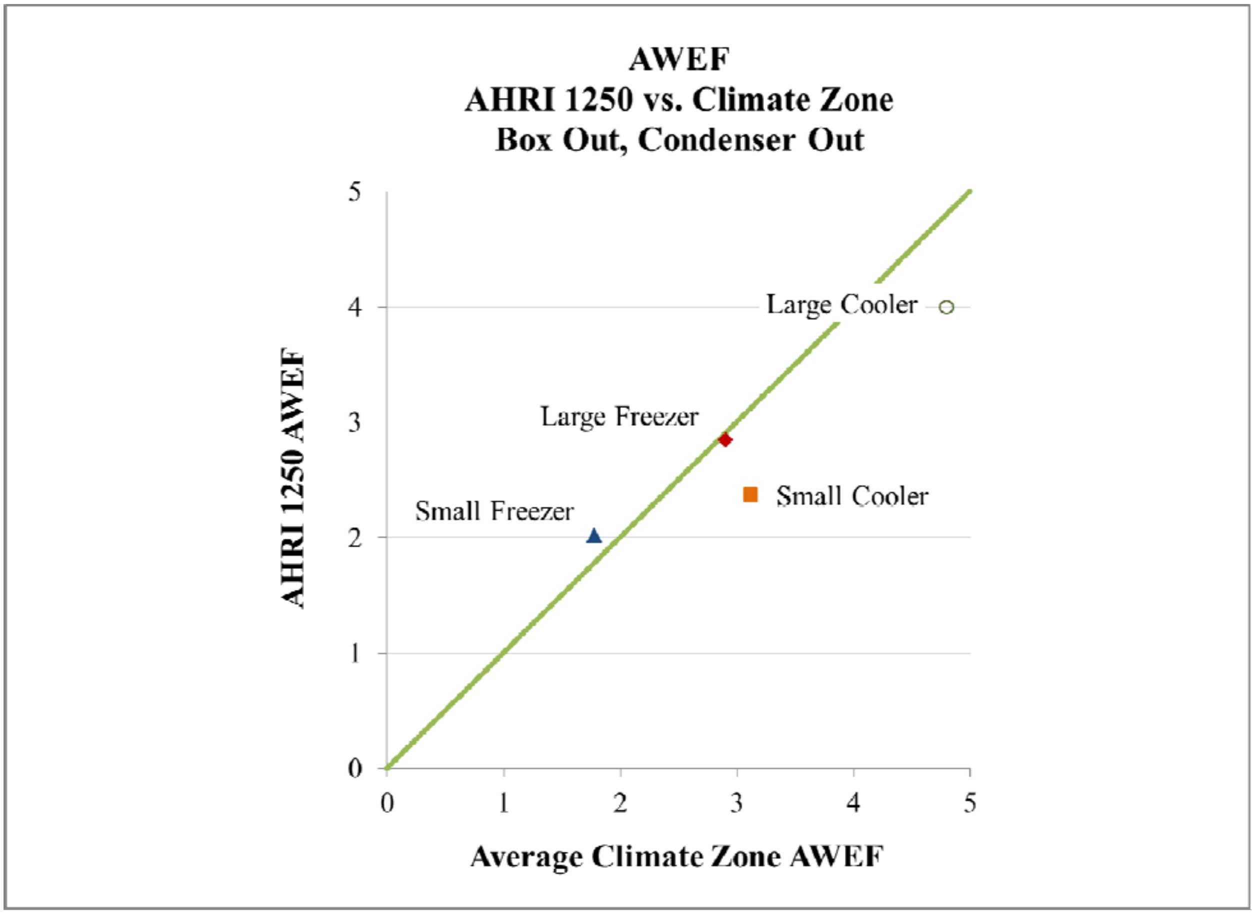


Figure 29. AHRI 1250 AWEF versus Average Climate Zone AWEF for the Configuration with the Walk-In Box Located Outdoors and the Condensing Unit Located Outdoors.

This plot indicates that the AHRI 1250/1251 method-of-test AWEF for the condensing unit located outdoors is a good predictor of the 'field' AWEF for the 'Box Out, Condenser Out' configuration of a walk-in freezer system, but not as good for a walk-in cooler system. This plot also shows that the 'field' AWEF's for the coolers exceeded the value of the AHRI 1250/1251 method-of-test AWEF's.

Summary

A state-of-the-art, publically available whole building energy model, *eQuest* (James J. Hirsch and Associates 2009), was selected to simulate a walk-in refrigeration system's capacity and energy usage as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in box and the condensing unit.

Using this simulation tool, the total annual energy consumption of four typical walk-in refrigeration systems as well as their total annual cooling was determined, using hourly weather data for each climatic zone in the United States, for the following three configurations:

- Walk-in box and condensing unit located inside

- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

The purpose of these climate zone simulations was to assess the field-site performance of walk-ins operating in the various regions of the United States, in terms of the Annual Walk-In Energy Factor (AWEF) (AHRI 2009b, 2009c).

eQuest was also used to simulate the AHRI Standard 1250/1251 method-of-test for rating the performance of walk-in coolers and freezers, in terms of the Annual Walk-In Energy Factor (AWEF), for the following two configurations:

- Condensing unit located inside
- Condensing unit located outside

The simulated climate zone AWEF's were then compared to the simulated AHRI 1250/1251 method-of-test AWEF's. When making this comparison, one must keep in mind that The AWEF's calculated from the climate zone simulations are based on 8760 hour-by-hour calculations of refrigeration capacity at varying ambient conditions determined from hour-by-hour weather data. The AWEF's calculated from the AHRI 1250/1251 method-of-test simulations are based on four steady state calculations of refrigeration capacity at four Standard Rating Conditions.

The bin analysis used to calculate the AHRI 1250/1251 method-of-test AWEF does not include the interaction between the time-of-day occurrences of the various load components, for example, door openings during the hottest hours of the day, while eQuest accounts for these interactions in the climate zone simulations and corresponding AWEF.

Furthermore, the bin analysis used to calculate the AHRI 1250/1251 method-of-test AWEF approximates system performance with three data points while eQuest makes use of the compressor map and other system details to determine system performance in the climate zone simulations and corresponding AWEF.

In summary, for the 'Box In, Condenser In' configuration, the climate zone AWEF's and run times are constant across all seven climate zones. For this configuration, the climate zone AWEF's match the 1250/1251 AWEF's for the condensing unit located indoors within 20% for the freezers and large cooler, but differ by almost 40% for the small cooler. The run times are within 5% for freezers, but differ by over 70% for the coolers. Comparing the average climate zone AWEF's for the 'Box In, Condenser In' configuration to the 1250/1251 AWEF for the condensing unit located indoors indicates that the 1250/1251 AWEF is a good predictor of the 'field' AWEF for a freezer, but not for a cooler.

For the 'Box In, Condenser Out' configuration, the climate zone AWEF's increased as the annual average ambient temperature of the climate zones decreased. The climate zone AWEF's match the 1250/1251 AWEF's for the condensing unit located outdoors within 10% for the freezers and within 25% for the large cooler, but differ by 40% to 60% for the small cooler. The run times differ by 20% to 50% for the freezers and over 100% for the coolers. Comparing the average climate zone AWEF's for the 'Box In, Condenser Out' configuration to the 1250/1251 AWEF's for the condensing unit located outdoors indicates that the 1250/1251 AWEF is a good predictor of the 'field' AWEF for a freezer, but not for a cooler.

For the 'Box Out, Condenser Out' configuration, the climate zone AWEF's increased with the increased run time that resulted from the increased refrigeration load as the annual average ambient temperature of the climate zones increased. The climate zone AWEF's match the 1250/1251 AWEF's for the condensing unit located outdoors within 20% for the freezers and within 25% for the large cooler, but differ by as much as 60% for the small cooler. The run times differ by 10% to 40% for the freezers and 80% to 95% for the coolers. Comparing the average climate zone AWEF's for the 'Box Out, Condenser Out' configuration to the 1250/1251 AWEF's for the condensing unit located outdoors indicates that the 1250/1251 AWEF is a good predictor of the 'field' AWEF for a freezer, but not for a cooler.

CONCLUSIONS

The objective of this project was to substantiate and provide support for AHRI Standard 1250/1251, 'Standard for Performance Rating of Walk-In Coolers and Freezers' (AHRI 2009b, 2009c). This objective was achieved by investigating walk-in cooler and freezer refrigeration load profiles and refrigeration system performance as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in and its condensing unit.

Literature Review

An extensive computerized literature search was performed that revealed over 300 references published between 1980 and 2010 pertaining to the operation, performance and refrigeration load of walk-in coolers and freezers as well as refrigeration system simulation. An industrial survey was also conducted in which members of the commercial refrigeration industry were interviewed to obtain measured data regarding walk-in coolers and freezers from monitored field sites and laboratory tests.

Analysis of Model Load Profiles

The literature review identified publications that contained model walk-in box refrigeration load profile data for walk-in coolers and/or freezers. The model load profiles found in the literature were analyzed and compared to the AHRI 1250/1251 model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a).

The AHRI 1250/1251 model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) agrees with the findings reported by the other researchers for a majority of the box specifications and refrigeration load components for both coolers and freezers. However, there are a few differences between the AHRI model load profile and the literature.

For both walk-in coolers and freezers, discrepancies between the AHRI model load profile and the literature include large walk-in box door size and number, omission of crack infiltration, and product loading for the small walk-in box. Although the AHRI 'door-open' time per door is comparable to that reported by DOE, when analyzed on a total door area per wall surface area basis, the AHRI large walk-in cooler/freezer had 1.5% of total door area per wall surface area compared to a literature average of 9.3% while the AHRI small walk-in cooler/freezer had 10.9%. Furthermore, the AHRI Load Spreadsheet does not include infiltration due to crack leakage. Finally, for the AHRI small walk-in, the daily product loading ratio is 3 times larger than that reported by DOE, while the AHRI large walk-in cooler/freezer product loading is comparable to that reported by other researchers.

In addition, for walk-in coolers, AHRI reports a walk-in cooler relative humidity of 90% that is higher than the average value of 73.6% reported by the other researchers. While for walk-in freezers, the R-value of the AHRI walk-in freezer construction is 32 h-ft^2-°F/Btu while the average freezer R-value found in the literature is approximately 26 h-ft^2-°F/Btu.

Analysis of Monitored Data from Field Sites

In addition to the literature review, an industrial survey was performed to acquire detailed measured data for walk-in coolers and freezers from commercial field sites. These commercial field site data were analyzed to determine the operating characteristics and refrigeration load of in-service walk-in coolers and freezers. The load data from these field sites were compared to the model walk-in box load profile given in the AHRI Load Spreadsheet (AHRI 2009a) that was used as a basis for the Standard 1250/1251 rating equations (AHRI 2009b, 2009c)

The AHRI Standard 1250/1251 (AHRI 2009b, 2009c) assumes 'low loads' for both coolers and freezers that correlates well with the measured 'low loads', however, the 'high loads' assumed in the AHRI Standard are higher than the measured 'high loads' for both coolers and freezers. In contrast, the AHRI Standard assumes that the refrigeration system of a cooler spends 33.2% more time in 'low load' operation as compared to the monitored data for the coolers. The AHRI Standard also assumes that the refrigeration system of a freezer spends 23.6% more time in 'low load' operation as compared to the monitored data for the freezer.

On the other hand, the AHRI 1250/1251 Load Spreadsheet (AHRI 2009a) agrees very closely with the field data on the average number of door opening events per day, however, the average duration of a door opening event in the field data is an order of magnitude greater than that specified in the AHRI 1250/1251 Load Spreadsheet.

The three monitored walk-in coolers averaged 2.42 defrosts per day with an average duration of 33.5 minutes per defrost while the monitored walk-in freezer experienced 3 defrost cycles per day averaging 37.8 minutes per defrost cycle. The AWEF, as defined in AHRI Standard 1250/1251, does not include the refrigeration loads due to both the defrost cycles and the operation of the unit cooler fans in the calculation of the AWEF. The Standard does include the electrical energy required to operate the defrost system and the unit cooler fans in the total energy consumption of the refrigeration system in the AWEF calculation.

Finally, the refrigeration load calculated by the AHRI 1250/1251 Load Spreadsheet (AHRI 2009a) for the 'small AHRI cooler' correlates well with the measured data while the load calculated for the 'large AHRI cooler' is less than half that given by the measured data. The refrigeration load calculated by the AHRI Load Spreadsheet for the 'small and large AHRI freezers' is about 20% of the measured value.

eQuest Simulations Of Walk-In Cooler And Freezer Performance

A state-of-the-art, publically available whole building energy model, *eQuest* (James J. Hirsch and Associates 2009), was selected to simulate a walk-in refrigeration system's capacity and energy usage as a function of the ambient dry-bulb and wet-bulb temperatures surrounding the walk-in box and the condensing unit.

Using this simulation tool, the total annual energy consumption of four typical walk-in refrigeration systems as well as their total annual cooling was determined, using hourly weather data for each climatic zone in the United States, for the following three configurations:

- Walk-in box and condensing unit located inside
- Walk-in box located inside and condensing unit located outside
- Walk-in box and condensing unit located outside

The purpose of these climate zone simulations was to assess the field-site performance of walk-ins operating in the various regions of the United States, in terms of the Annual Walk-In Energy Factor (AWEF) (AHRI 2009b, 2009c).

eQuest was also used to simulate the AHRI Standard 1250/1251 method-of-test for rating the performance of walk-in coolers and freezers, in terms of the Annual Walk-In Energy Factor (AWEF), for the following two configurations:

- Condensing unit located inside
- Condensing unit located outside

The simulated climate zone AWEF's were then compared to the simulated AHRI 1250/1251 method-of-test AWEF's. When making this comparison, one must keep in mind that the AWEF's calculated from the climate zone simulations are based on 8760 hour-by-hour calculations of refrigeration capacity at varying ambient conditions determined from hour-by-hour weather data. The AWEF's calculated from the AHRI 1250/1251 method-of-test simulations are based on four steady state calculations of refrigeration capacity at four Standard Rating Conditions.

The bin analysis used to calculate the AHRI 1250/1251 method-of-test AWEF does not include the interaction between the time-of-day occurrences of the various load components, for example, door openings during the hottest hours of the day, while eQuest accounts for these interactions in the climate zone simulations and corresponding AWEF.

Furthermore, the bin analysis used to calculate the AHRI 1250/1251 method-of-test AWEF approximates system performance with three data points while eQuest makes use of the compressor map and other system details to determine system performance in the climate zone simulations and corresponding AWEF.

For the 'Box In, Condenser In' configuration, the climate zone AWEF's and run times are constant across all seven climate zones. For this configuration, the climate zone AWEF's match the 1250/1251 AWEF's for the condensing unit located indoors within 20% for the freezers and large cooler, but differ by almost 40% for the small cooler. The run times are within 5% for freezers, but differ by over 70% for the coolers. Comparing the average climate zone AWEF's for the 'Box In, Condenser In' configuration to the 1250/1251 AWEF for the condensing unit located indoors indicates that the 1250/1251 AWEF is a good predictor of the 'field' AWEF for a freezer, but not for a cooler.

For the 'Box In, Condenser Out' configuration, the climate zone AWEF's increased as the annual average ambient temperature of the climate zones decreased. The climate zone AWEF's match the 1250/1251 AWEF's for the condensing unit located outdoors within 10% for the freezers and within 25% for the large cooler, but differ by 40% to 60% for the small cooler. The run times differ by 20% to 50% for the freezers and over 100% for the coolers. Comparing the average climate zone AWEF's for the 'Box In, Condenser Out' configuration to the 1250/1251

AWEF's for the condensing unit located outdoors indicates that the 1250/1251 AWEF is a good predictor of the 'field' AWEF for a freezer, but not for a cooler.

For the 'Box Out, Condenser Out' configuration, the climate zone AWEF's increased with the increased run time that resulted from the increased refrigeration load as the annual average ambient temperature of the climate zones increased. The climate zone AWEF's match the 1250/1251 AWEF's for the condensing unit located outdoors within 20% for the freezers and within 25% for the large cooler, but differ by as much as 60% for the small cooler. The run times differ by 10% to 40% for the freezers and 80% to 95% for the coolers. Comparing the average climate zone AWEF's for the 'Box Out, Condenser Out' configuration to the 1250/1251 AWEF's for the condensing unit located outdoors indicates that the 1250/1251 AWEF is a good predictor of the 'field' AWEF for a freezer, but not for a cooler.

In summary, the most important findings of this project include the following:

- The AWEF generally increases with increasing compressor run time and with decreasing average ambient temperature. However, the behavior of a walk-in system is further complicated because a reduced average ambient temperature usually results in a reduced compressor run time. So these two general trends tend to compete against each other and the combined effect on the AWEF of a walk-in refrigeration system depends upon the walk-in refrigeration system's operating characteristics.

- In general, the AHRI load profile agrees well with load profiles reported by other researchers. However, a few discrepancies exist in the AHRI load profile, including less door area for large walk-in coolers/freezers, absence of crack infiltration, and higher product loading for small walk-ins.

- The small AHRI cooler load correlates well with measured data from small in-service walk-in coolers, while there is less agreement between the large AHRI cooler and measured data for large in-service coolers. The loads for the AHRI small and large freezers are considerably less than the measured data from in-service walk-in freezers.

- Comparison of simulated climate zone AWEF's versus simulated AHRI 1250/1251 method-of-test AWEF's for walk-in freezers shows very good agreement. However, significant differences exist between the simulated climate zone AWEF's and the simulated AHRI 1250/1251 method-of-test AWEF's for walk-in coolers.

RECOMMENDATIONS

Based upon the results of this project, the research team makes the following recommendations:

1. The research team recommends that an additional research project be initiated that would focus on monitoring walk-ins located in all seven climate zones that make up the continental United States.

2. The research team recommends that the calculation procedures of AHRI 1250/1251 be reviewed, especially the AHRI 1250/1251 Rating Equations for coolers and, in particular, the product loading for the coolers specified in the underlying AHRI Load Spreadsheet (2009a).

3 . The research team recommends that an additional research project be initiated that would focus on determining and verifying a more balanced refrigeration load profile for walk-ins, especially for coolers.

4 . The research team recommends that an additional research project be initiated that would focus on developing *eQuest* models of the small walk-in cooler/freezer (64 ft^2 plan area) and the large walk-in cooler/freezer (2500 ft^2 plan area) as they are described in the AHRI Load Spreadsheet (2009a) with the appropriate refrigeration load profiles as also specified in the AHRI Load Spreadsheet (2009a), thereby providing a one-to-one comparison between the AHRI Method of Test and Kansas City weather data.

5 . The research team recommends that additional work be done to determine the causes of the differences between the AHRI 1250 results and the climate zone results for AWEF and compressor runtime.

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Appendix A: Walk-In Cooler and Freezer Performance Data from National Resource Management, Inc.

Tedeschi 11-Door Display Cooler:

Figure 30 shows the run-time chart for the Tedeschi 11-door display walk-in cooler on 1 July 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), and the set-point temperature (green). Three defrost cycles occurred on 1 July 2009, as evidenced by the three spikes in both the space and evaporator temperatures that occurred at approximately 7:00am, 3:00pm and 10:00pm.

The lower portion of the run-time chart shown in Figure 30 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 July 2009. The minimum hourly compressor run-time on 1 July 2009 was 11.1% while the maximum hourly compressor run-time was 53.1%. The average compressor run-time for 1 July 2009 was 35.0%. The average run-time for those values less than or equal to the daily average (‘low load’ condition) was 26.1% while the average run-time for those values greater than the daily average (‘high load’ condition) was 41.3%. During 1 July 2009, the compressor operated 41.7% of the time at ‘low load’ conditions and 58.3% of the time at ‘high load’ conditions.

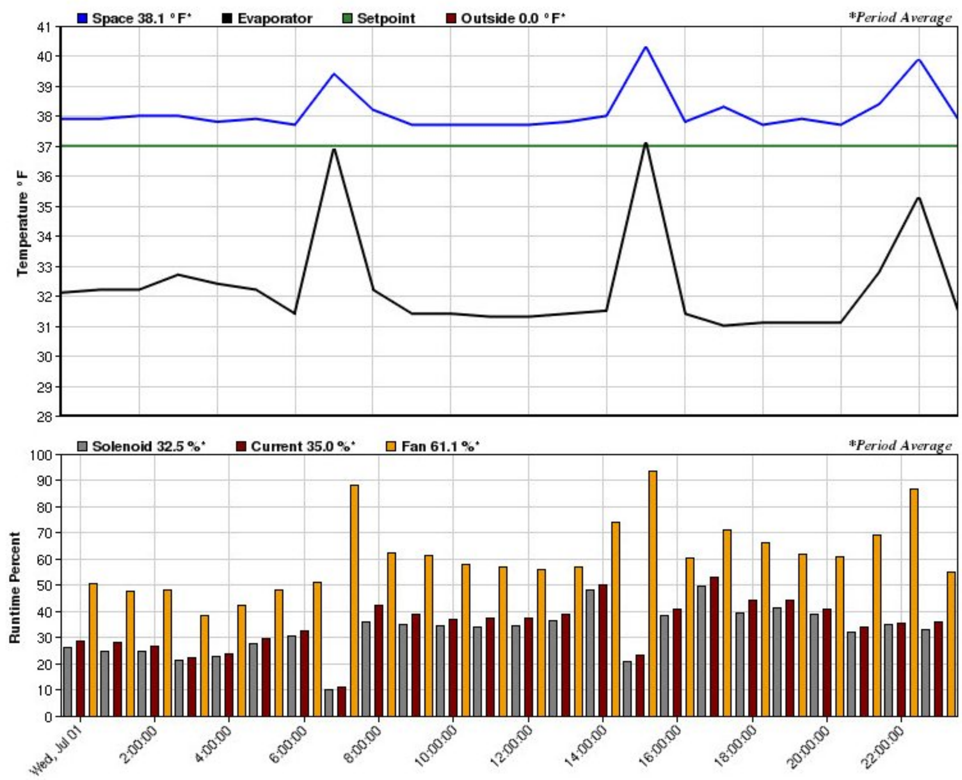


Figure 30. Run-Time Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 July 2009.

Figure 31 shows the trend chart for the Tedeschi 11-door display walk-in cooler during 1 July 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 1 July 2009. In addition, the door status shows that nine door openings occurred during 1 July 2009.

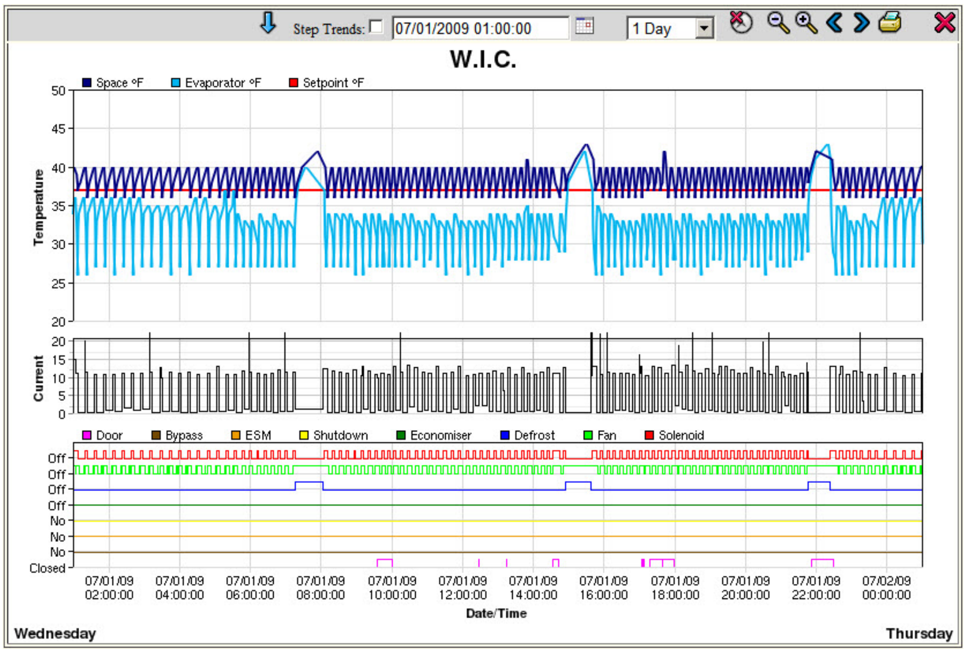


Figure 31. Trend Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 July 2009.

Figure 32 shows the run-time chart for the Tedeschi 11-door display walk-in cooler on 1 October 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon). Two defrost cycles occurred on 1 October 2009, as evidenced by the two spikes in both the space and evaporator temperatures that occurred at approximately 10:00am and 6:00pm.

The lower portion of the run-time chart shown in Figure 32 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 October 2009. The minimum hourly compressor run-time on 1 July 2009 was 16.8% while the maximum hourly compressor run-time was 41.1%. The average compressor run-time for 1 October 2009 was 30.0%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 21.6% while the average run-time for those values greater than the daily average ('high load' condition) was 36.1%. During 1 October 2009, the compressor operated 41.7% of the time at 'low load' conditions and 58.3% of the time at 'high load' conditions.

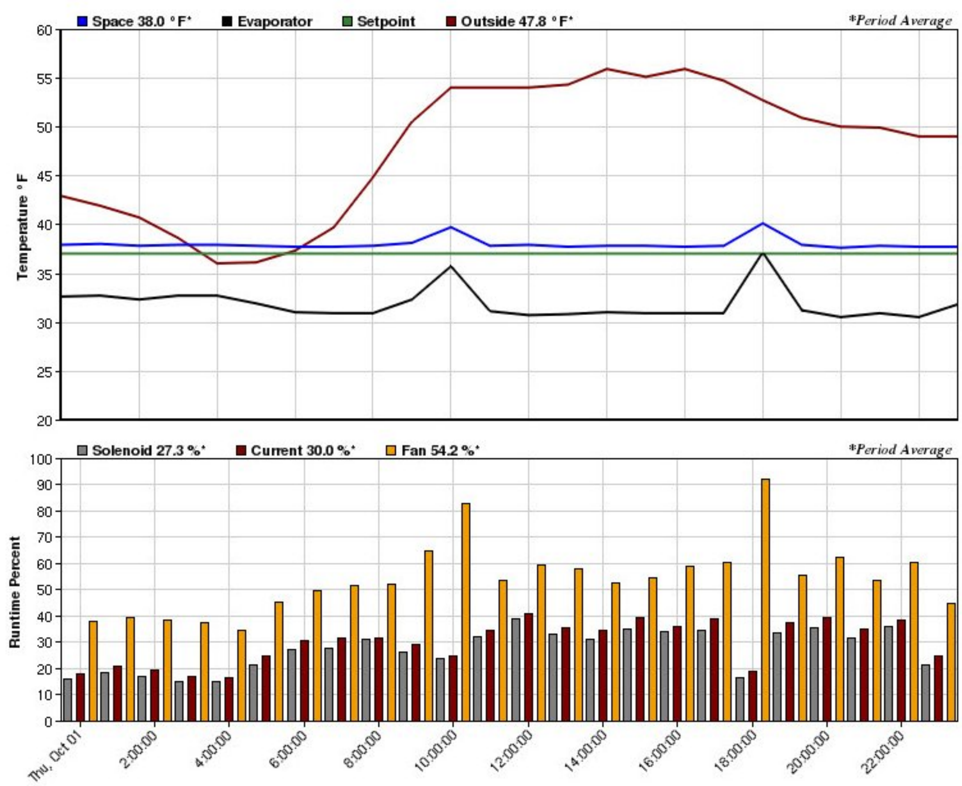


Figure 32. Run-Time Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 October 2009.

Figure 33 shows the trend chart for the Tedeschi 11-door display walk-in cooler during 1 October 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that two defrost cycles occurred during 1 October 2009. In addition, the door status shows that 12 door openings occurred during 1 October 2009.

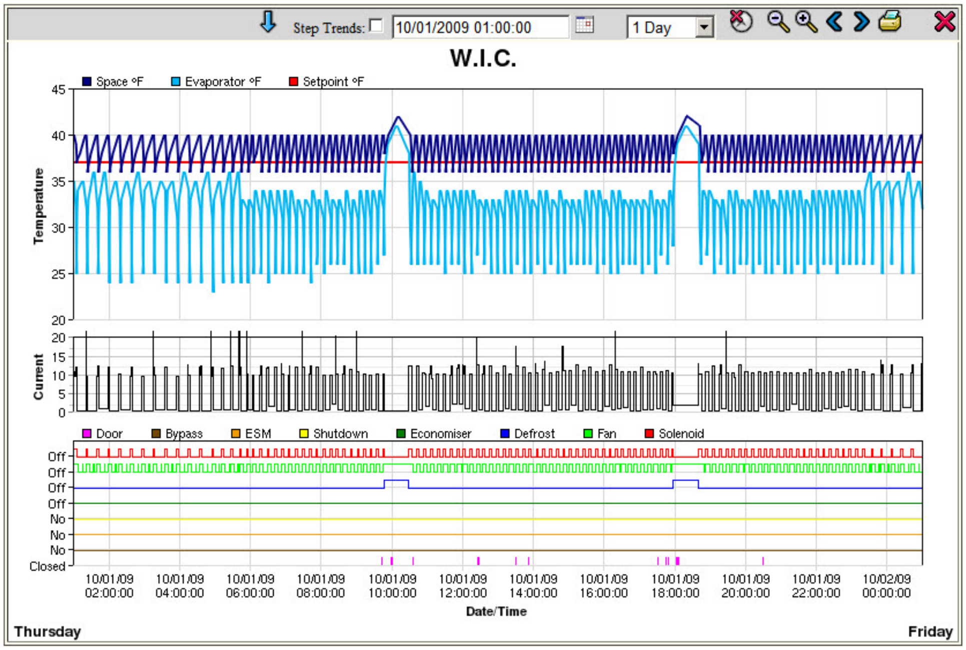


Figure 33. Trend Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 October 2009.

Figure 34 shows the run-time chart for the Tedeschi 11-door display walk-in cooler on 1 January 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon). No defrost cycles occurred on 1 January 2010.

The lower portion of the run-time chart shown in Figure 34 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 January 2010. The minimum hourly compressor run-time on 1 January 2010 was 0.0% while the maximum hourly compressor run-time was 29.6%. The average compressor run-time for 1 January 2010 was 10.5%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 3.0% while the average run-time for those values greater than the daily average ('high load' condition) was 23.1%. During 1 January 2010, the compressor operated 62.5% of the time at 'low load' conditions and 37.5% of the time at 'high load' conditions.

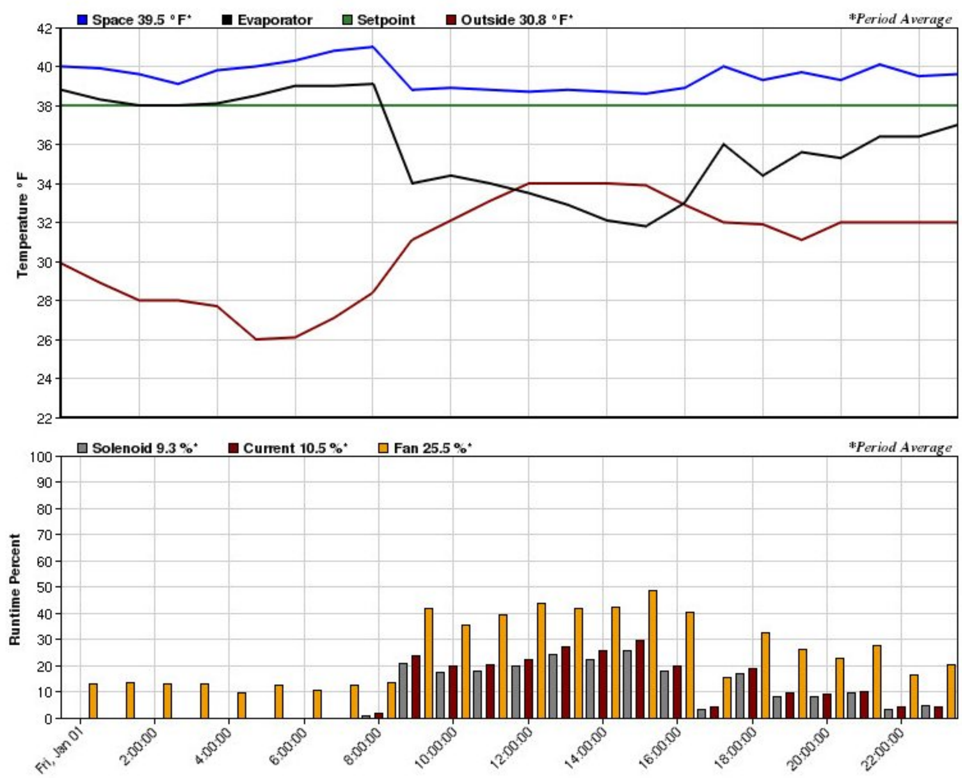


Figure 34. Run-Time Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 January 2010.

Figure 35 shows the trend chart for the Tedeschi 11-door display walk-in cooler during 1 January 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue), the door openings (magenta) and the economizer status (dark green), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that no defrost cycles occurred during 1 January 2010. In addition, the door status shows that 11 door openings occurred during 1 January 2010. Furthermore, it can be seen that the economizer operated for a significant portion of the day during 1 January 2010, and thus, the daily average compressor run-time was very low.

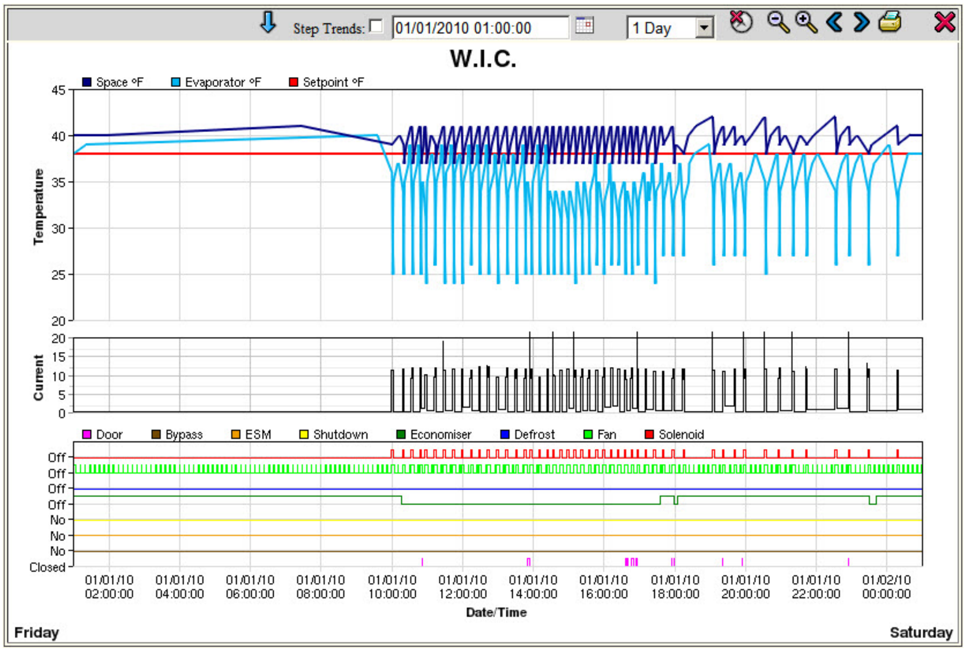


Figure 35. Trend Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 January 2010.

Figure 36 shows the run-time chart for the Tedeschi 11-door display walk-in cooler on 1 April 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon). Two defrost cycles occurred on 1 April 2010, as evidenced by the two spikes in both the space and evaporator temperatures that occurred at approximately 10:00am and 8:00pm.

The lower portion of the run-time chart shown in Figure 36 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 April 2010. The minimum hourly compressor run-time on 1 April 2010 was 9.9% while the maximum hourly compressor run-time was 33.9%. The average compressor run-time for 1 April 2010 was 23.6%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 15.1% while the average run-time for those values greater than the daily average ('high load' condition) was 28.7%. During 1 April 2010, the compressor operated 37.5% of the time at 'low load' conditions and 62.5% of the time at 'high load' conditions.

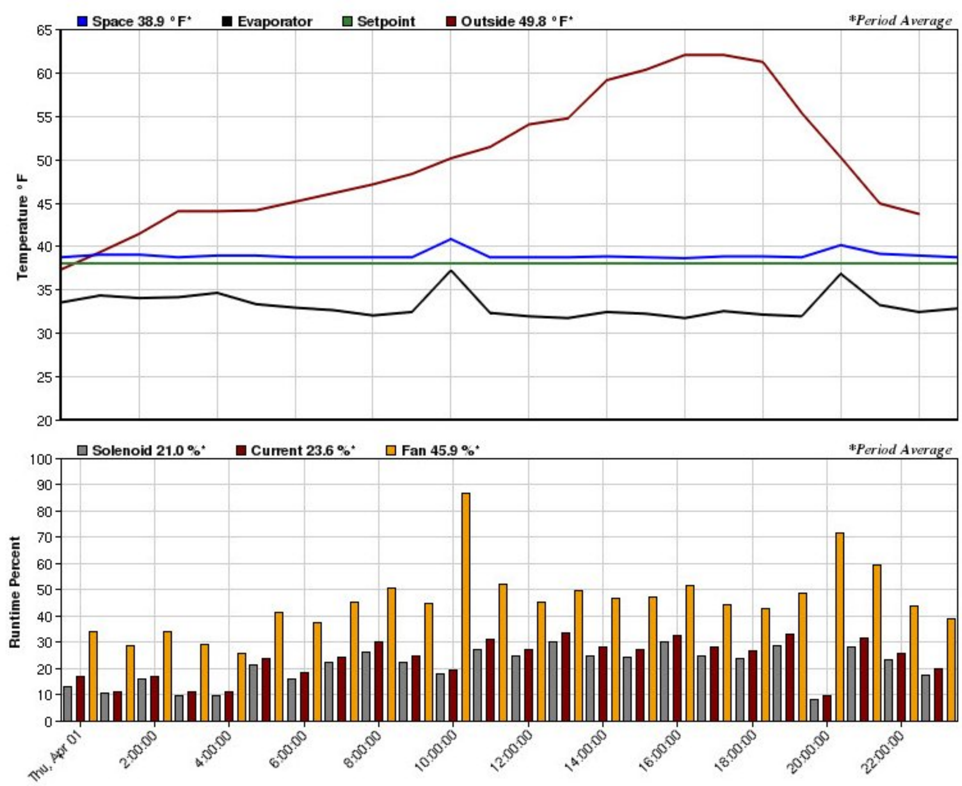


Figure 36. Run-Time Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 April 2010.

Figure 37 shows the trend chart for the Tedeschi 11-door display walk-in cooler during 1 April 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that two defrost cycles occurred during 1 April 2010. In addition, the door status shows that five door openings occurred during 1 April 2010.

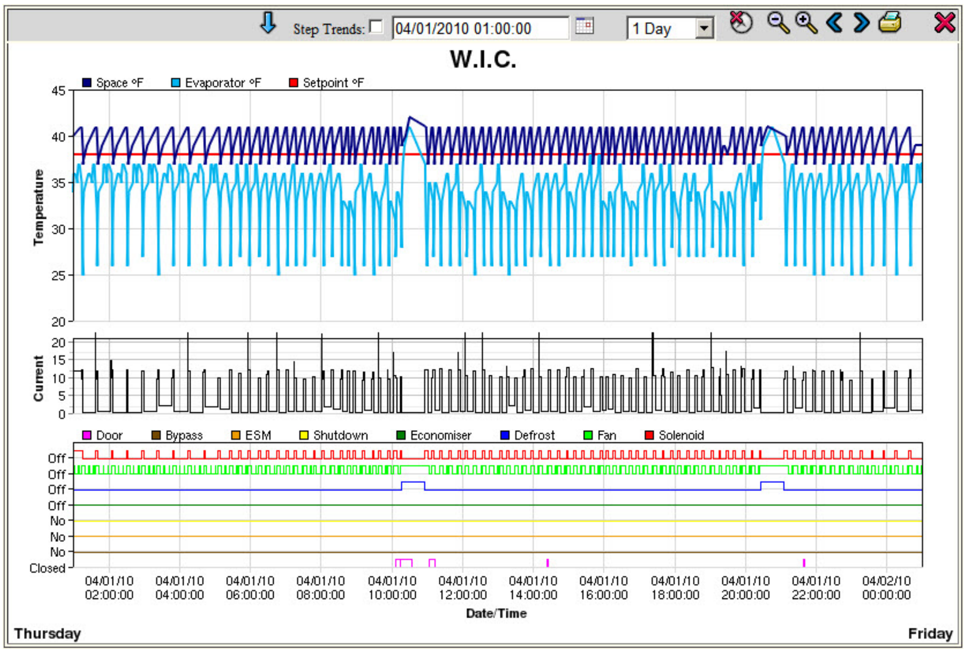


Figure 37. Trend Chart for Tedeschi 11-Door Walk-In Display Cooler, 1 April 2010.

Chili's Walk-In Beer Cooler:

Figure 38 shows the run-time chart for the Chili's walk-in beer cooler on 1 July 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), and the set-point temperature (green).

The lower portion of the run-time chart shown in Figure 38 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 July 2009. The minimum hourly compressor run-time on 1 July 2009 was 0.8% while the maximum hourly compressor run-time was 22.6%. The average compressor run-time for 1 July 2009 was 11.7%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 6.7% while the average run-time for those values greater than the daily average ('high load' condition) was 17.6%. During 1 July 2009, the compressor operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

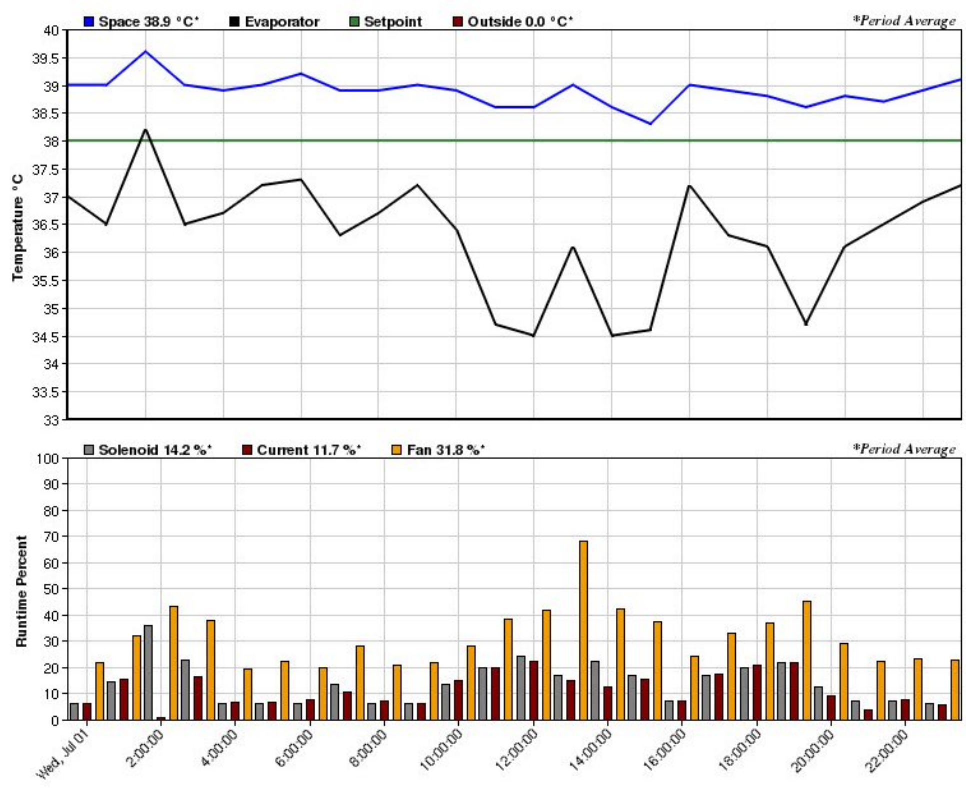


Figure 38. Run-Time Chart for Chili's Walk-In Beer Cooler, 1 July 2009.

Figure 39 shows the trend chart for the Chili's walk-in beer cooler during 1 July 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that one defrost cycle occurred during 1 July 2009. As can be seen from Figure 39, no door opening data was reported for the Chili's walk-in beer cooler.

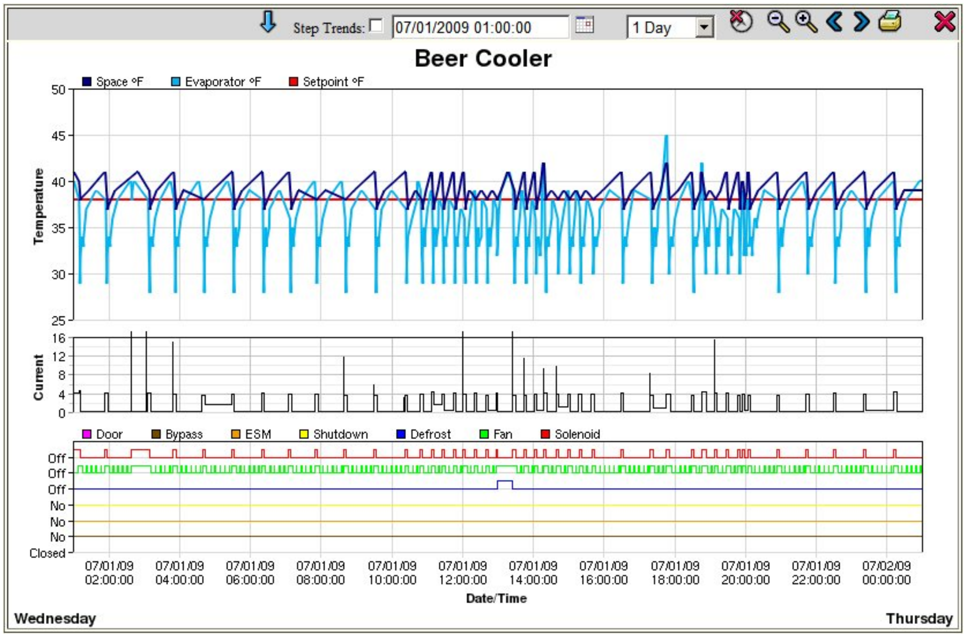


Figure 39. Trend Chart for Chili's Walk-In Beer Cooler, 1 July 2009.

Figure 40 shows the run-time chart for the Chili's walk-in beer cooler on 2 October 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 40 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 2 October 2009. The minimum hourly compressor run-time on 2 July 2009 was 6.5% while the maximum hourly compressor run-time was 31.3%. The average compressor run-time for 2 October 2009 was 14.6%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 11.8% while the average run-time for those values greater than the daily average ('high load' condition) was 17.9%. During 2 October 2009, the compressor operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

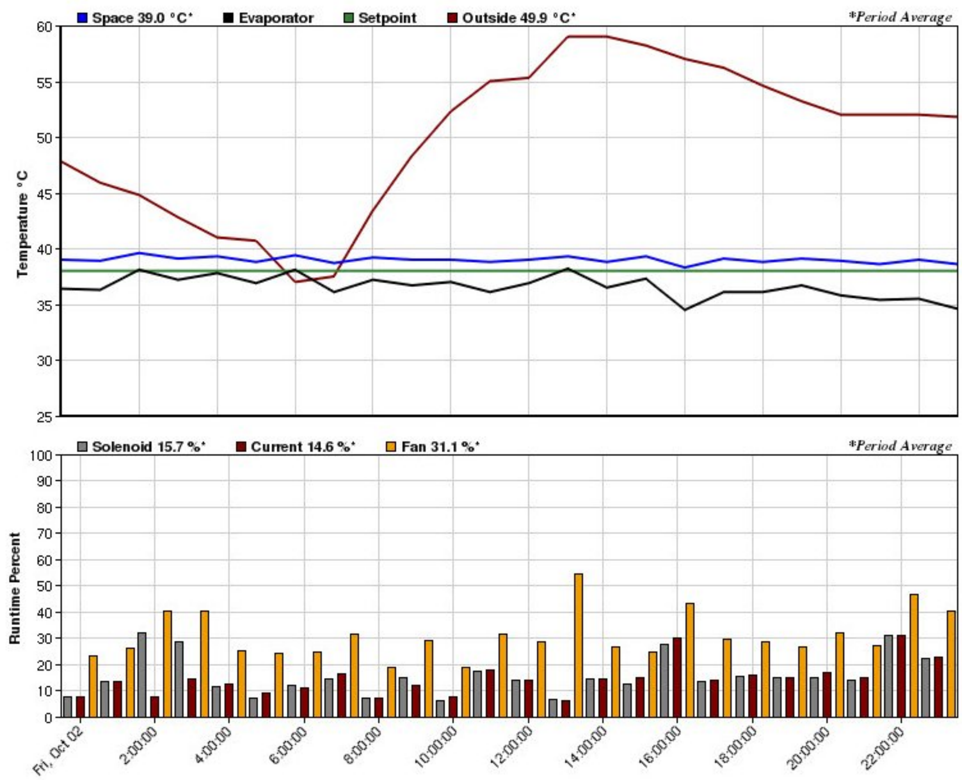


Figure 40. Run-Time Chart for Chili's Walk-In Beer Cooler, 2 October 2009.

Figure 41 shows the trend chart for the Chili's walk-in beer cooler during 2 October 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that one defrost cycle occurred during 2 October 2009. As can be seen from Figure 41, no door opening data was reported for the Chili's walk-in beer cooler.

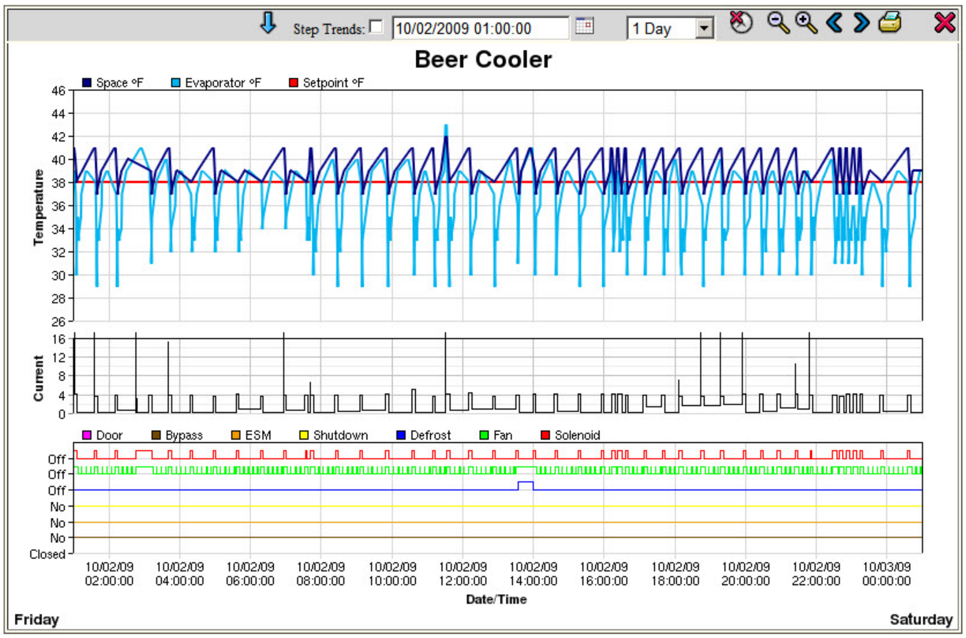


Figure 41. Trend Chart for Chili's Walk-In Beer Cooler, 2 October 2009.

Figure 42 shows the run-time chart for the Chili's walk-in beer cooler on 1 January 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 42 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 January 2010. The minimum hourly compressor run-time on 1 January 2010 was 0.0% while the maximum hourly compressor run-time was 39.3%. The average compressor run-time for 1 January 2010 was 10.0%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 5.1% while the average run-time for those values greater than the daily average ('high load' condition) was 18.2%. During 1 January 2010, the compressor operated 62.5% of the time at 'low load' conditions and 37.5% of the time at 'high load' conditions.

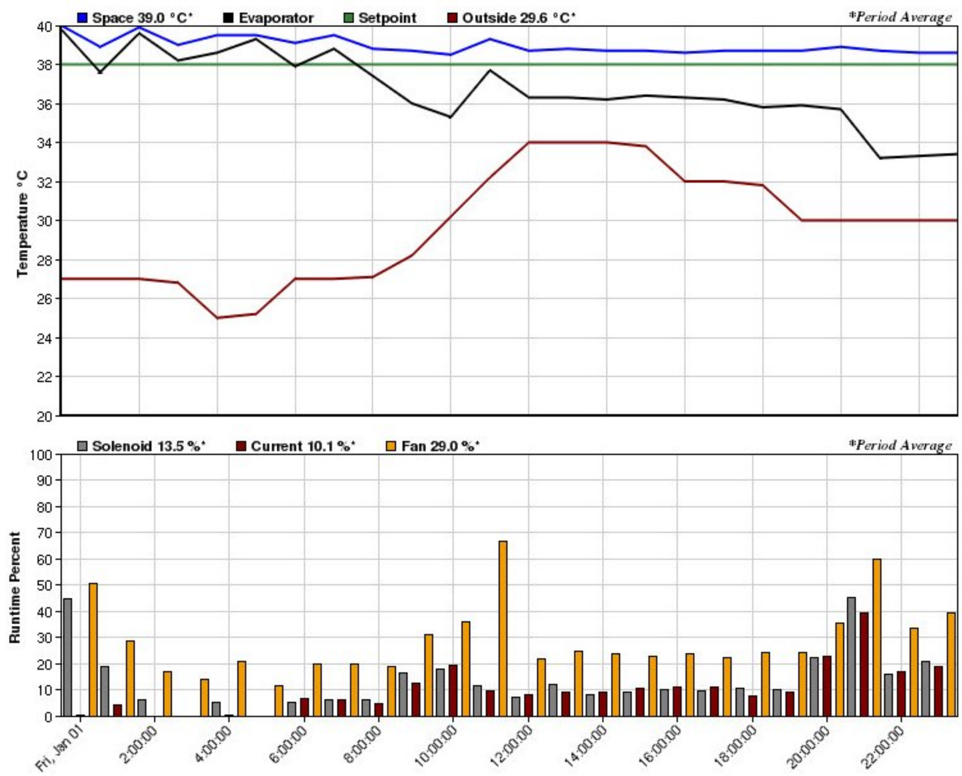


Figure 42. Run-Time Chart for Chili's Walk-In Beer Cooler, 1 January 2010.

Figure 43 shows the trend chart for the Chili's walk-in beer cooler during 1 January 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that one defrost cycle occurred during 1 January 2010. As can be seen from Figure 43, no door opening data was reported for the Chili's walk-in beer cooler.

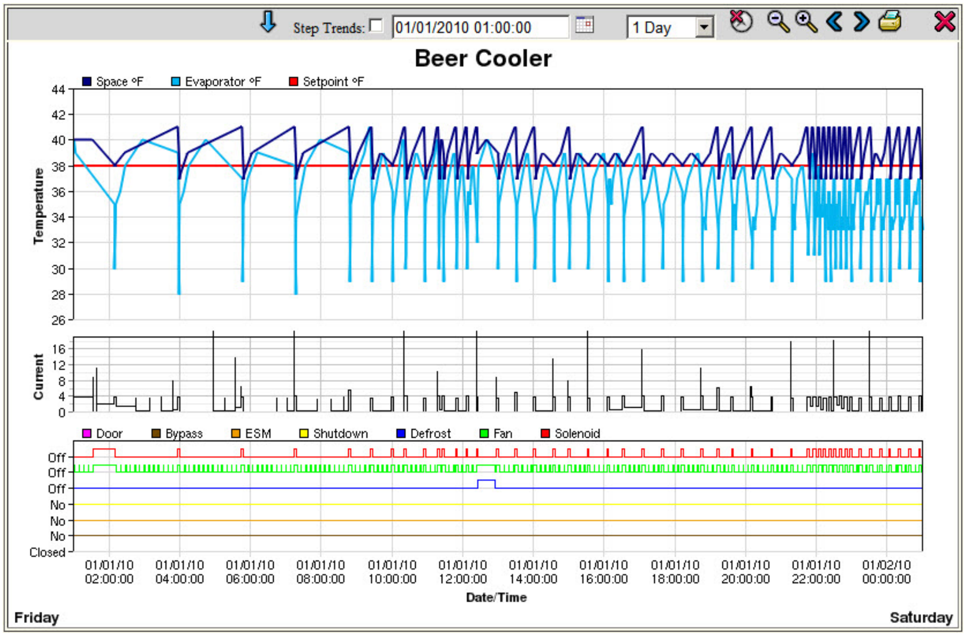


Figure 43. Trend Chart for Chili's Walk-In Beer Cooler, 1 January 2010.

Figure 44 shows the run-time chart for the Chili's walk-in beer cooler on 1 April 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 44 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 April 2010. The minimum hourly compressor run-time on 1 April 2010 was 0.0% while the maximum hourly compressor run-time was 34.8%. The average compressor run-time for 1 April 2010 was 15.9%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 7.1% while the average run-time for those values greater than the daily average ('high load' condition) was 24.8%. During 1 April 2010, the compressor operated 50.0% of the time at 'low load' conditions and 50.0% of the time at 'high load' conditions.

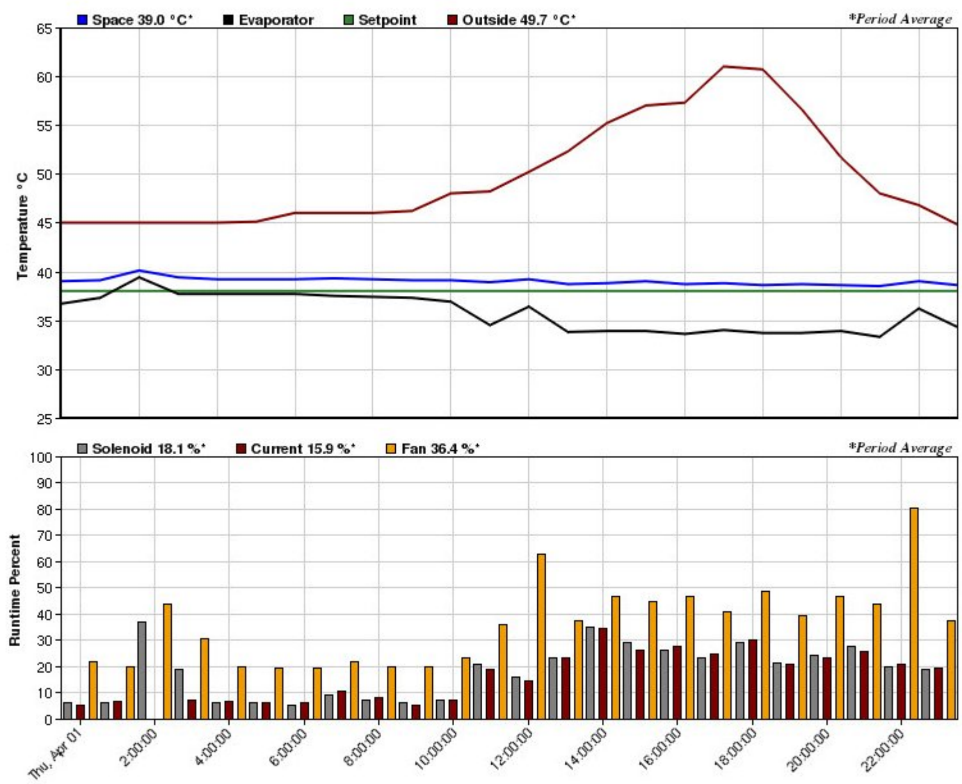


Figure 44. Run-Time Chart for Chili's Walk-In Beer Cooler, 1 April 2010.

Figure 45 shows the trend chart for the Chili's walk-in beer cooler during 1 April 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that two defrost cycles occurred during 1 April 2010. As can be seen from Figure 45, no door opening data was reported for the Chili's walk-in beer cooler.

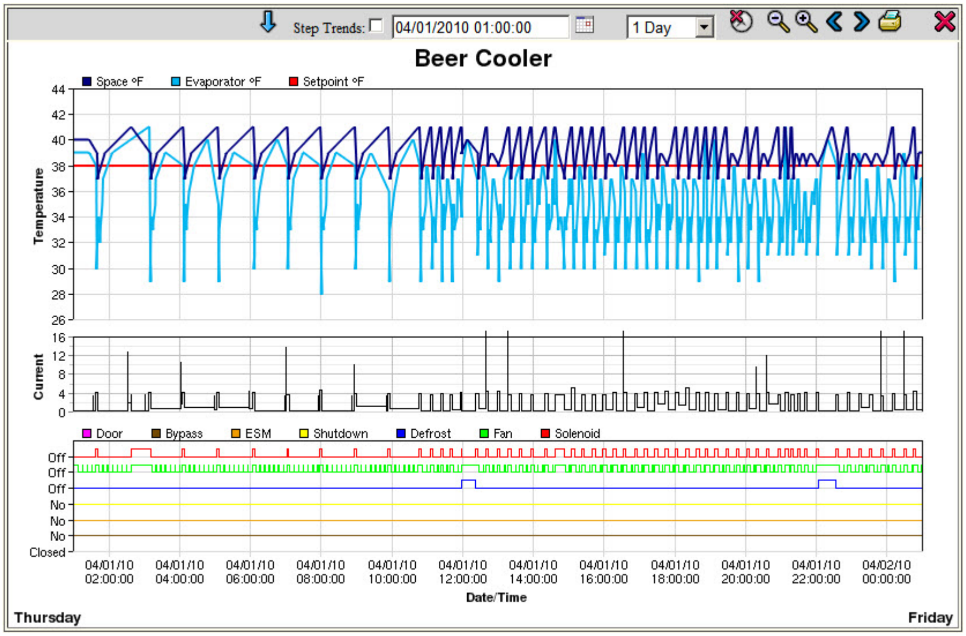


Figure 45. Trend Chart for Chili's Walk-In Beer Cooler, 1 April 2010.

Chili's Walk-In Food Cooler:

Figure 46 shows the run-time chart for the Chili's walk-in food cooler on 1 July 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), and the set-point temperature (green).

The lower portion of the run-time chart shown in Figure 46 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 July 2009. The minimum hourly compressor run-time on 1 July 2009 was 14.8% while the maximum hourly compressor run-time was 100.0%. The average compressor run-time for 1 July 2009 was 54.8%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 33.2% while the average run-time for those values greater than the daily average ('high load' condition) was 73.1%. During 1 July 2009, the compressor operated 45.8% of the time at 'low load' conditions and 54.2% of the time at 'high load' conditions.

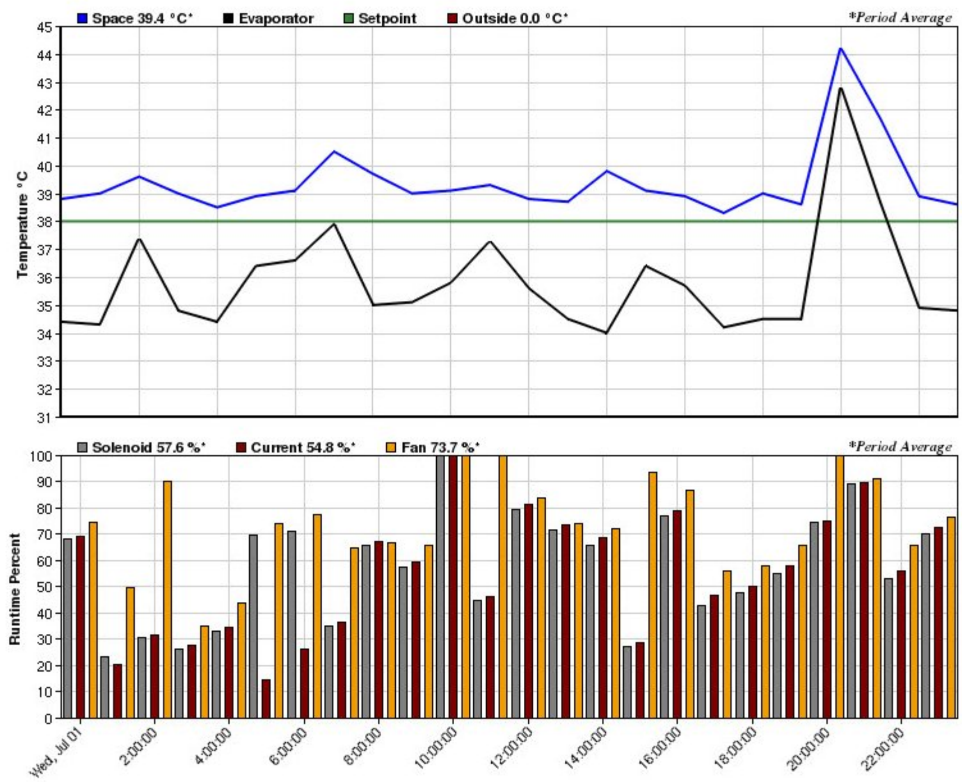


Figure 46. Run-Time Chart for Chili's Walk-In Food Cooler, 1 July 2009.

Figure 47 shows the trend chart for the Chili's walk-in food cooler during 1 July 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that six defrost cycles occurred during 1 July 2009. In addition, the door status shows that 14 door openings occurred during 1 July 2009.

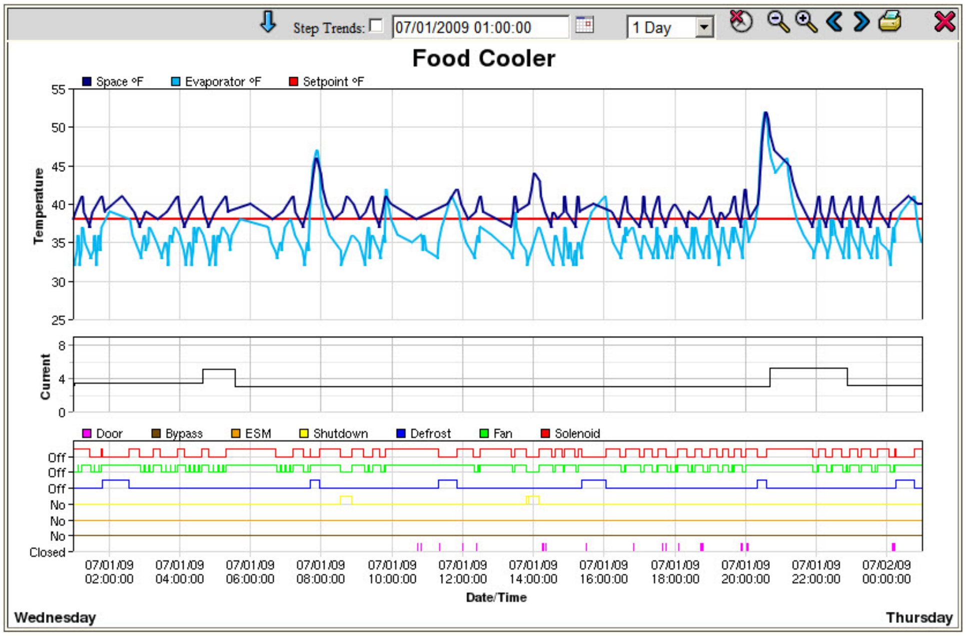


Figure 47. Trend Chart for Chili's Walk-In Food Cooler, 1 July 2009.

Figure 48 shows the run-time chart for the Chili's walk-in food cooler on 2 October 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 48 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 2 October 2009. The minimum hourly compressor run-time on 2 July 2009 was 0.0% while the maximum hourly compressor run-time was 100.0%. The average compressor run-time for 2 October 2009 was 52.3%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 29.9% while the average run-time for those values greater than the daily average ('high load' condition) was 74.7%. During 2 October 2009, the compressor operated 50.0% of the time at 'low load' conditions and 50.0% of the time at 'high load' conditions.

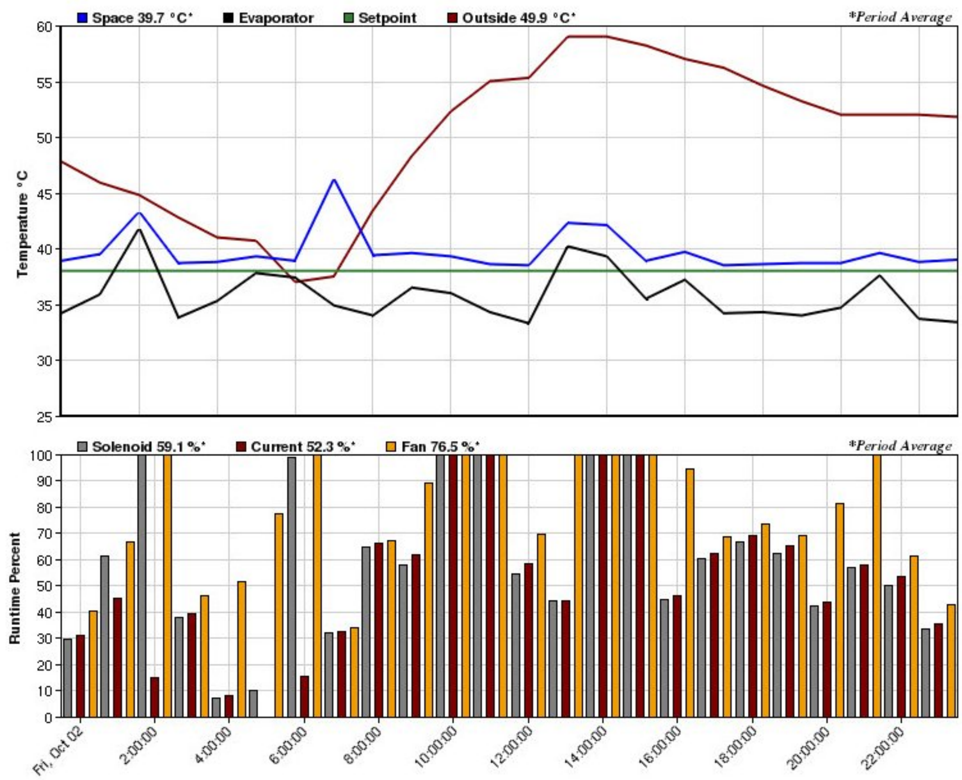


Figure 48. Run-Time Chart for Chili's Walk-In Food Cooler, 2 October 2009.

Figure 49 shows the trend chart for the Chili's walk-in food cooler during 2 October 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that five defrost cycles occurred during 2 October 2009. In addition, the door status shows that 21 door openings occurred during 2 October 2009.

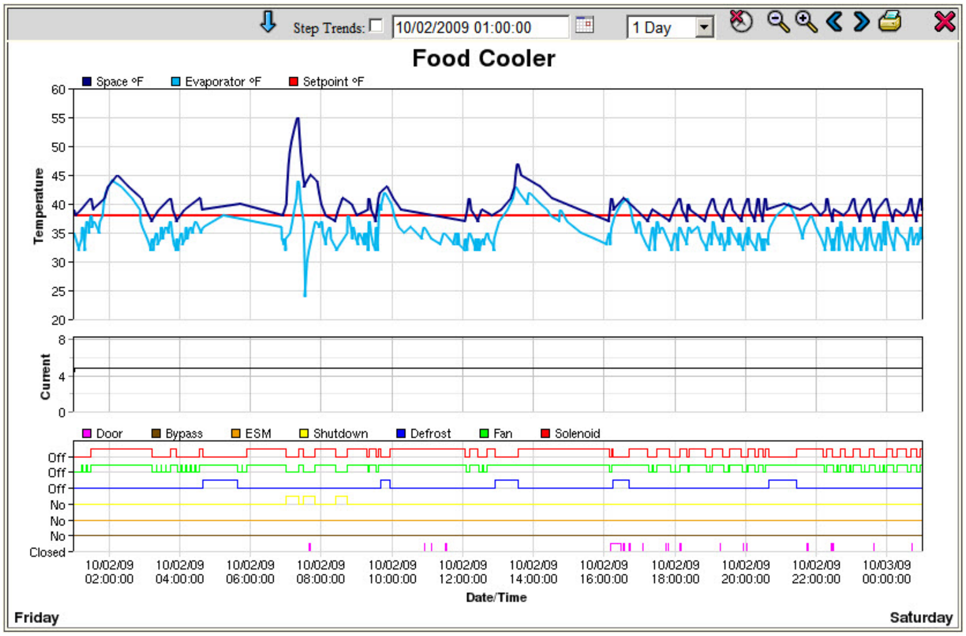


Figure 49. Trend Chart for Chili's Walk-In Food Cooler, 2 October 2009.

Figure 50 shows the run-time chart for the Chili's walk-in food cooler on 1 January 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 50 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 January 2010. The minimum hourly compressor run-time on 1 January 2010 was 9.2% while the maximum hourly compressor run-time was 69.0%. The average compressor run-time for 1 January 2010 was 34.6%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 23.3% while the average run-time for those values greater than the daily average ('high load' condition) was 53.4%. During 1 January 2010, the compressor operated 62.5% of the time at 'low load' conditions and 37.5% of the time at 'high load' conditions.

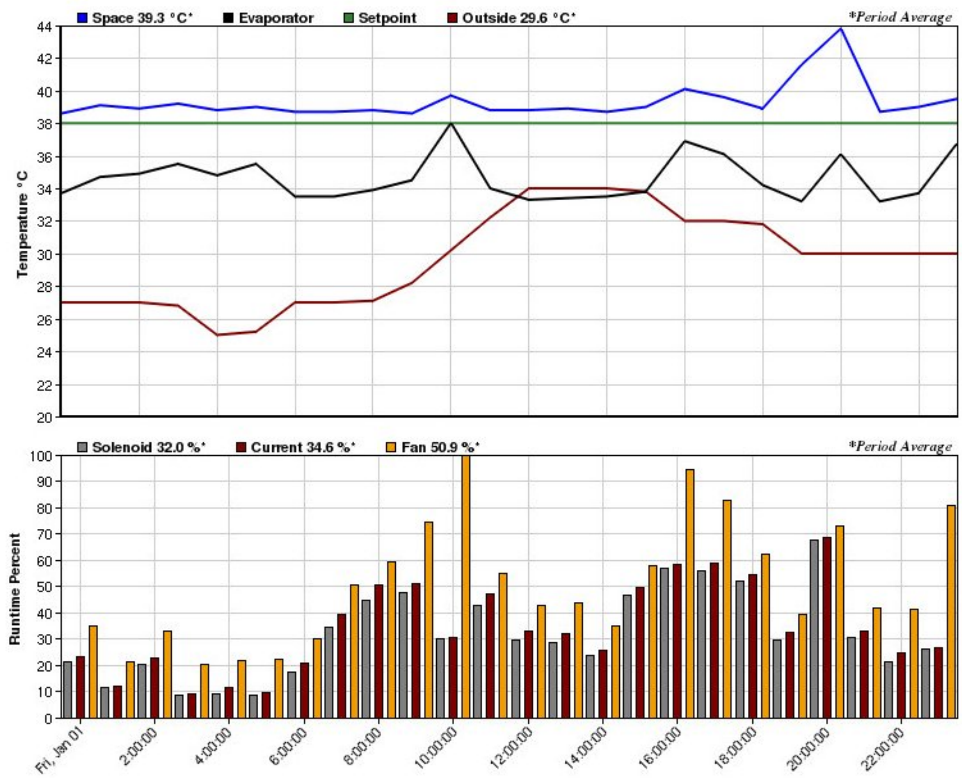


Figure 50. Run-Time Chart for Chili's Walk-In Food Cooler, 1 January 2010.

Figure 51 shows the trend chart for the Chili's walk-in food cooler during 1 January 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 1 January 2010. In addition, the door status shows that 20 door openings occurred during 1 January 2010.

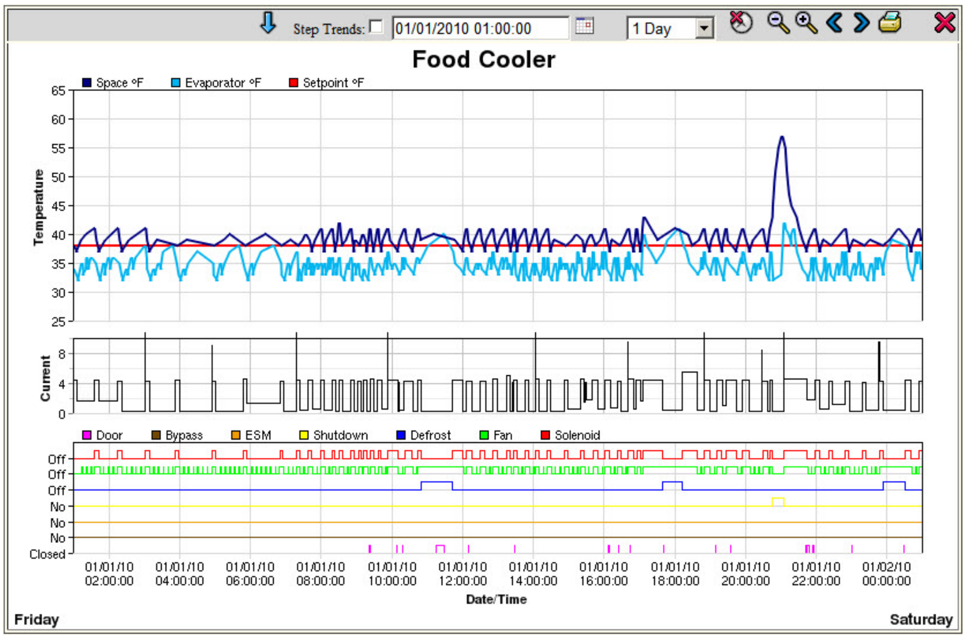


Figure 51. Trend Chart for Chili's Walk-In Food Cooler, 1 January 2010.

Figure 52 shows the run-time chart for the Chili's walk-in food cooler on 1 April 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 52 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 April 2010. The minimum hourly compressor run-time on 1 April 2010 was 9.4% while the maximum hourly compressor run-time was 61.5%. The average compressor run-time for 1 April 2010 was 34.2%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 16.8% while the average run-time for those values greater than the daily average ('high load' condition) was 46.6%. During 1 April 2010, the compressor operated 41.7% of the time at 'low load' conditions and 58.3% of the time at 'high load' conditions.

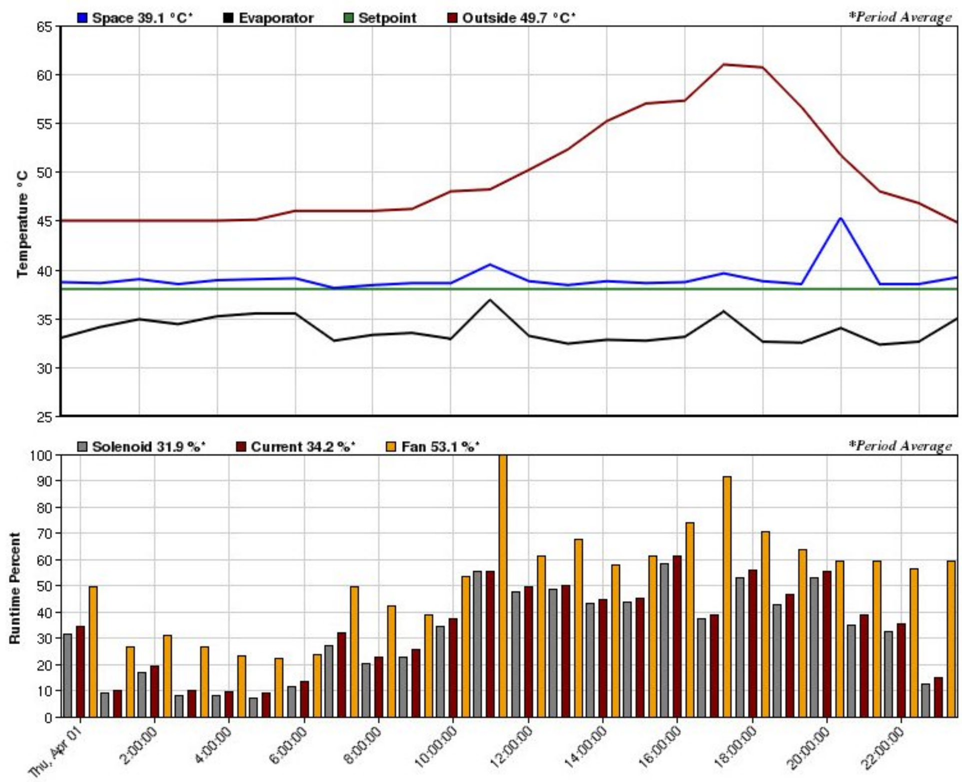


Figure 52. Run-Time Chart for Chili's Walk-In Food Cooler, 1 April 2010.

Figure 53 shows the trend chart for the Chili's walk-in food cooler during 1 April 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 1 April 2010. In addition, the door status shows that 33 door openings occurred during 1 April 2010.

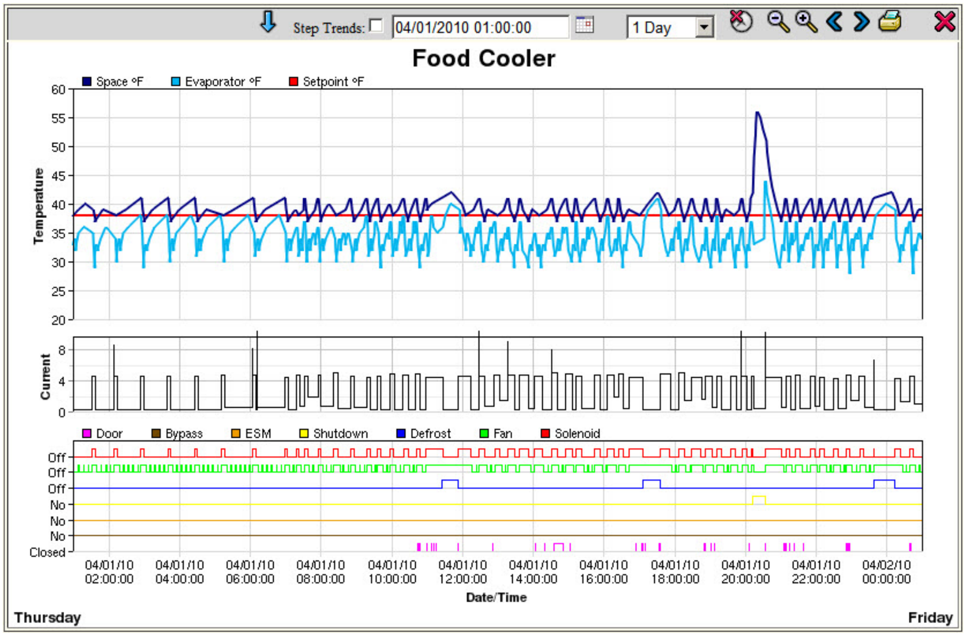


Figure 53. Trend Chart for Chili's Walk-In Food Cooler, 1 April 2010.

Chili's Walk-In Food Freezer:

Figure 54 shows the run-time chart for the Chili's walk-in food freezer on 1 July 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), and the set-point temperature (green).

The lower portion of the run-time chart shown in Figure 54 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 July 2009. The minimum hourly compressor run-time on 1 July 2009 was 25.2% while the maximum hourly compressor run-time was 77.6%. The average compressor run-time for 1 July 2009 was 48.0%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 35.3% while the average run-time for those values greater than the daily average ('high load' condition) was 62.9%. During 1 July 2009, the compressor operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

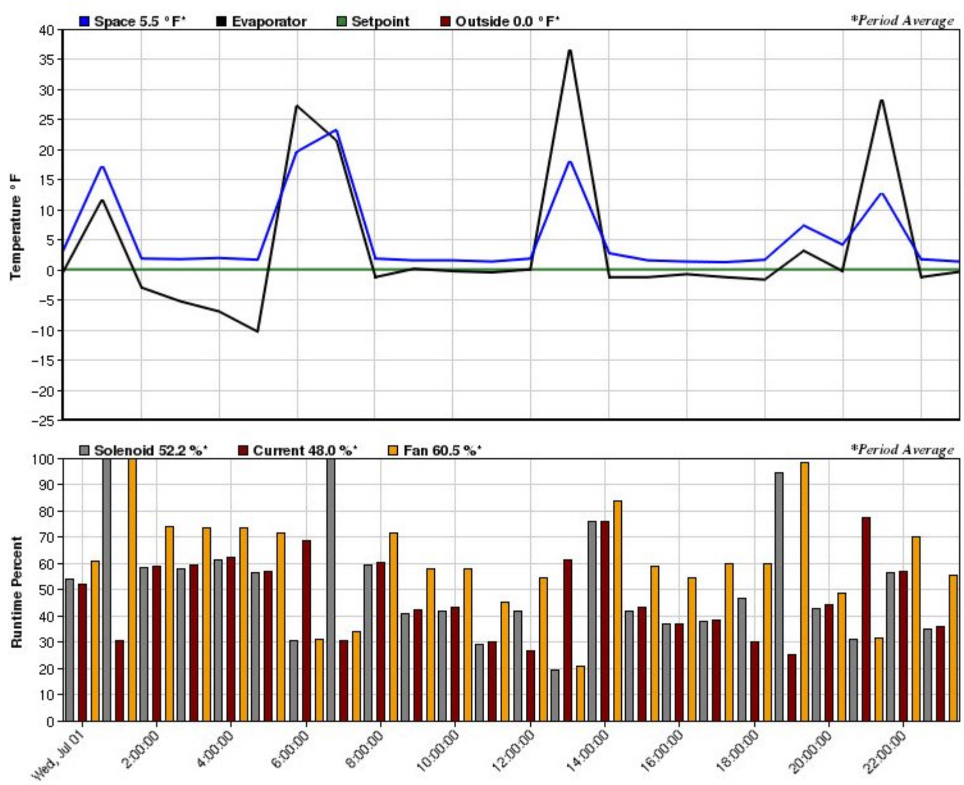


Figure 54. Run-Time Chart for Chili's Walk-In Food Freezer, 1 July 2009.

Figure 55 shows the trend chart for the Chili's walk-in food freezer during 1 July 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 1 July 2009. In addition, the door status shows that 79 door openings occurred during 1 July 2009.

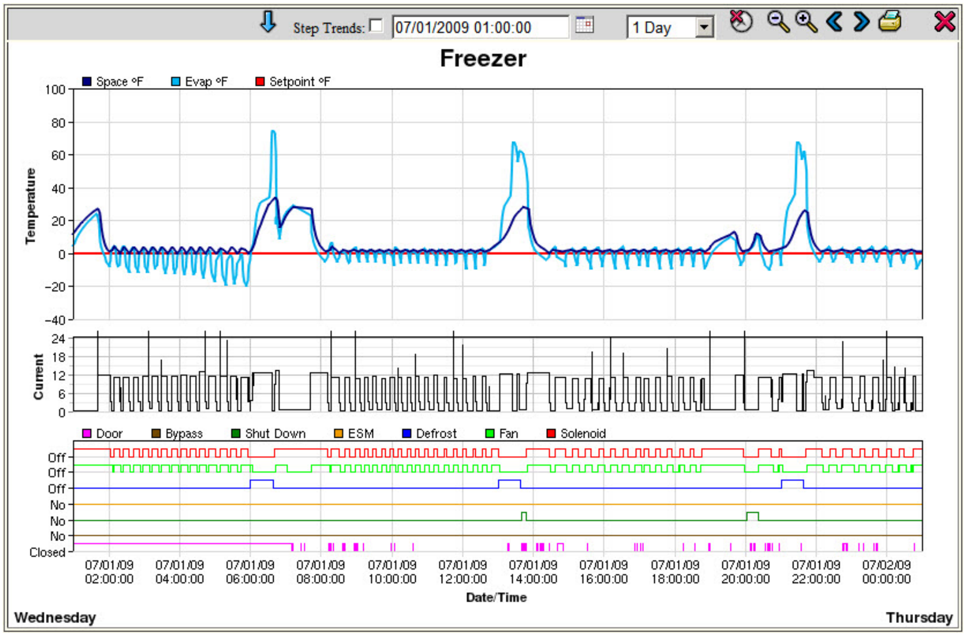


Figure 55. Trend Chart for Chili's Walk-In Food Freezer, 1 July 2009.

Figure 56 shows the run-time chart for the Chili's walk-in food freezer on 2 October 2009. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 56 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 2 October 2009. The minimum hourly compressor run-time on 2 July 2009 was 24.3% while the maximum hourly compressor run-time was 91.9%. The average compressor run-time for 2 October 2009 was 46.4%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 33.0% while the average run-time for those values greater than the daily average ('high load' condition) was 62.2%. During 2 October 2009, the compressor operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

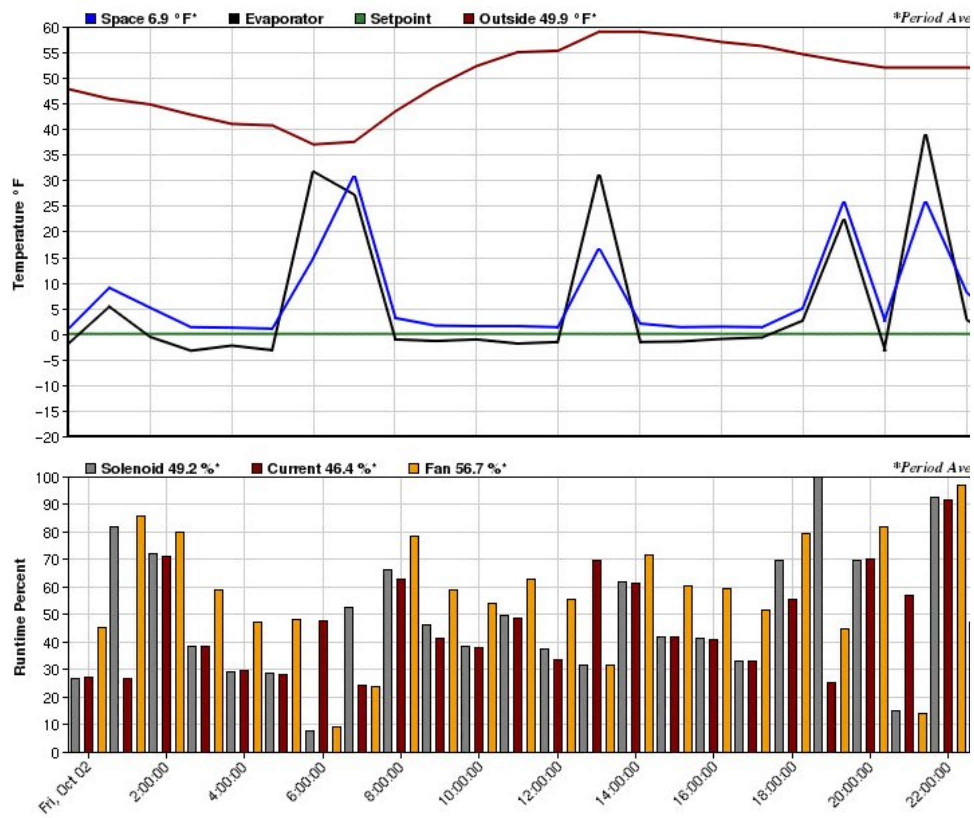


Figure 56. Run-Time Chart for Chili's Walk-In Food Freezer, 2 October 2009.

Figure 57 shows the trend chart for the Chili's walk-in food freezer during 2 October 2009. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 2 October 2009. In addition, the door status shows that 109 door openings occurred during 2 October 2009.

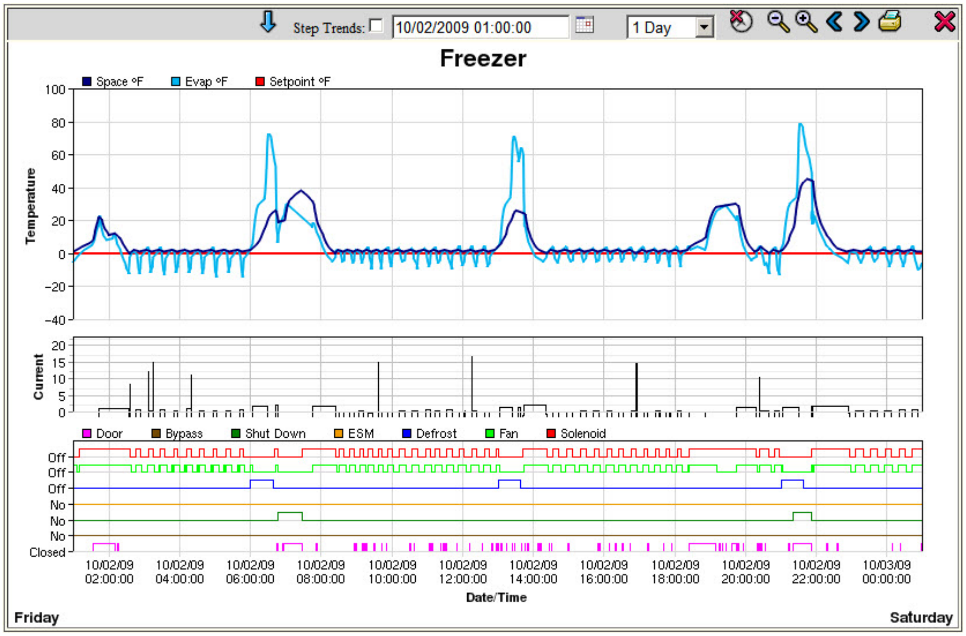


Figure 57. Trend Chart for Chili's Walk-In Food Freezer, 2 October 2009.

Figure 58 shows the run-time chart for the Chili's walk-in food freezer on 1 January 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 58 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 January 2010. The minimum hourly compressor run-time on 1 January 2010 was 26.1% while the maximum hourly compressor run-time was 68.5%. The average compressor run-time for 1 January 2010 was 44.5%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 35.7% while the average run-time for those values greater than the daily average ('high load' condition) was 55.0%. During 1 January 2010, the compressor operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

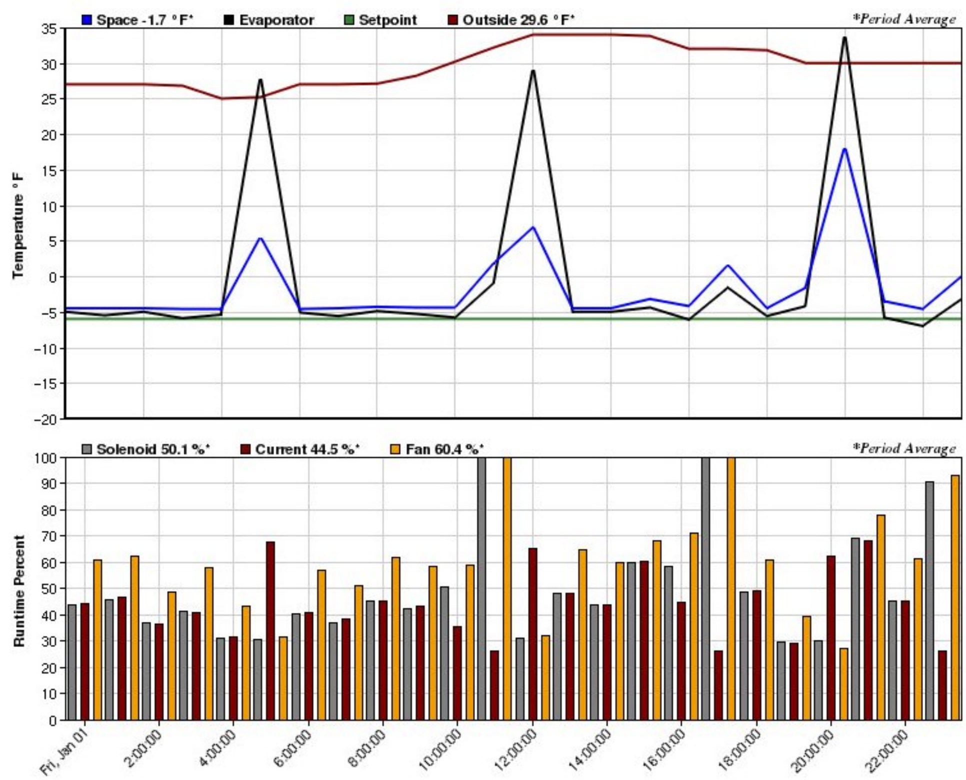


Figure 58. Run-Time Chart for Chili's Walk-In Food Freezer, 1 January 2010.

Figure 59 shows the trend chart for the Chili's walk-in food freezer during 1 January 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 1 January 2010. In addition, the door status shows that 87 door openings occurred during 1 January 2010.

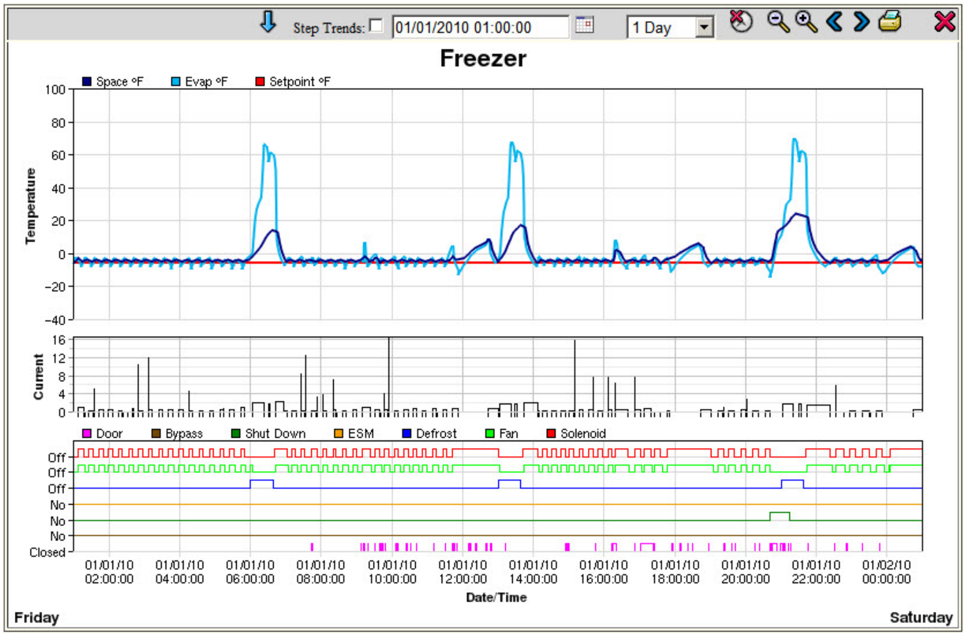


Figure 59. Trend Chart for Chili's Walk-In Food Freezer, 1 January 2010.

Figure 60 shows the run-time chart for the Chili's walk-in food freezer on 1 April 2010. The upper portion of the chart shows the internal space temperature (blue), the evaporator temperature (black), the set-point temperature (green), and the outdoor ambient temperature (maroon).

The lower portion of the run-time chart shown in Figure 60 displays the percentage run-time of the liquid solenoid valve (gray), the compressor (maroon), and evaporator fans (orange) for each hour of the day during 1 April 2010. The minimum hourly compressor run-time on 1 April 2010 was 20.2% while the maximum hourly compressor run-time was 98.7%. The average compressor run-time for 1 April 2010 was 44.0%. The average run-time for those values less than or equal to the daily average ('low load' condition) was 29.2% while the average run-time for those values greater than the daily average ('high load' condition) was 61.6%. During 1 April 2010, the compressor operated 54.2% of the time at 'low load' conditions and 45.8% of the time at 'high load' conditions.

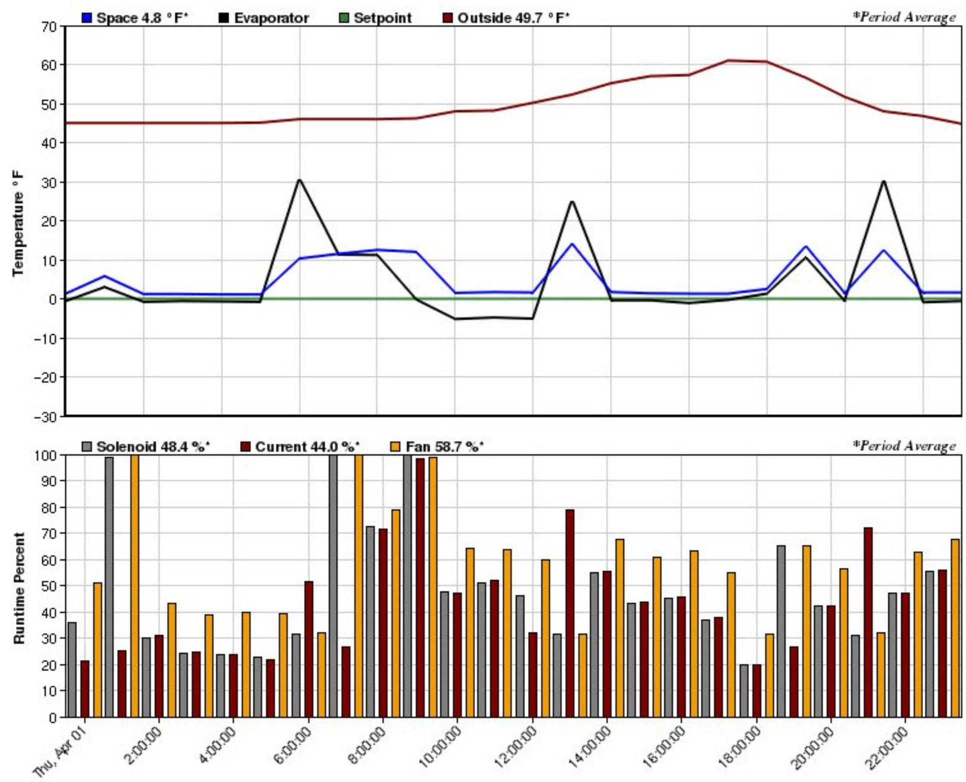


Figure 60. Run-Time Chart for Chili's Walk-In Food Freezer, 1 April 2010.

Figure 61 shows the trend chart for the Chili's walk-in food freezer during 1 April 2010. The upper portion of the chart shows the internal space temperature (dark blue), the evaporator temperature (light blue) and the set-point temperature (red). The lower portion of the chart shows the defrost heater status (blue) and the door openings (magenta), as well as the status of other parameters of the refrigeration system. The defrost heater status shows that three defrost cycles occurred during 1 April 2010. In addition, the door status shows that 65 door openings occurred during 1 April 2010.

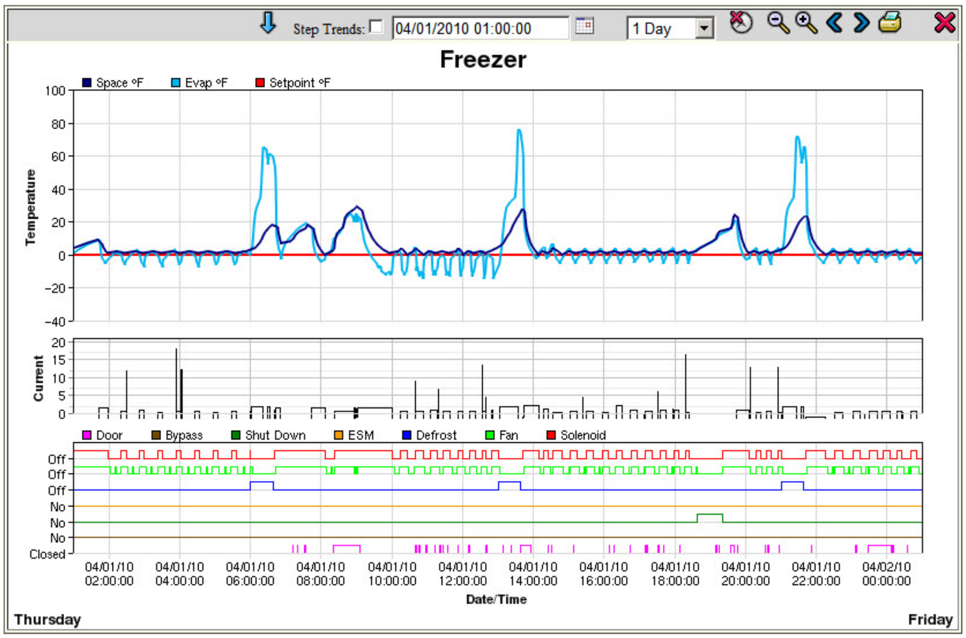


Figure 61. Trend Chart for Chili's Walk-In Food Freezer, 1 April 2010.

Appendix B: PG&E FSTC Walk-In Freezer Specifications, Test Procedure and Sample Data

FSTC Test Walk-In Freezer:
Freezer interior dimensions: 113" x 89" x 95" (L x W x H)
Door opening dimensions: 39" x 80" (W x H)
Box Construction: 3.5" urethane foam insulated panels
Box located with rear and side walls adjacent to interior building walls (4" air gap)
Remote split system w/ condensing unit mounted directly on top of box
Condensing unit: 2.5 HP, R404a, electric defrost
4 defrost cycles per day, time/temp. terminated
Power data for combined cond & evap unit circuit and includes continuous ~90 W door/frame heater
Internal freezer temperature measured at horizontal center of box at a height of 4 ft.
Ambient temperature and RH measured at 4 ft. in front of box corner at a height of 4 ft.
Condensing unit ambient temperature measured at front of coil air intake

Freezer content:
The freezer contained a fixed product load consisting of existing miscellaneous bagged and boxed food product loaded to approximately 50 % of the freezer volume capacity.

Door opening and loading test procedure:
During each 24-hr trial, the freezer door was opened for 15 minutes at 10:00 a.m. and again at 4:00 p.m.
An active product load consisting of two full-size hotel pans each filled with one gallon of room-temperature water was introduced during each door-opening period.

Table 34. Sample Measured Data from PG&E FSTC Walk-In Freezer.

Date	Time	Avg. KW	RH (%)	Amb. (°F)	Cond amb (°F)	Box air (°F)
10/1/2009	0:00:00	0.391	31.3	68.1	68.7	1.0
10/1/2009	0:00:15	0.391	31.3	68.1	68.7	1.1
10/1/2009	0:00:30	0.391	31.3	68.1	68.7	1.3
10/1/2009	0:00:45	0.39	31.3	68.0	68.5	1.4
10/1/2009	0:01:00	0.391	31.3	68.0	68.4	1.6
10/1/2009	0:01:15	0.391	31.3	68.0	68.4	1.7
10/1/2009	0:01:30	0.39	31.3	68.0	68.5	1.9
10/1/2009	0:01:45	0.39	31.3	68.0	68.4	2.0
10/1/2009	0:02:00	0.39	31.4	67.9	68.4	2.1
10/1/2009	0:02:15	0.39	31.4	67.9	68.5	2.2
10/1/2009	0:02:30	0.39	31.4	67.9	68.4	2.3
10/1/2009	0:02:45	0.39	31.3	67.9	67.8	2.0
10/1/2009	0:03:00	1.423	31.3	67.9	67.5	0.2

Appendix C: Analysis of Measured Data from the FSTC Instrumented Walk-In Freezer

Trial 1, Day 1:

Figure 62 shows the walk-in freezer internal temperature during Day 1 of Trial 1. Figure 63 shows the corresponding power consumption. The uniform oscillation of the walk-in freezer internal temperature and power consumption results from the cycling of the refrigeration system.

Figure 64 shows the ambient conditions surrounding the walk-in freezer. For Trial 1, the ambient conditions near the condenser, averaged over the entire test period, were nominally 80°F (27°C), 41% RH.

From Figures 62 and 63, the four defrost cycles occurring at approximately midnight, 6:00am, 12:00pm and 6:00pm can clearly be seen. These defrost cycles are approximately 20 minutes in length and the air temperature inside the walk-in freezer increases from approximately 0°F to 18°F. The two door openings occurring at approximately 9:00am and 3:00pm can also be seen as the 40°F and 50°F temperature spikes.

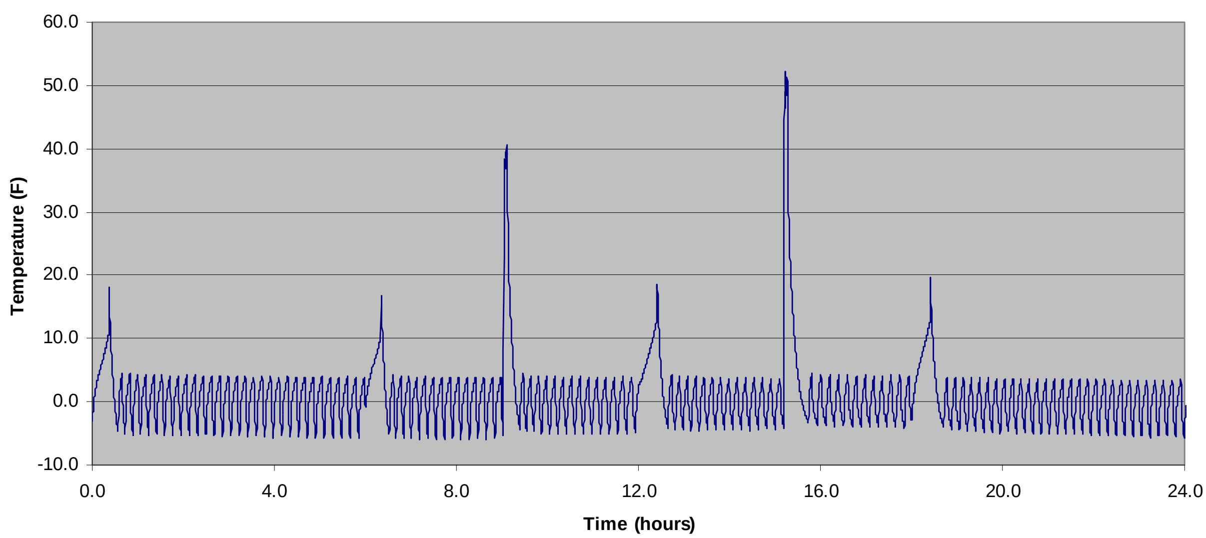


Figure 62. Walk-In Freezer Internal Temperature during Day 1 of Trial 1.

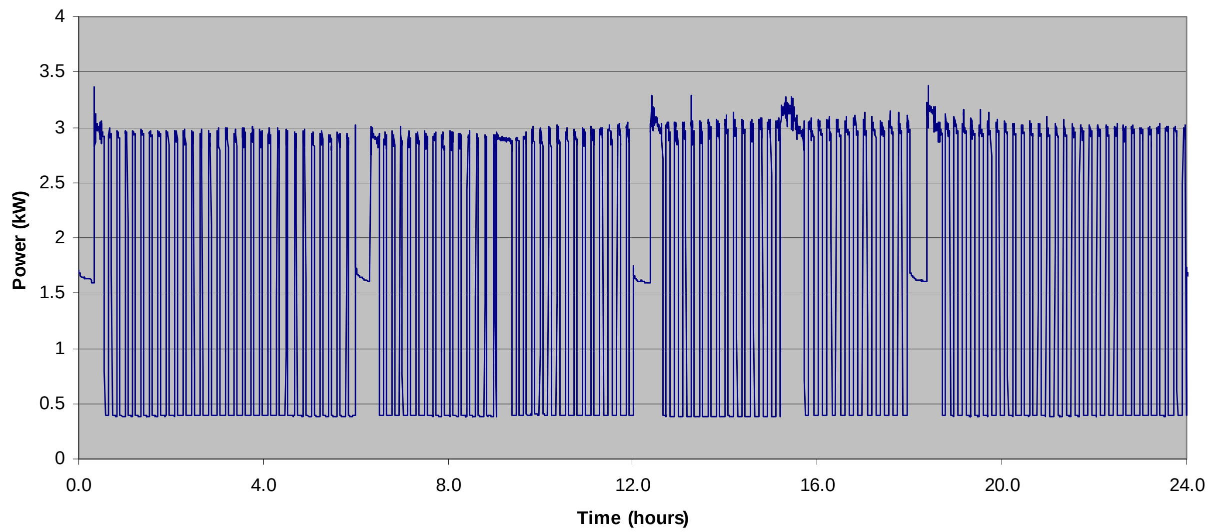


Figure 63. Power Consumption of the Walk-In Freezer during Day 1 of Trial 1.

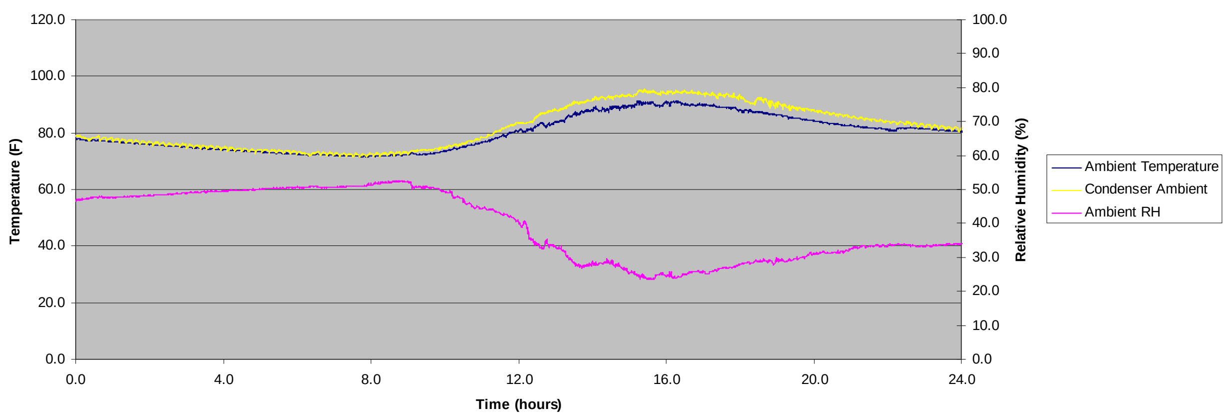


Figure 64. Ambient Conditions Surrounding the Walk-In Freezer during Day 1 of Trial 1.

Figure 65 shows detail of the walk-in freezer internal temperature during one of the defrost cycles occurring during Day 1 of Trial 1. Figure 66 shows the corresponding power consumption during that particular defrost cycle. From Figures 65 and 66, it can be seen that the initiation of the defrost cycle, at 6.0 hours, interrupted the operation of the condensing unit. It can also be seen that the condensing unit turns on immediately following the defrost cycle to reduce the internal temperature of the walk-in freezer from approximately 18°F to -5°F.

From Figure 66, it can be seen that the refrigeration system baseline power consumption, which consists of the door/frame heater and the evaporator fans, is approximately 400 W. Furthermore, from Figure 66, it can be seen that an additional 1200 W is consumed by the defrost heater during the defrost cycle. Thus, the total power consumption of the refrigeration system during a defrost cycle is approximately 1600 W, which consists of the power consumption of the door/frame heater, the evaporator fans and the defrost heater.

From Figure 66, it can also be seen that the total power required by the refrigeration system when the condensing unit is operating is approximately 3 kW, which consists of the power consumption of the door/frame heater, the evaporator fans and the condensing unit.

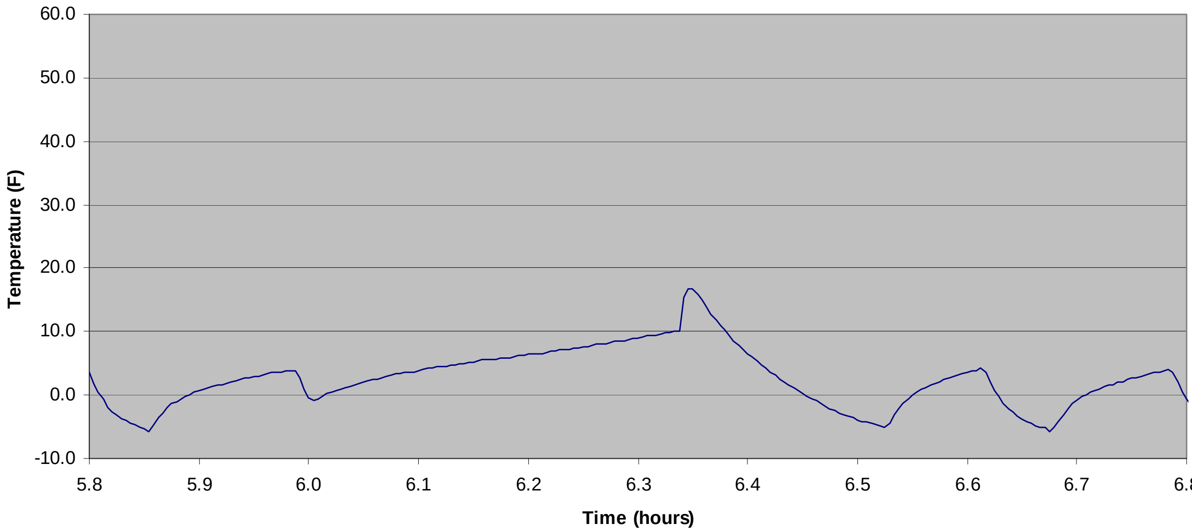


Figure 65. Walk-In Freezer Internal Temperature during One Defrost Cycle, Day 1 of Trial 1.

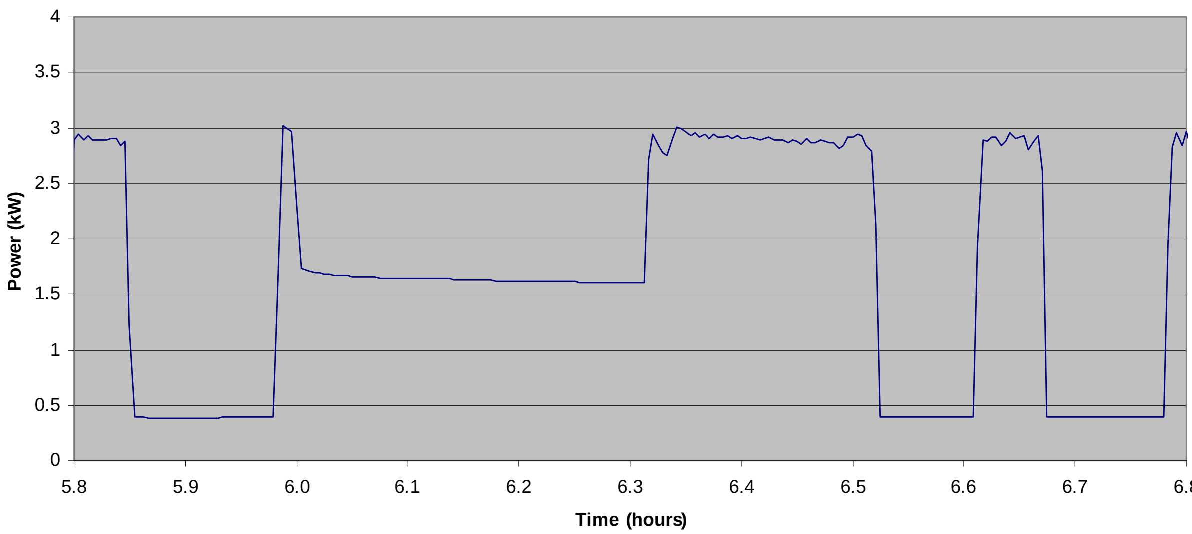


Figure 66. Power Consumption of the Walk-In Freezer during One Defrost Cycle, Day 1 of Trial 1.

Figure 67 shows detail of the walk-in freezer internal temperature during one of the door opening cycles occurring at approximately 9.05 hours on Day 1 of Trial 1. Figure 68 shows the corresponding power consumption during that particular door opening cycle. From Figures 67 and 68, it can be seen that the initiation of the door opening cycle occurred immediately after the condensing unit completed its cooling cycle and shut off. From Figure 67, it can be seen that the internal temperature of the walk-in freezer increases from approximately -5°F to 40°F during the door opening cycle. Also, it can be seen from Figure 68 that the condensing unit turns on when the door is opened and continues to operate until the internal temperature of the walk-in freezer is reduced to -5°F.

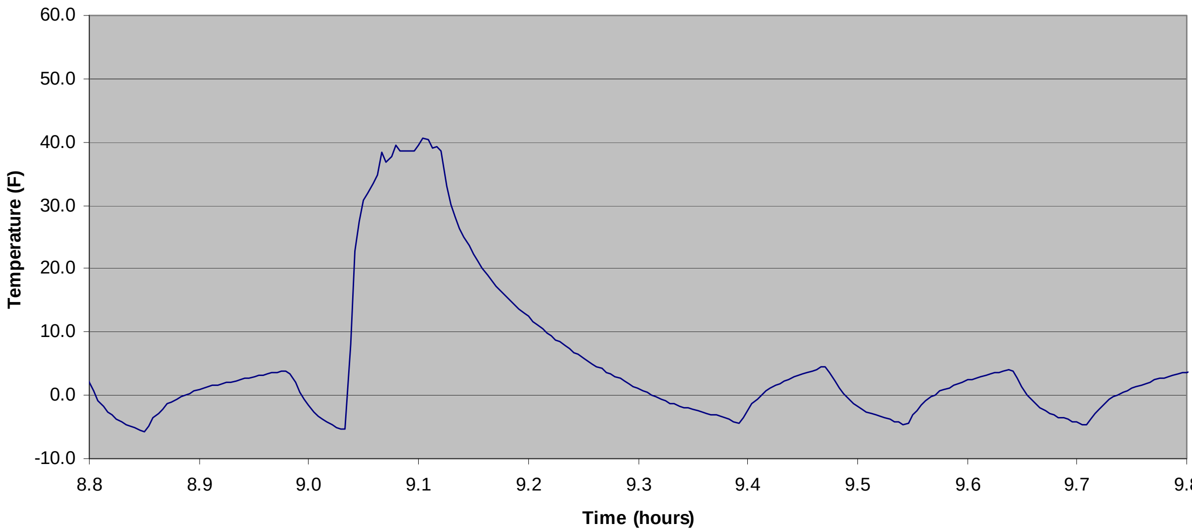


Figure 67. Walk-In Freezer Internal Temperature during One Door Opening Cycle, Day 1 of Trial 1.

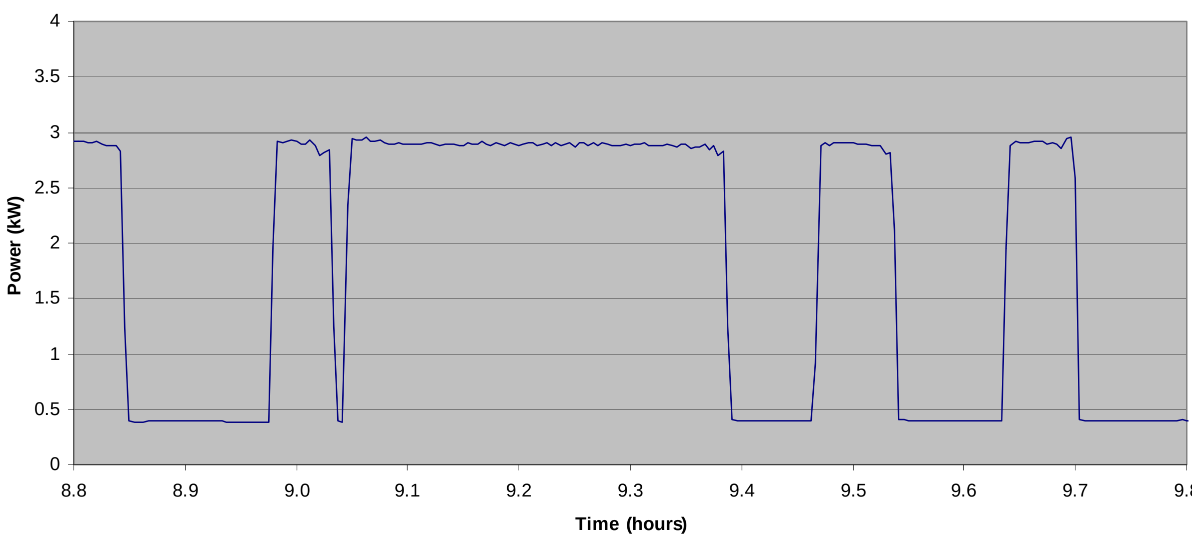


Figure 68. Power Consumption of the Walk-In Freezer during One Door Opening Cycle, Day 1 of Trial 1.

Trial 1, Day 2:

Figures 69, 70 and 71 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 2 of Trial 1. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 2 of Trial 1.

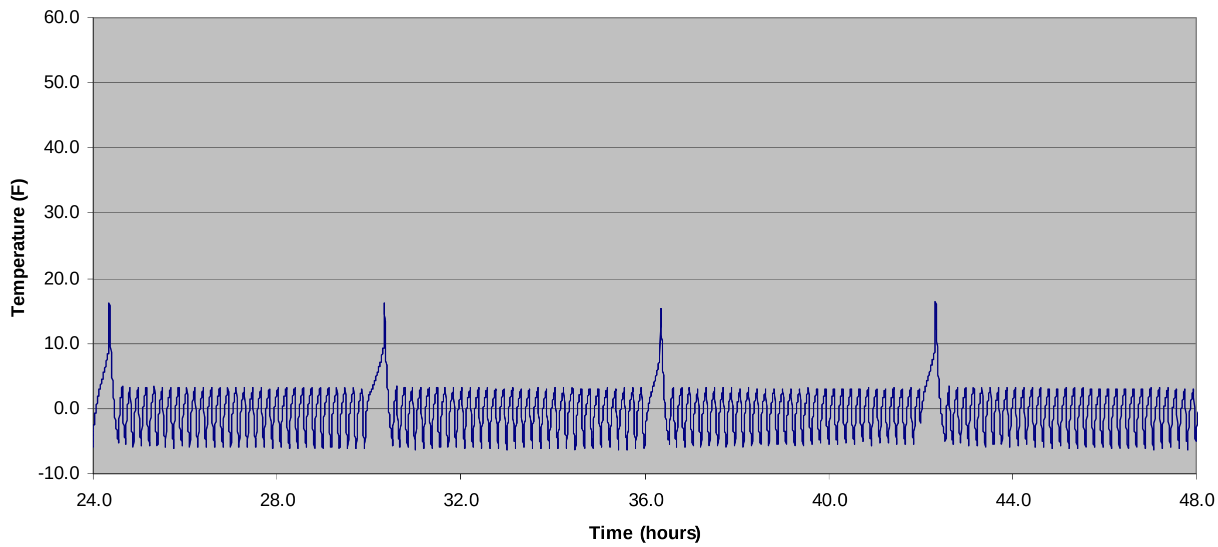


Figure 69. Walk-In Freezer Internal Temperature during Day 2 of Trial 1.

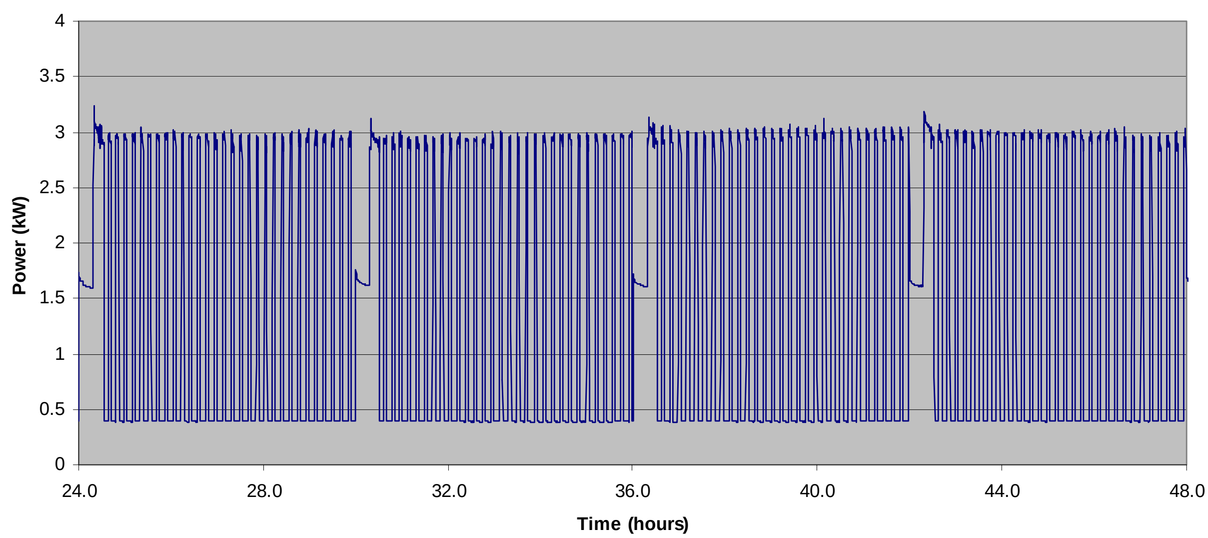


Figure 70. Power Consumption of the Walk-In Freezer during Day 2 of Trial 1.

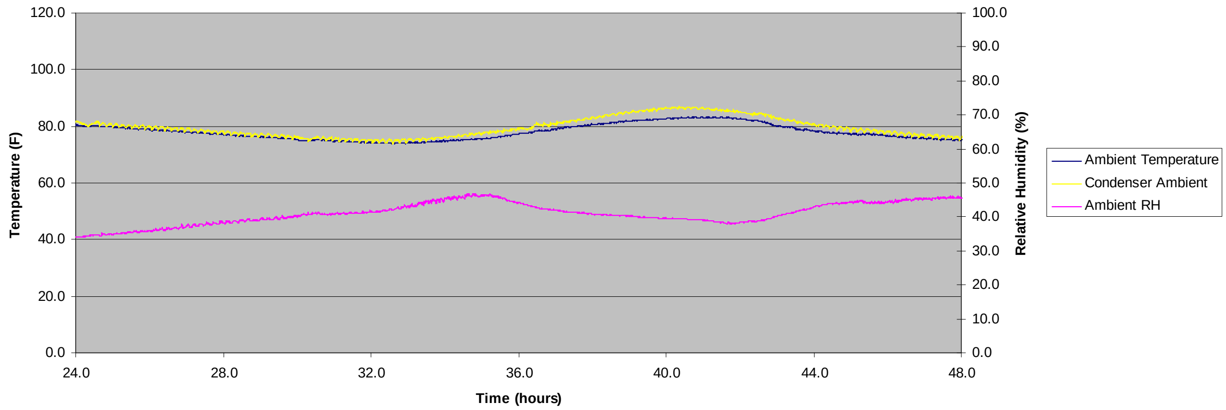


Figure 71. Ambient Conditions Surrounding the Walk-In Freezer during Day 2 of Trial 1.

<u>Trial 1, Day 3:</u>

Figures 72, 73 and 74 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 3 of Trial 1. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 3 of Trial 1.

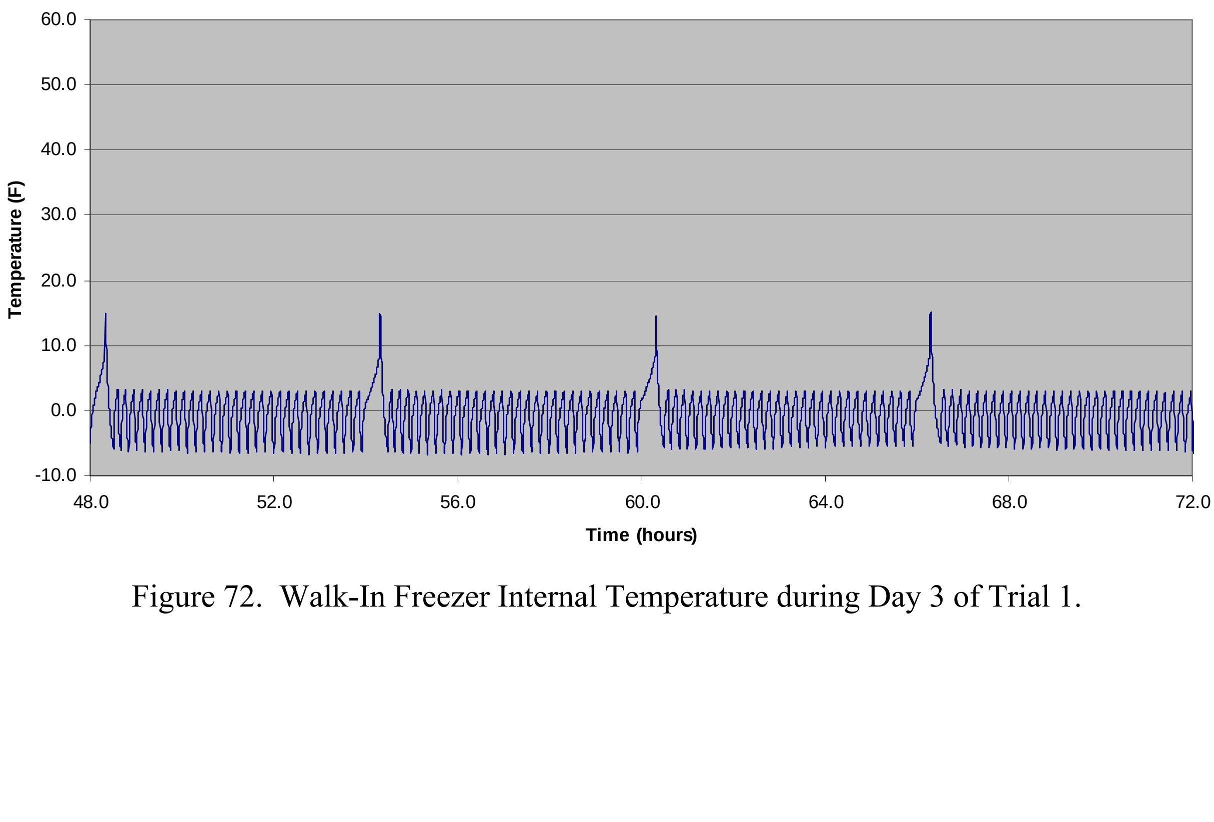


Figure 72. Walk-In Freezer Internal Temperature during Day 3 of Trial 1.

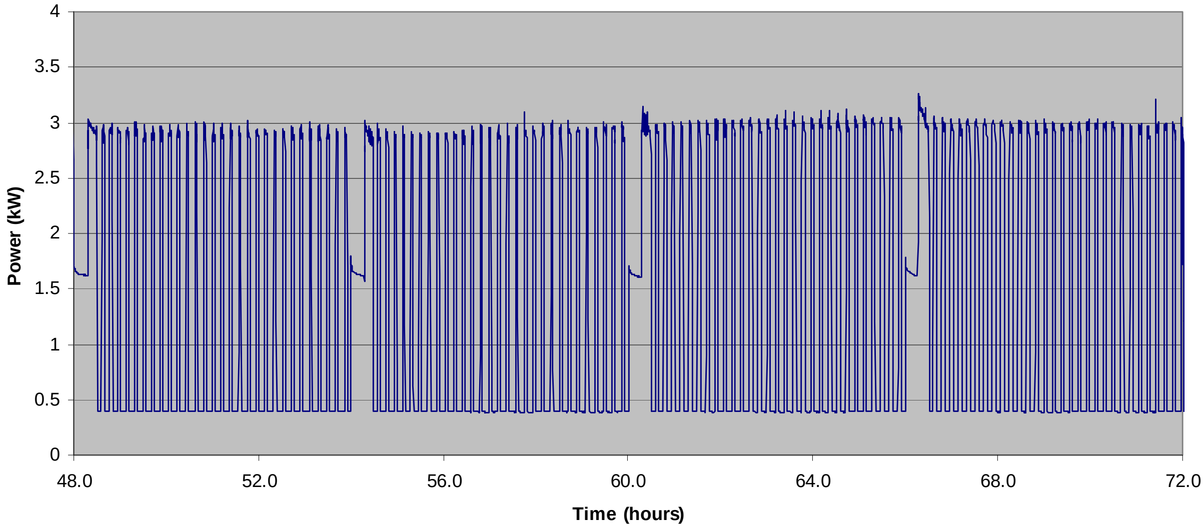


Figure 73. Power Consumption of the Walk-In Freezer during Day 3 of Trial 1.

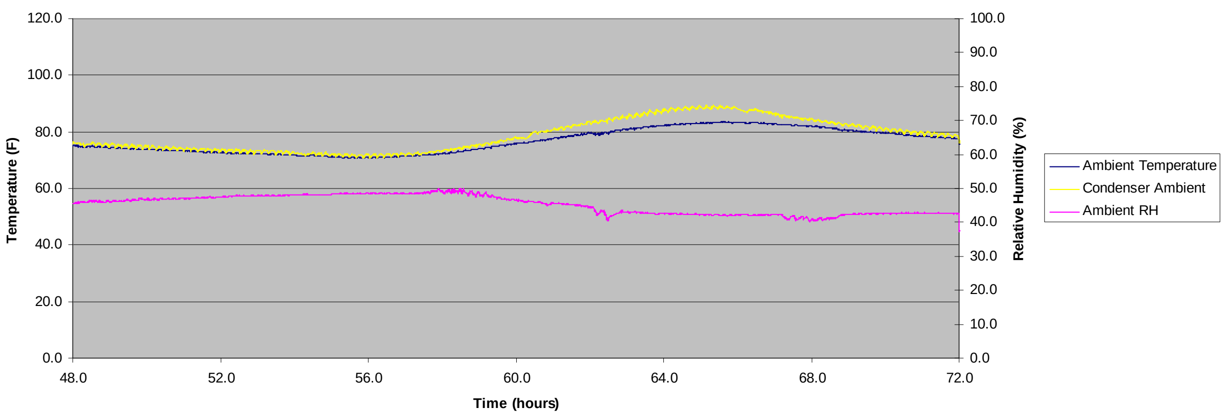


Figure 74. Ambient Conditions Surrounding the Walk-In Freezer during Day 3 of Trial 1.

Trial 1, Day 4:

Figures 75, 76 and 77 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 4 of Trial 1. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 4 of Trial 1.

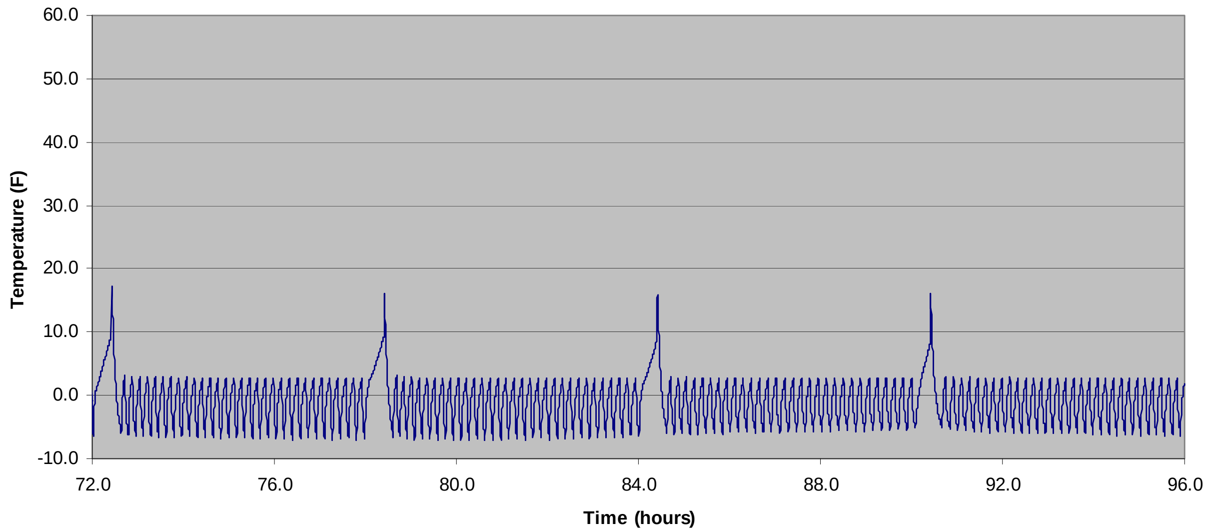


Figure 75. Walk-In Freezer Internal Temperature during Day 4 of Trial 1.

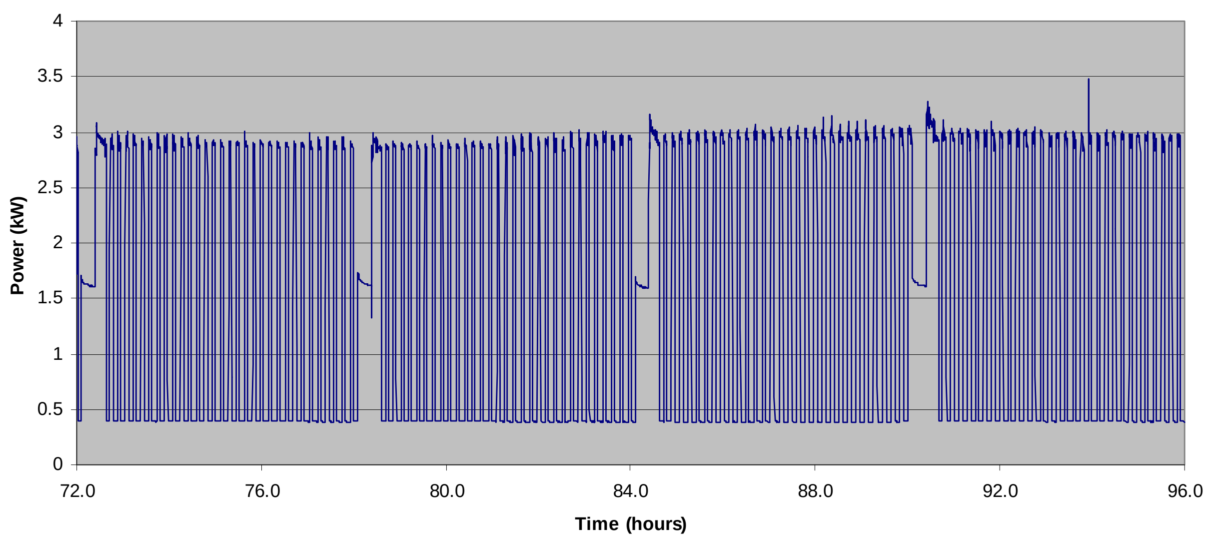


Figure 76. Power Consumption of the Walk-In Freezer during Day 4 of Trial 1.

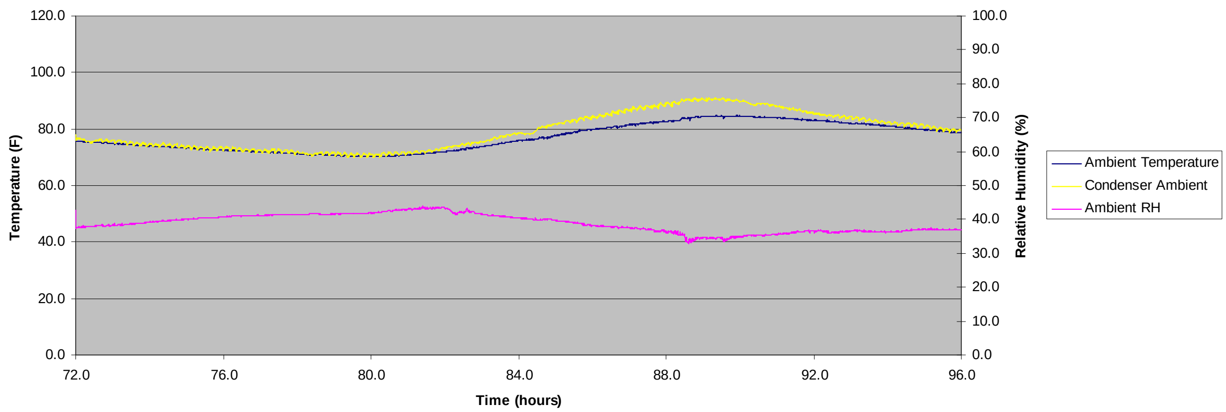


Figure 77. Ambient Conditions Surrounding the Walk-In Freezer during Day 4 of Trial 1.

Trial 2, Day 1:

Figure 78 shows the walk-in freezer internal temperature during Day 1 of Trial 2. Figure 79 shows the corresponding power consumption. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 1 of Trial 2.

Figure 80 shows the ambient conditions surrounding the walk-in freezer. For Trial 2, the ambient conditions near the condenser, averaged over the entire test period, were nominally 70°F (21°C), 34% RH.

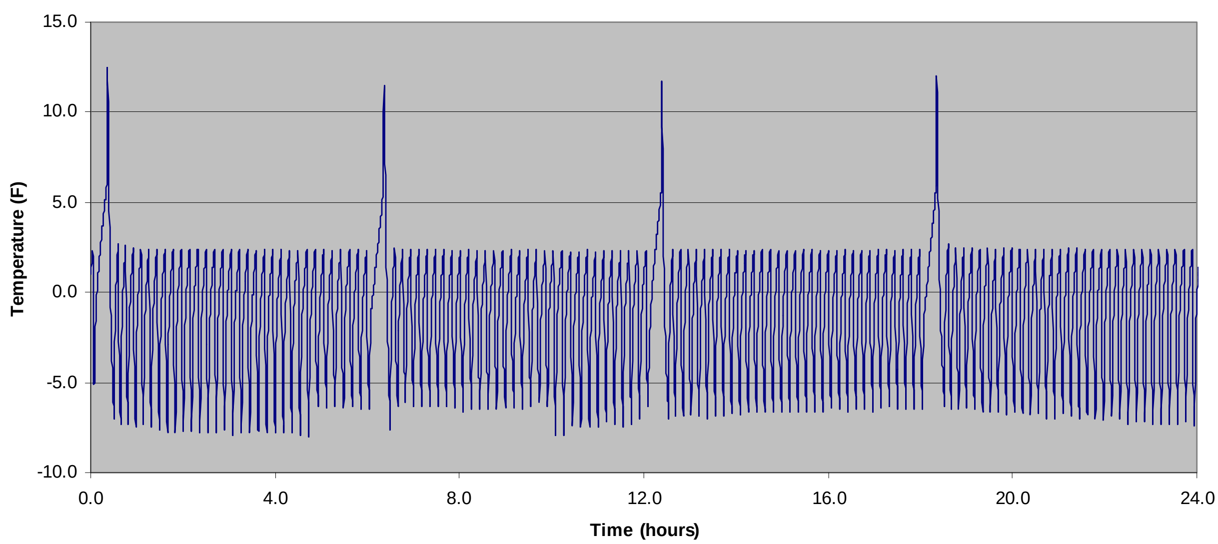


Figure 78. Walk-In Freezer Internal Temperature during Day 1 of Trial 2.

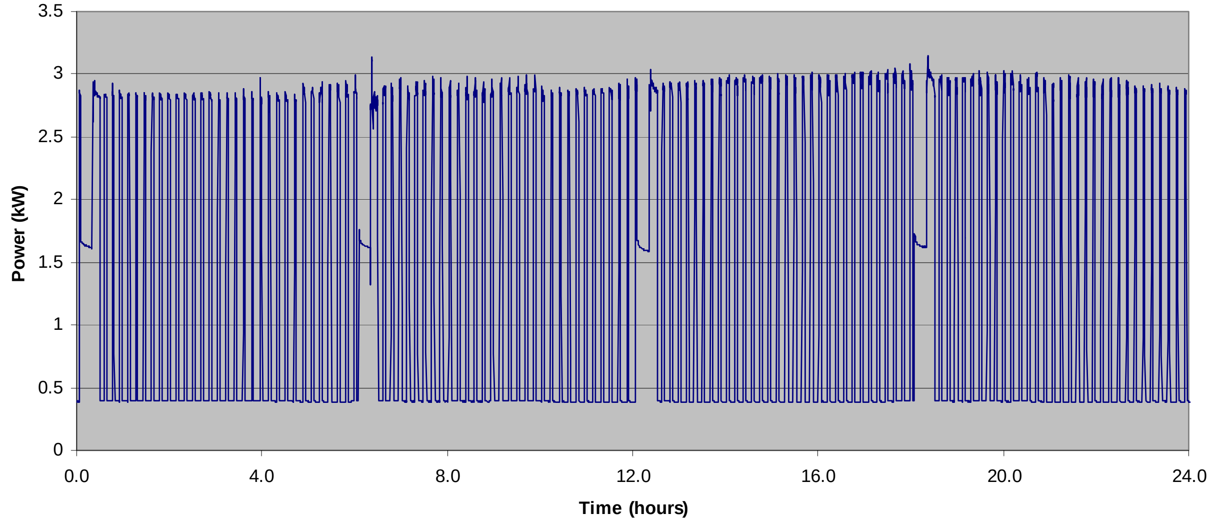


Figure 79. Power Consumption of the Walk-In Freezer during Day 1 of Trial 2.

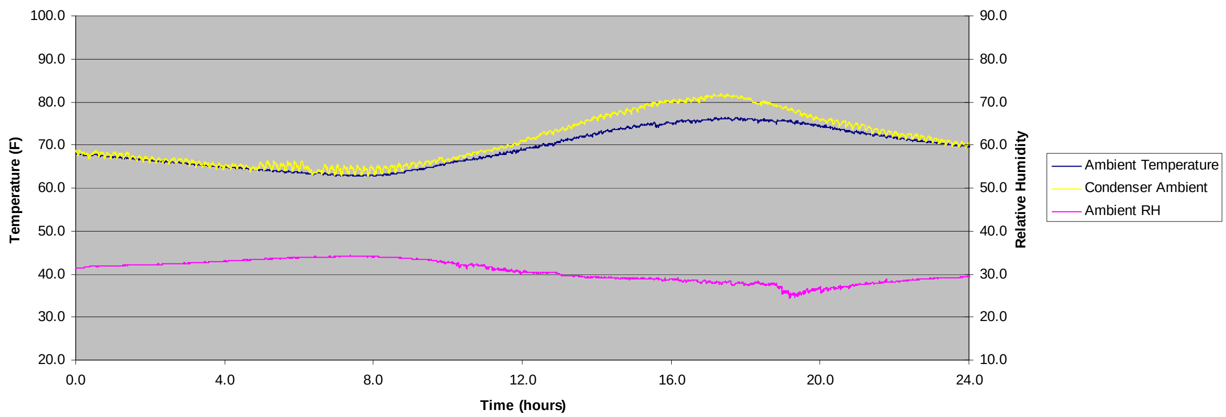


Figure 80. Ambient Conditions Surrounding the Walk-In Freezer during Day 1 of Trial 2.

<u>Trial 2, Day 2:</u>

Figures 81, 82 and 83 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 2 of Trial 2. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 2 of Trial 2.

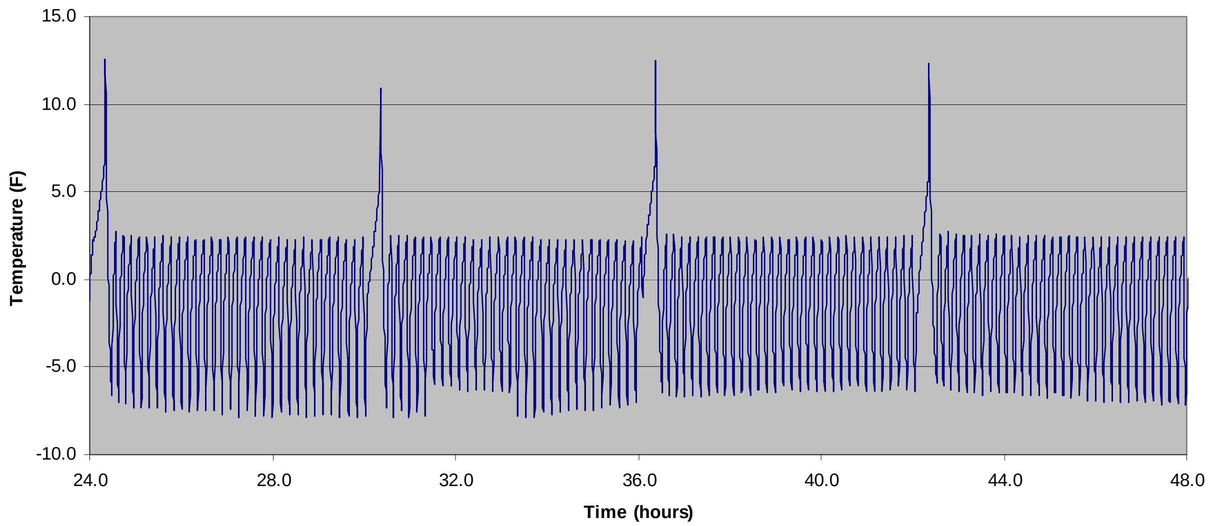


Figure 81. Walk-In Freezer Internal Temperature during Day 2 of Trial 2.

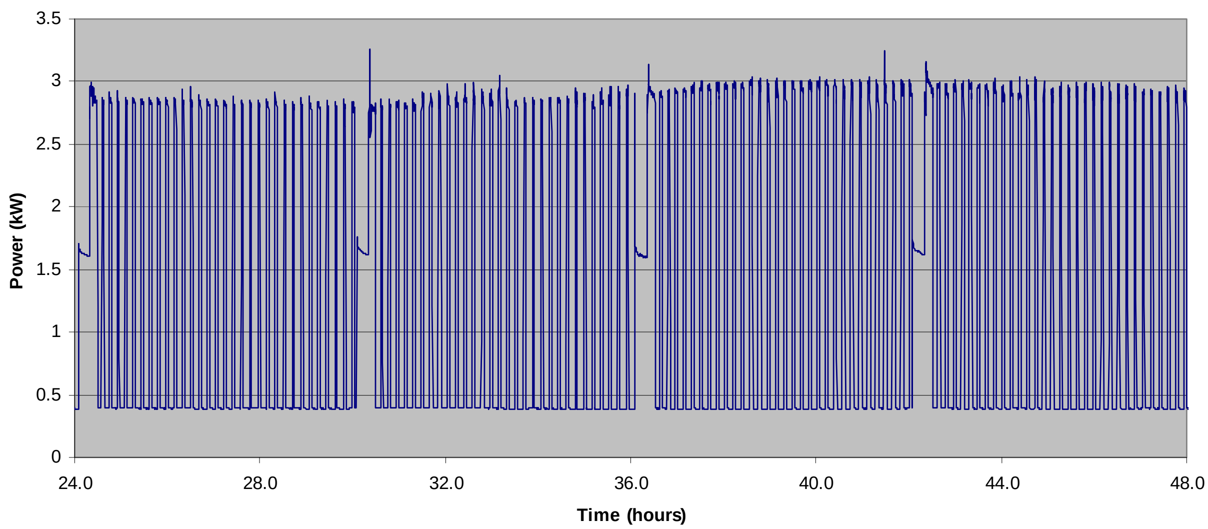


Figure 82. Power Consumption of the Walk-In Freezer during Day 2 of Trial 2.

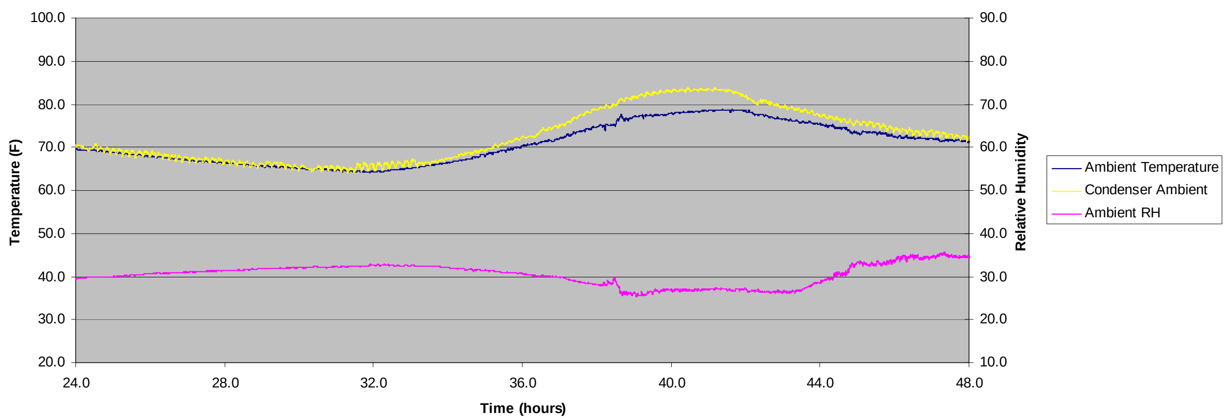


Figure 83. Ambient Conditions Surrounding the Walk-In Freezer during Day 2 of Trial 2.

<u>Trial 2, Day 3:</u>

Figures 84, 85 and 86 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 3 of Trial 2. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 3 of Trial 2.

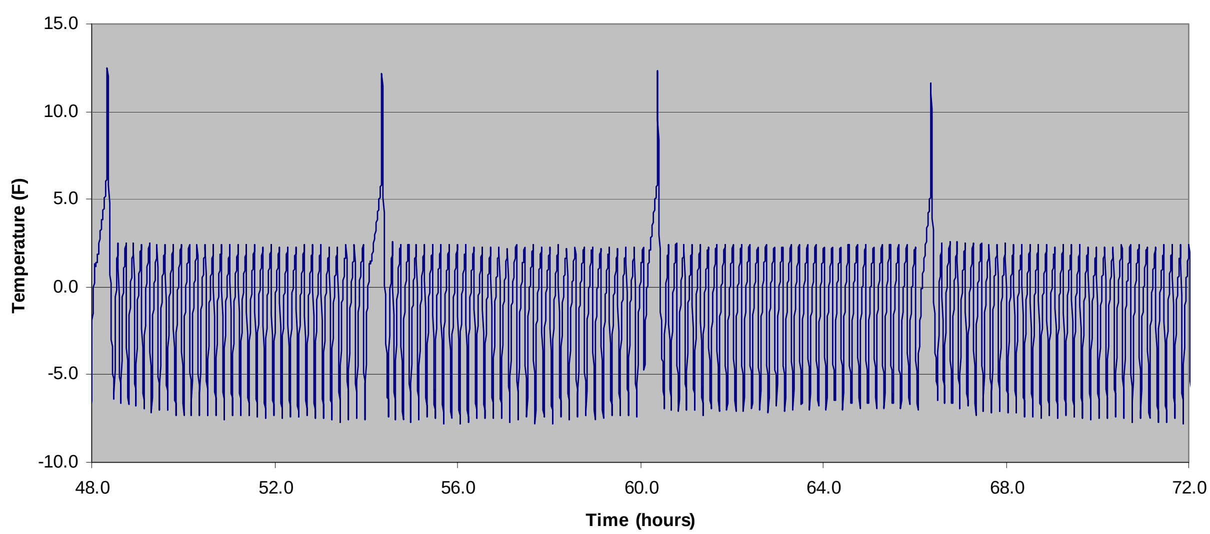


Figure 84. Walk-In Freezer Internal Temperature during Day 3 of Trial 2.

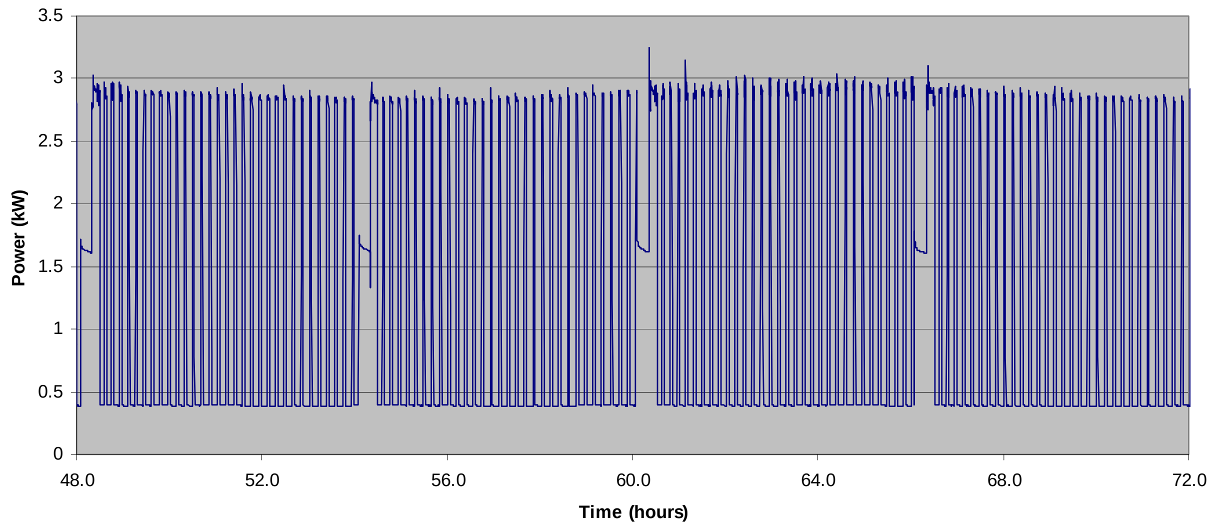


Figure 85. Power Consumption of the Walk-In Freezer during Day 3 of Trial 2.

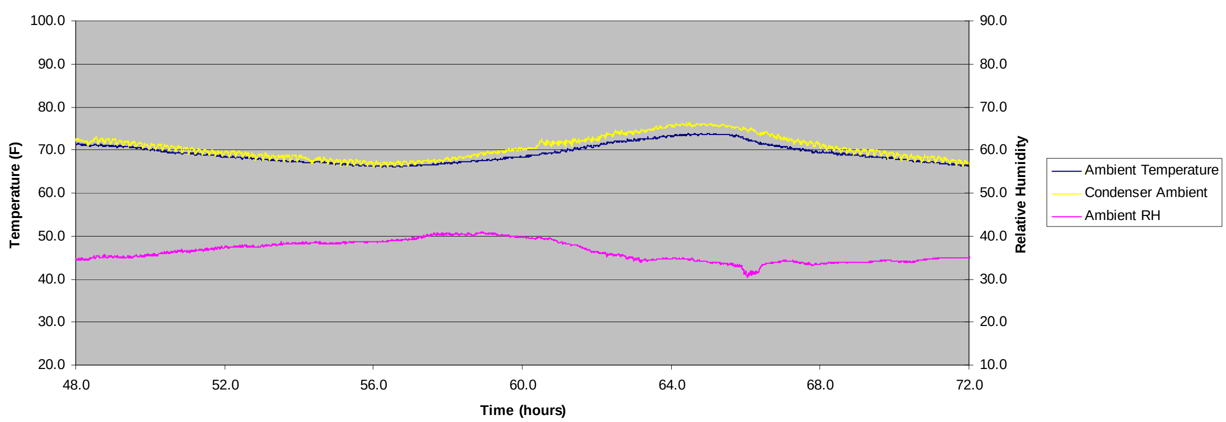


Figure 86. Ambient Conditions Surrounding the Walk-In Freezer during Day 3 of Trial 2.

Trial 2, Day 4:

Figures 87, 88 and 89 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 4 of Trial 2. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 4 of Trial 2.

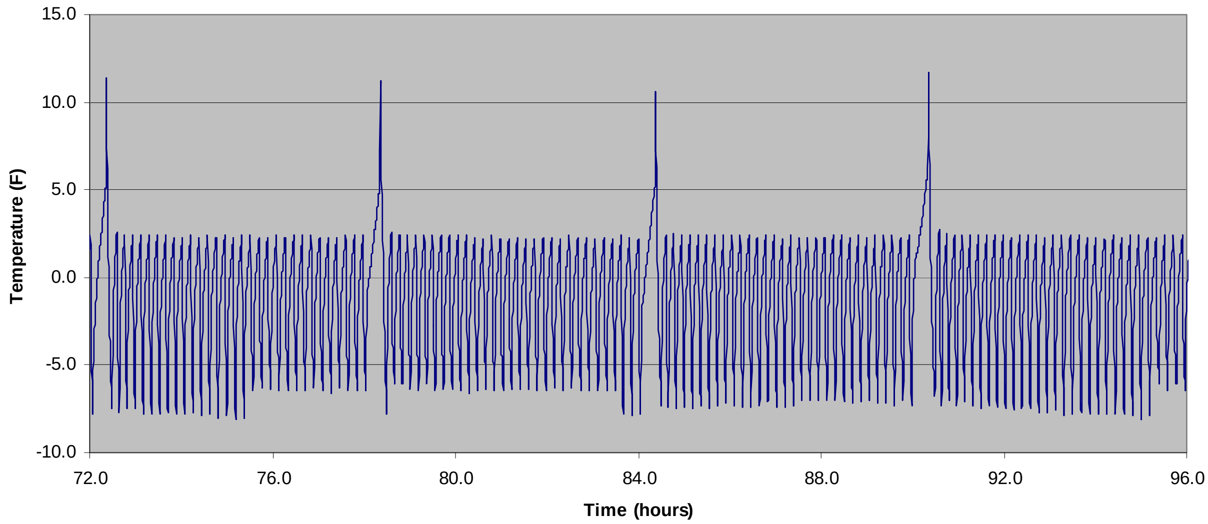


Figure 87. Walk-In Freezer Internal Temperature during Day 4 of Trial 2.

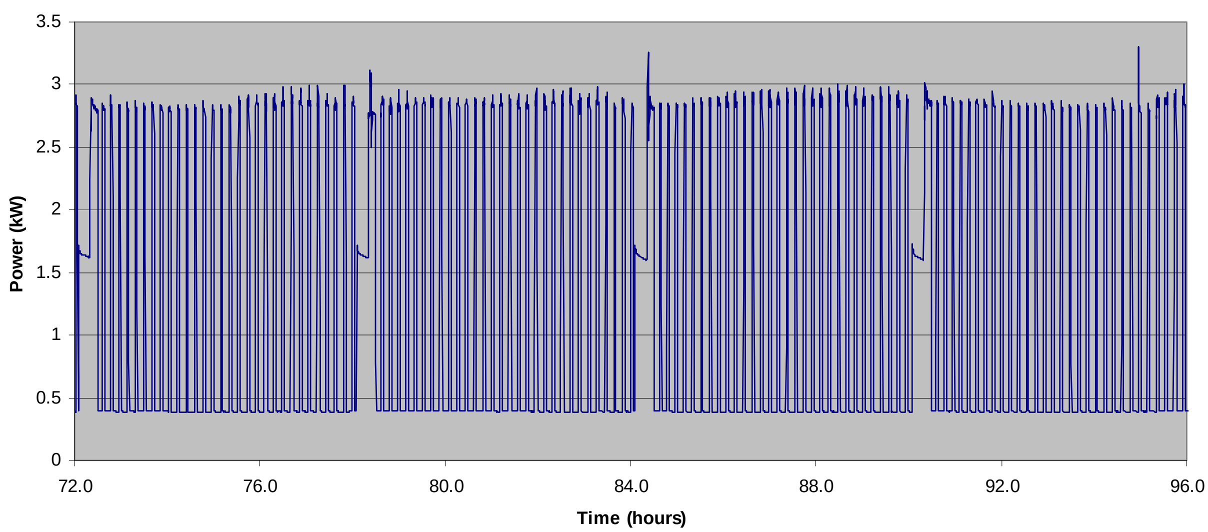


Figure 88. Power Consumption of the Walk-In Freezer during Day 4 of Trial 2.

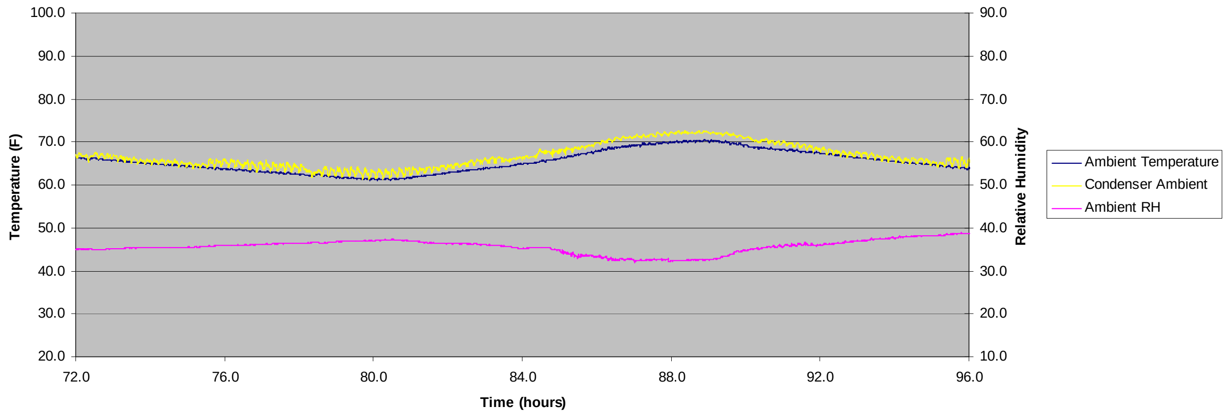


Figure 89. Ambient Conditions Surrounding the Walk-In Freezer during Day 4 of Trial 2.

Trial 2, Day 5:

Figures 90, 91 and 92 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 5 of Trial 2. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 5 of Trial 2.

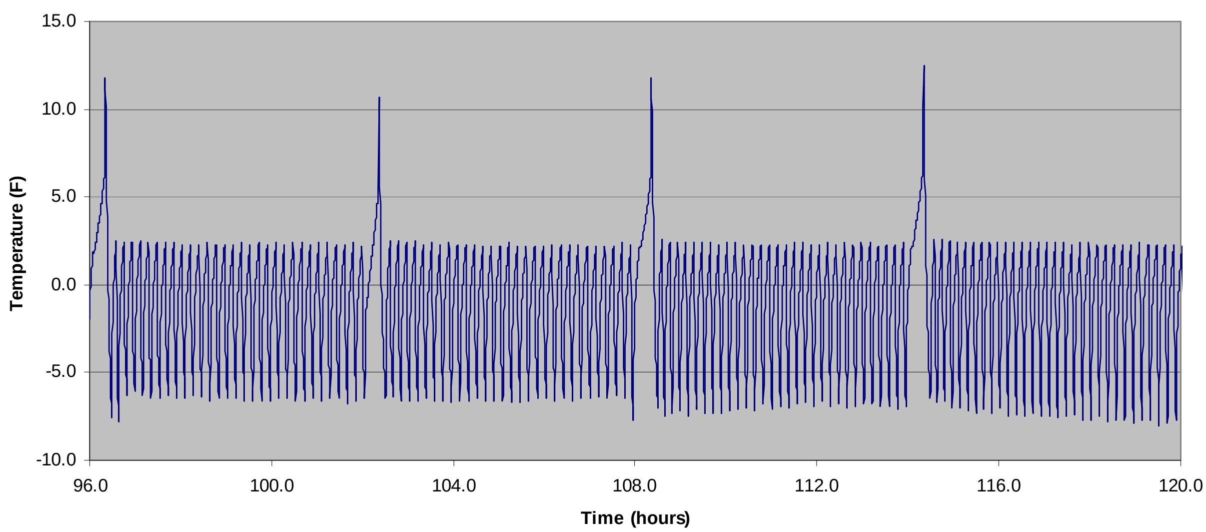


Figure 90. Walk-In Freezer Internal Temperature during Day 5 of Trial 2.

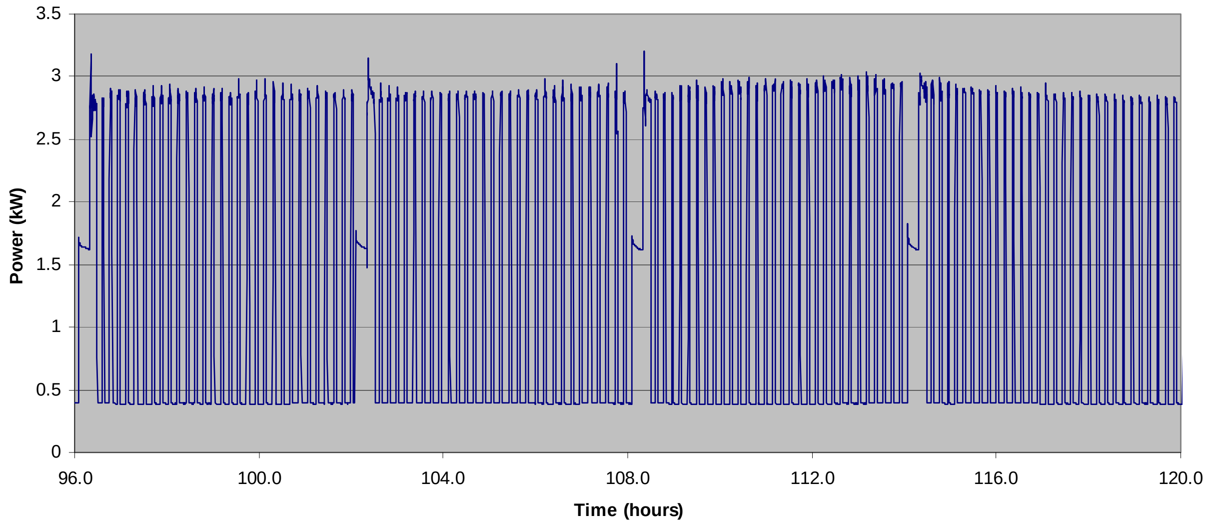


Figure 91. Power Consumption of the Walk-In Freezer during Day 5 of Trial 2.

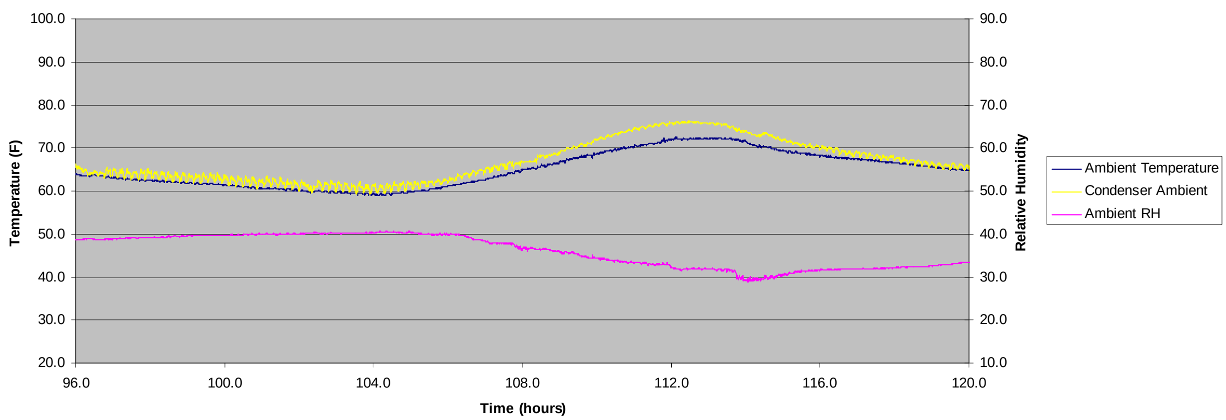


Figure 92. Ambient Conditions Surrounding the Walk-In Freezer during Day 5 of Trial 2.

Trial 2, Day 6:

Figures 93, 94 and 95 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 6 of Trial 2. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 6 of Trial 2.

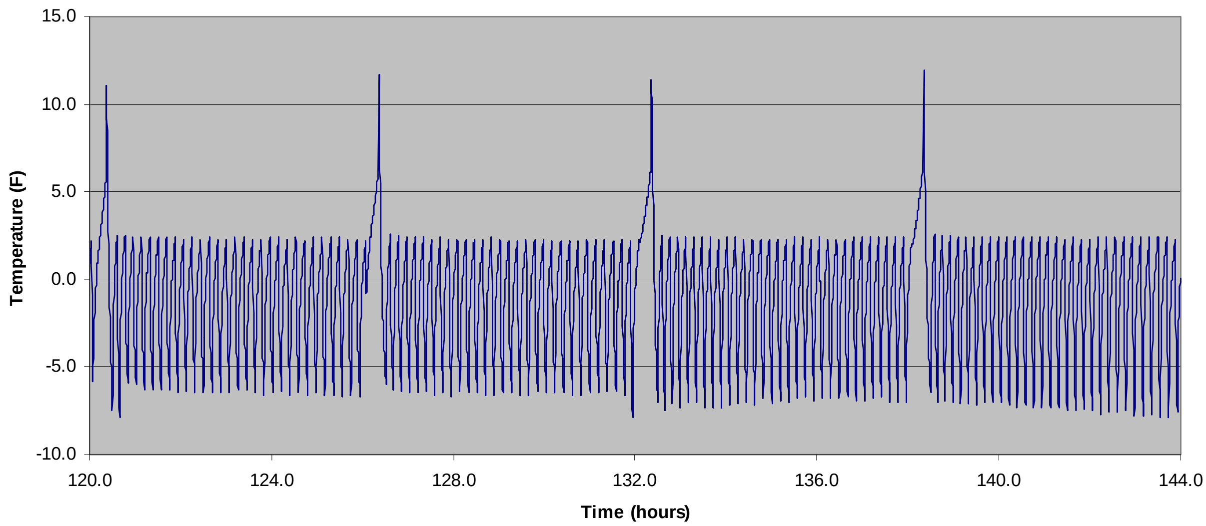


Figure 93. Walk-In Freezer Internal Temperature during Day 6 of Trial 2.

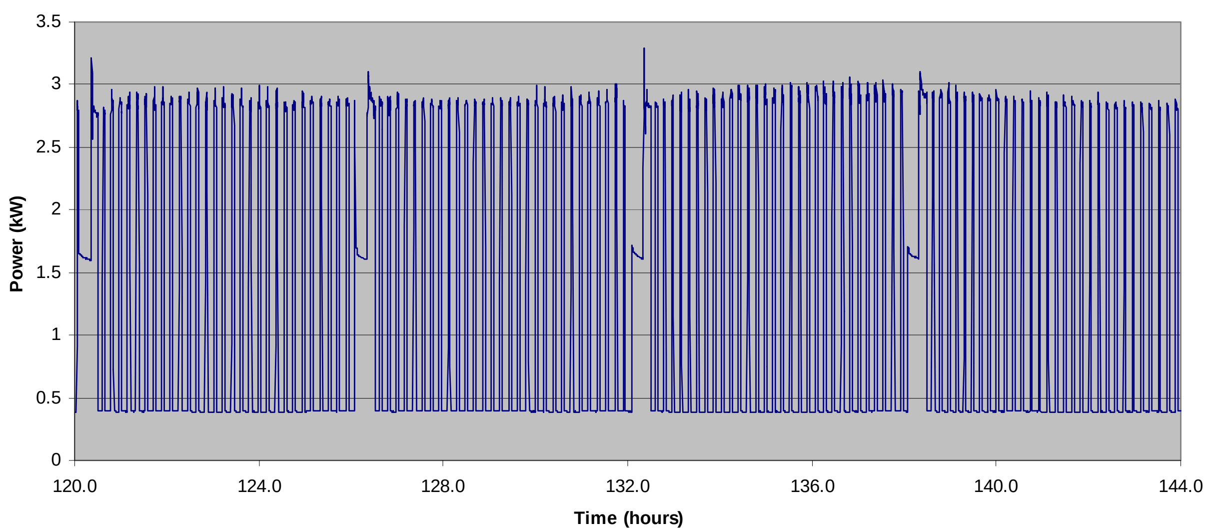


Figure 94. Power Consumption of the Walk-In Freezer during Day 6 of Trial 2.

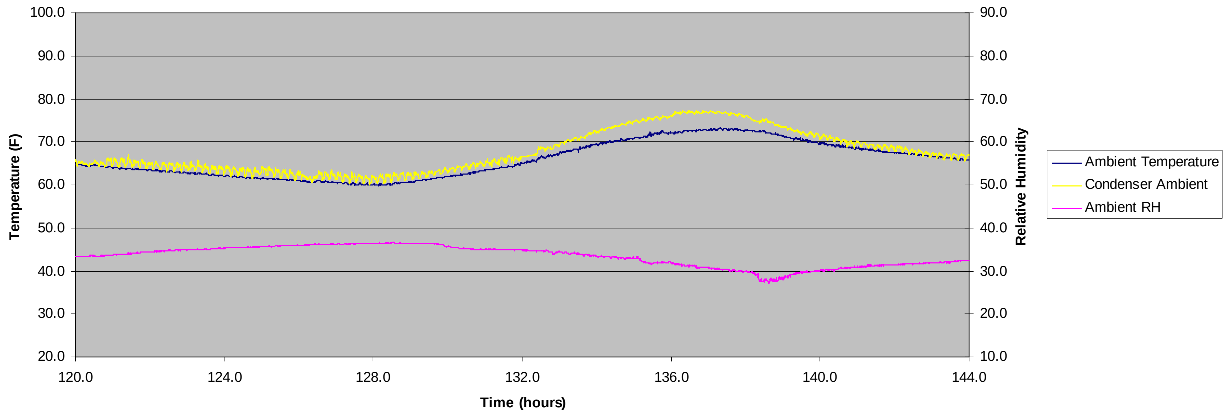


Figure 95. Ambient Conditions Surrounding the Walk-In Freezer during Day 6 of Trial 2.

Trial 3, Day 1:

Figure 96 shows the walk-in freezer internal temperature during Day 1 of Trial 3. Figure 97 shows the corresponding power consumption. Note that four defrost cycles, as well as two door openings with product loadings, occurred during Day 1 of Trial 3. The door openings with product loadings can be seen as the 35°F and 40°F temperature spikes at approximately 15:20 hours and 21:10 hours.

Figure 98 shows the ambient conditions surrounding the walk-in freezer. For Trial 3, the ambient conditions near the condenser, averaged over the entire test period, were nominally 75°F (24°C), 55% RH.

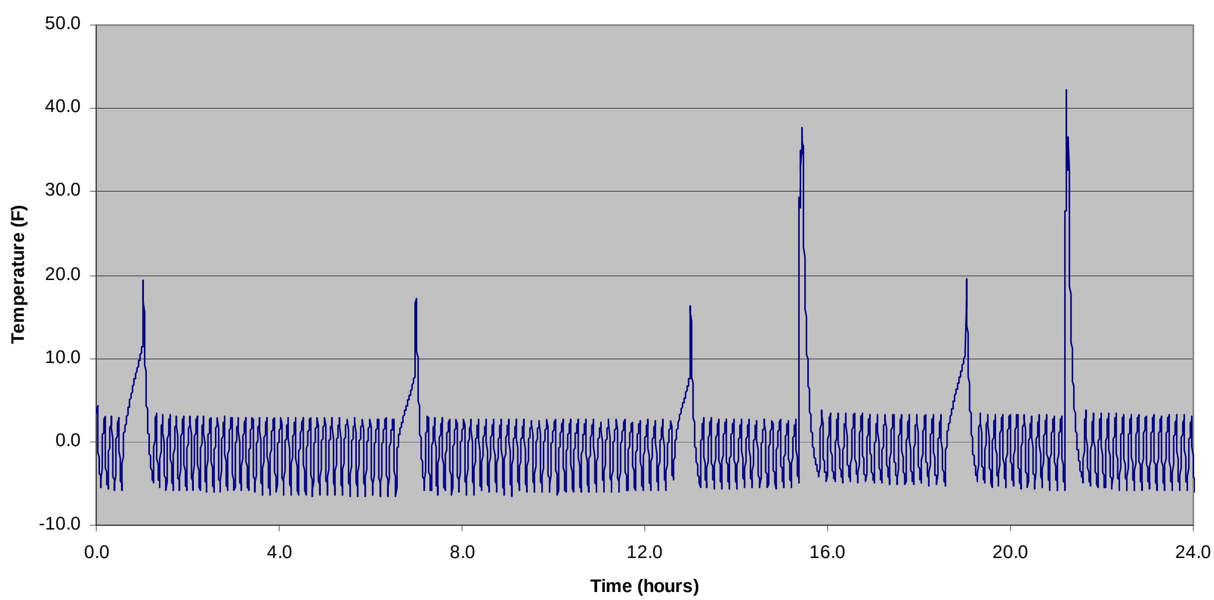


Figure 96. Walk-In Freezer Internal Temperature during Day 1 of Trial 3.

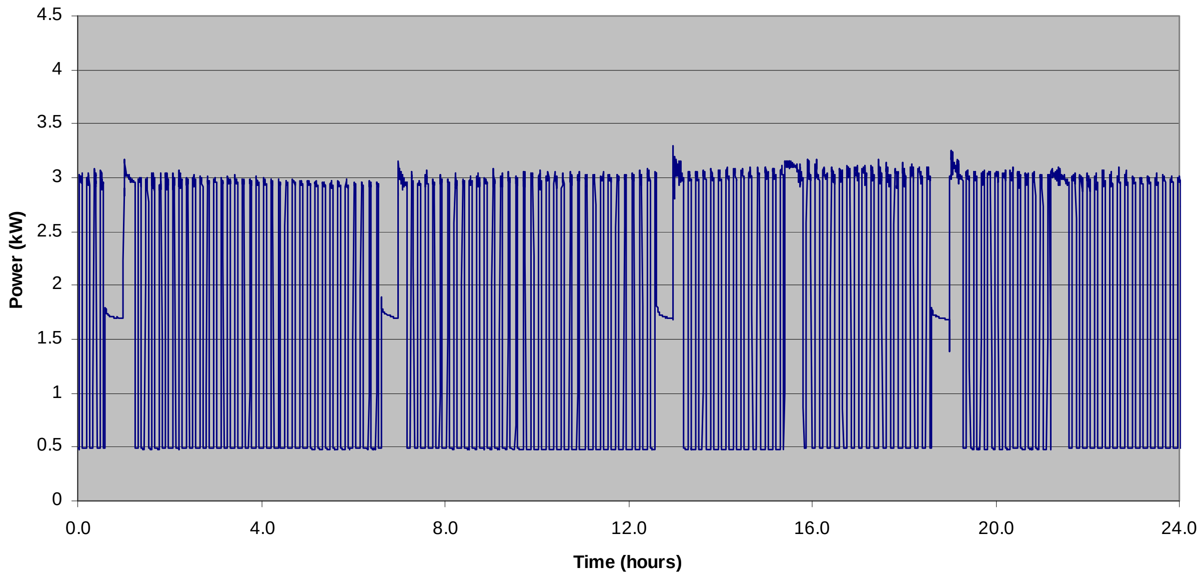


Figure 97. Power Consumption of the Walk-In Freezer during Day 1 of Trial 3.

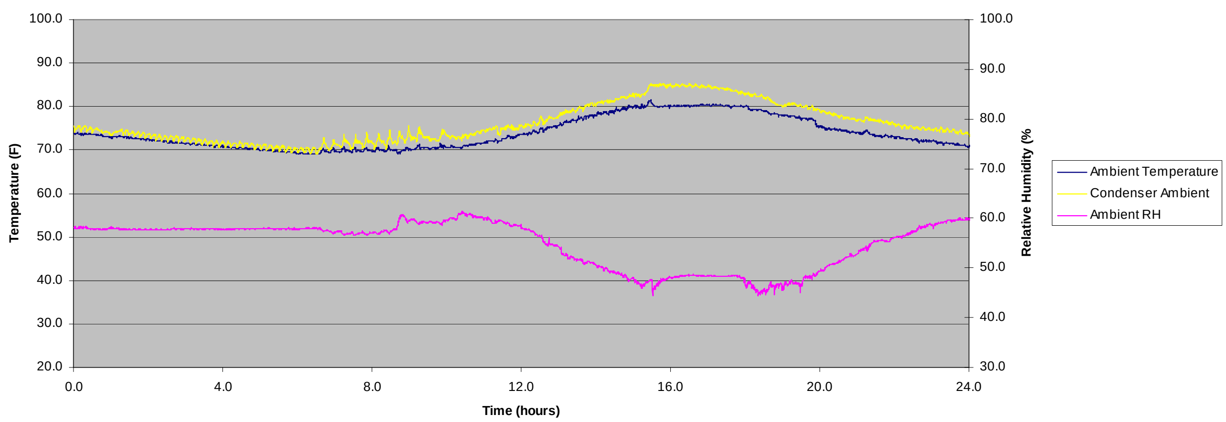


Figure 98. Ambient Conditions Surrounding the Walk-In Freezer during Day 1 of Trial 3.

Trial 3, Day 2:

Figures 99, 100 and 101 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 2 of Trial 3. Note that four defrost cycles occurred and no door openings or product loadings occurred during Day 2 of Trial 3.

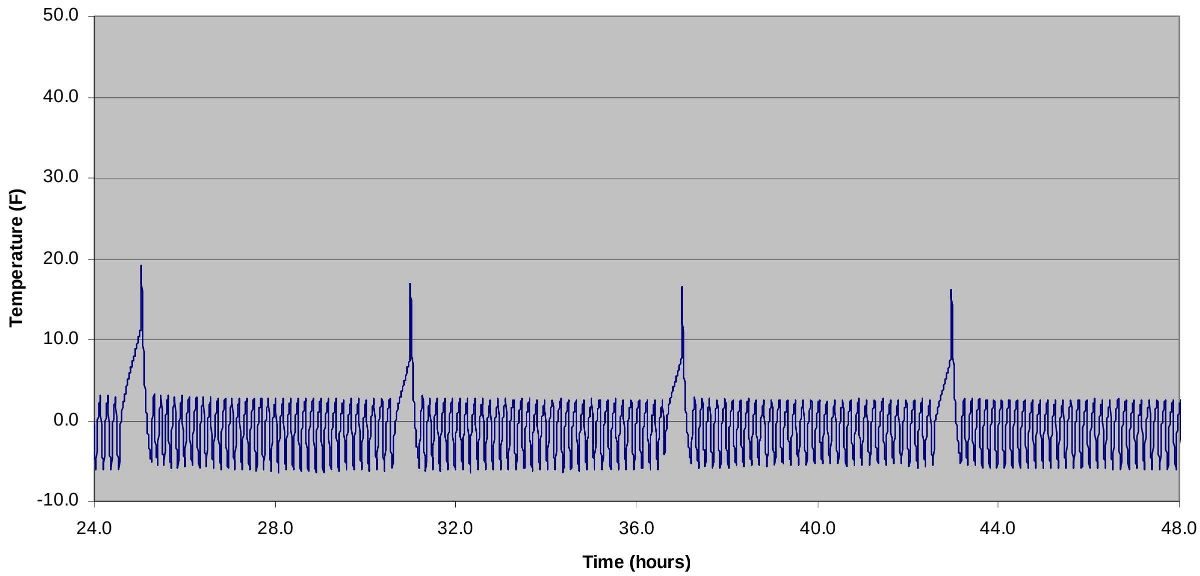


Figure 99. Walk-In Freezer Internal Temperature during Day 2 of Trial 3.

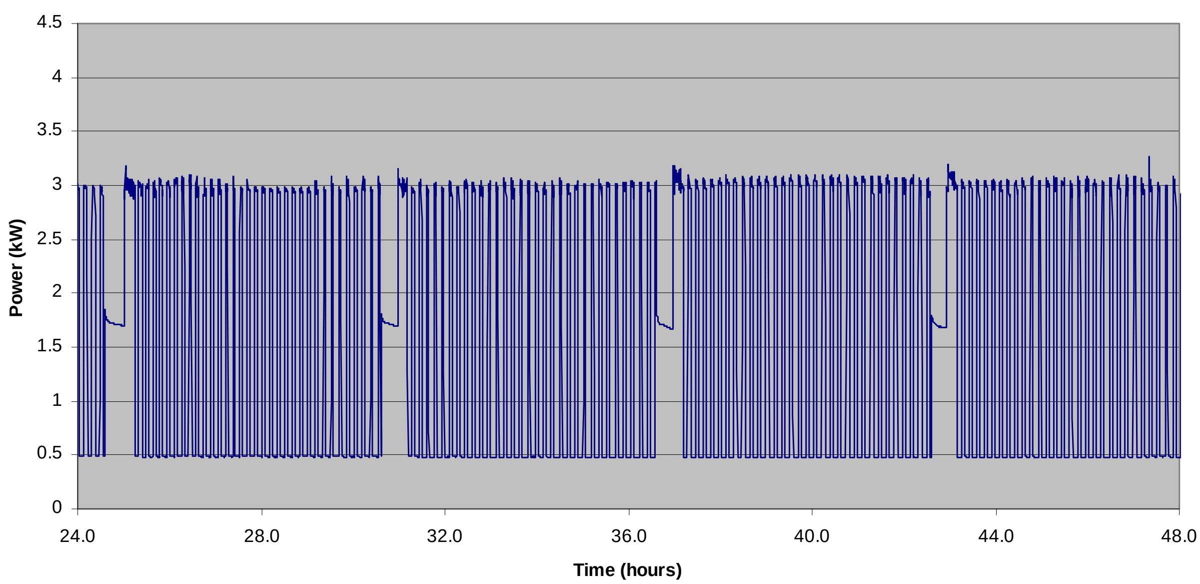


Figure 100. Power Consumption of the Walk-In Freezer during Day 2 of Trial 3.

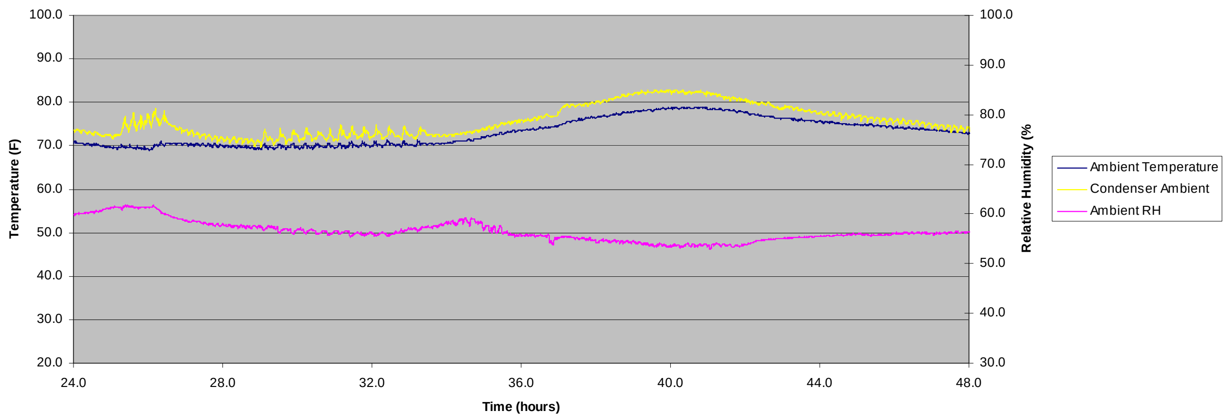


Figure 101. Ambient Conditions Surrounding the Walk-In Freezer during Day 2 of Trial 3.

Trial 3, Day 3:

Figures 102, 103 and 104 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 3 of Trial 3. Note that four defrost cycles, as well as two door openings with product loadings, occurred during Day 3 of Trial 3. The door openings with product loadings can be seen as the 35°F temperature spikes at approximately 58:15 hours and 62:15 hours.

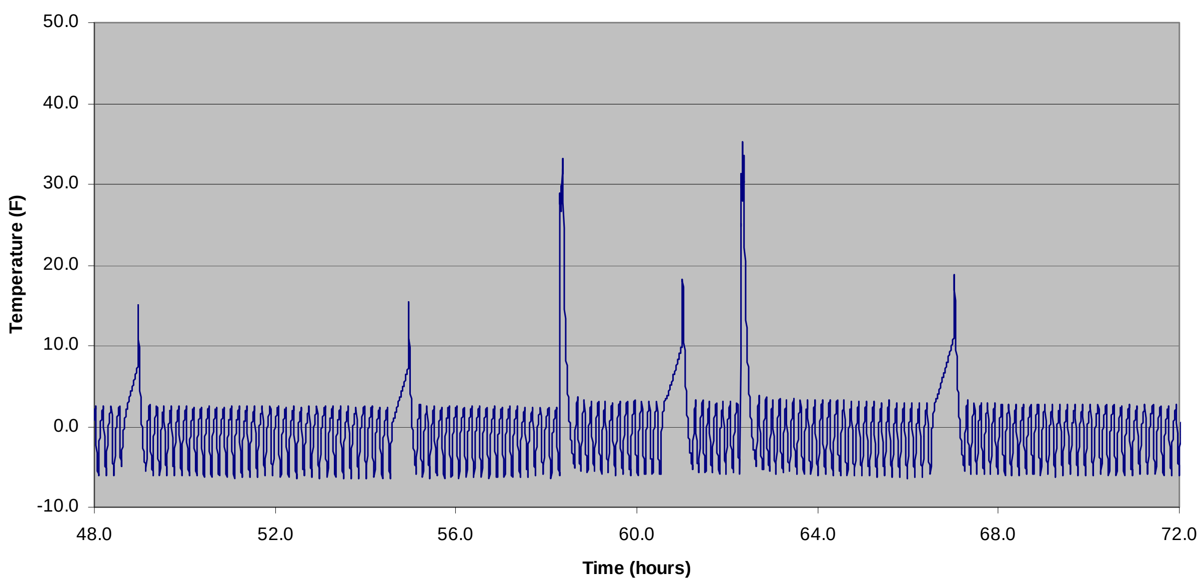


Figure 102. Walk-In Freezer Internal Temperature during Day 3 of Trial 3.

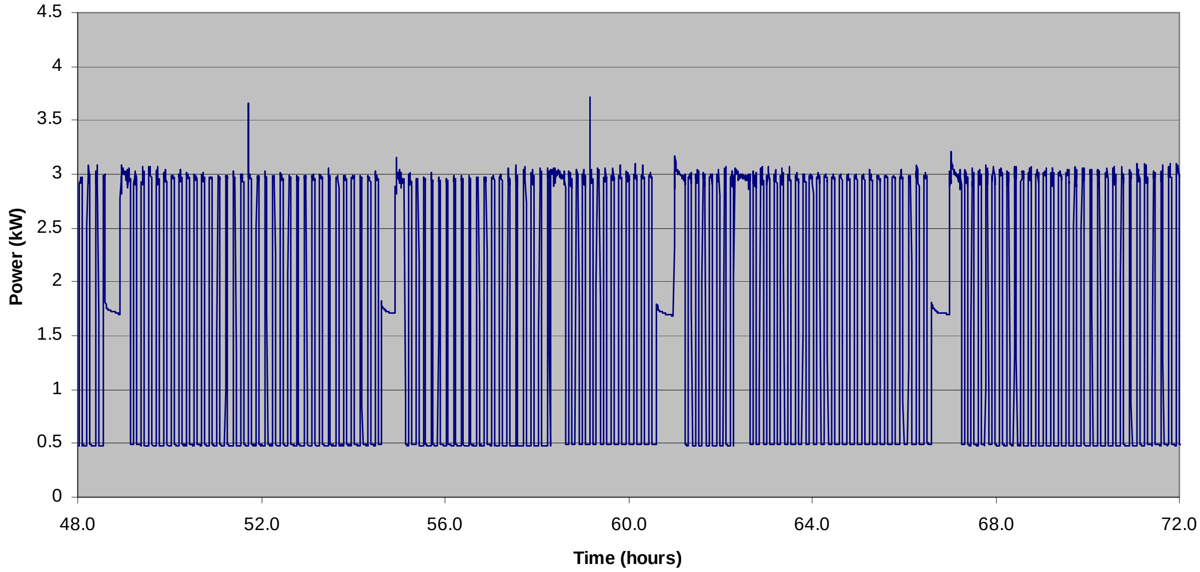


Figure 103. Power Consumption of the Walk-In Freezer during Day 3 of Trial 3.

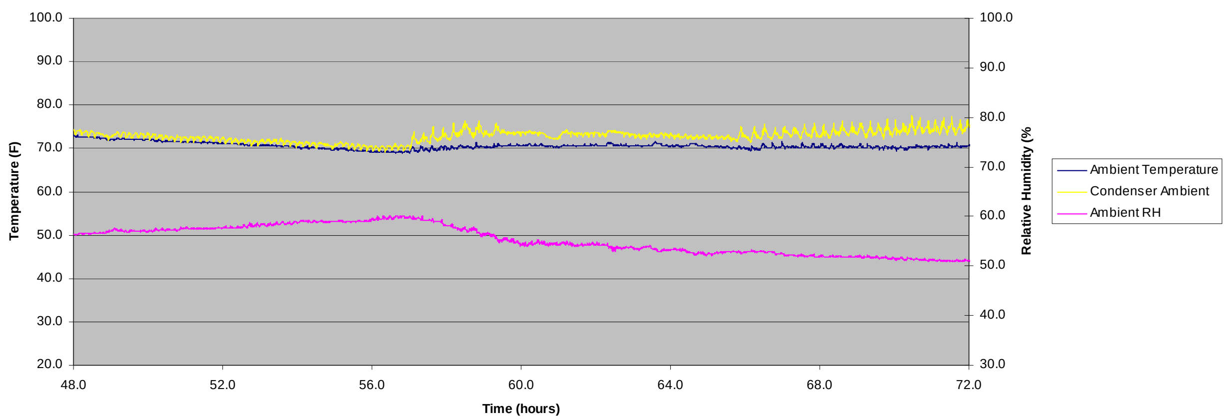


Figure 104. Ambient Conditions Surrounding the Walk-In Freezer during Day 3 of Trial 3.

Trial 3, Day 4:

Figures 105, 106 and 107 show the walk-in freezer internal temperature, corresponding power consumption and the ambient conditions surrounding the walk-in freezer, respectively, during Day 4 of Trial 3. Note that four defrost cycles, as well as two door openings with product loadings, occurred during Day 4 of Trial 3. The door openings with product loadings can be seen as the 35°F temperature spikes at approximately 82:15 hours and 88:15 hours.

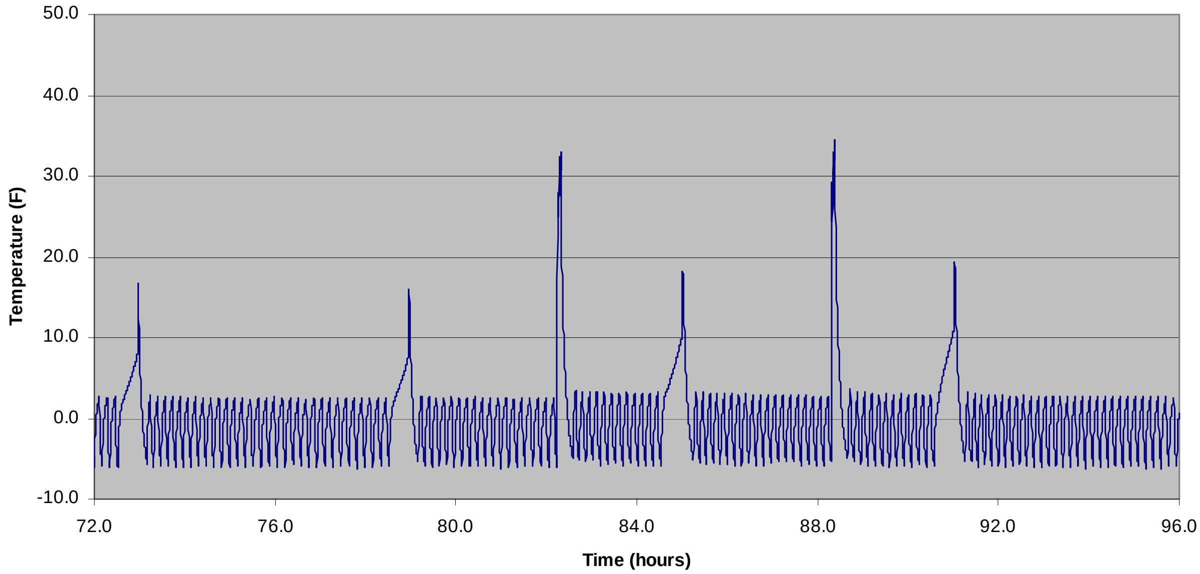


Figure 105. Walk-In Freezer Internal Temperature during Day 4 of Trial 3.

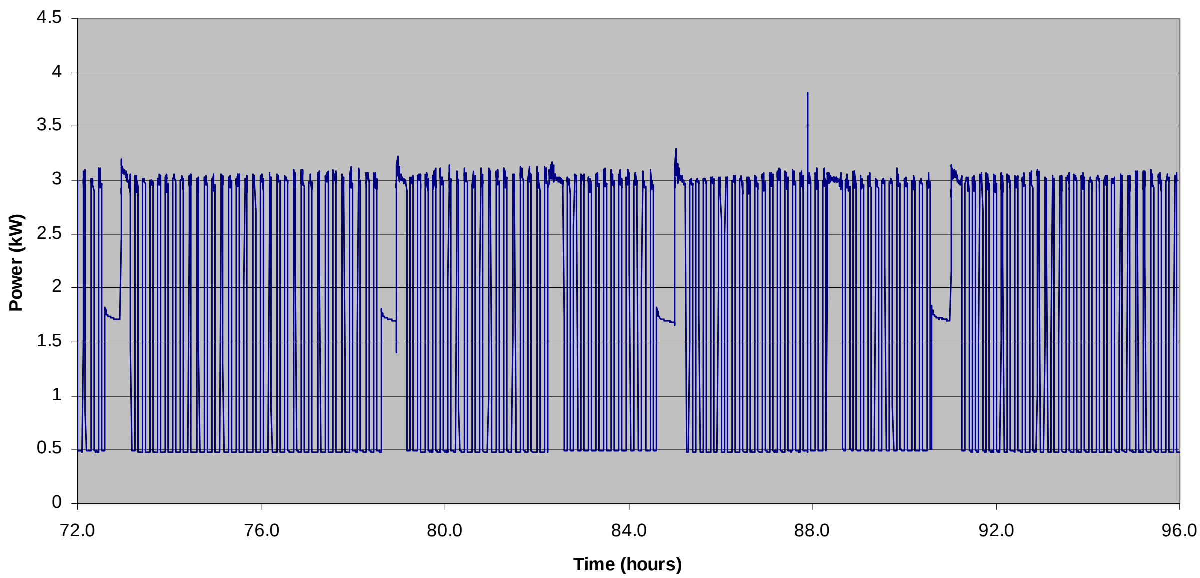


Figure 106. Power Consumption of the Walk-In Freezer during Day 4 of Trial 3.

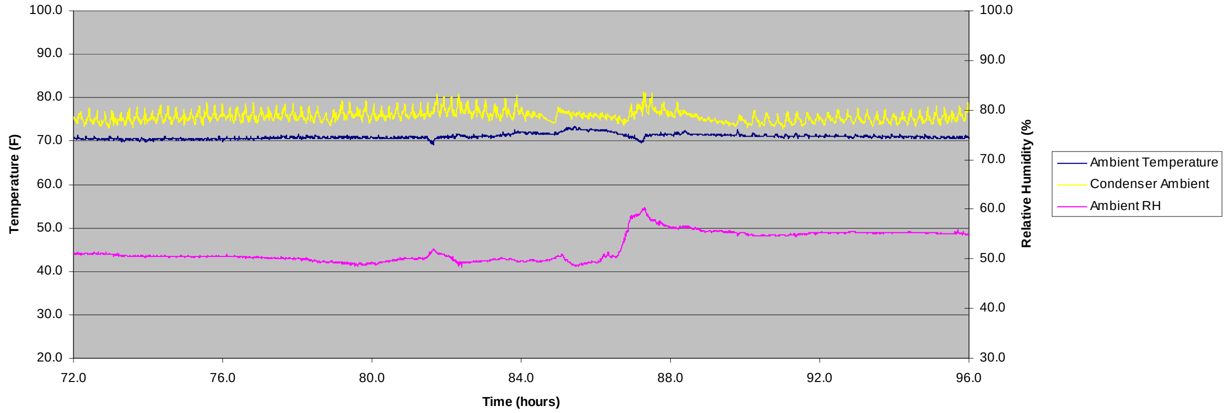


Figure 107. Ambient Conditions Surrounding the Walk-In Freezer during Day 4 of Trial 3.

Appendix D: Specifications of Prototypical Walk-In Cooler

Dimensions: 15.8 ft × 15.8 ft × 12 ft
Floor Area: 249.6 ft^2
Volume: 2996 ft^3

Box Internal Air Temperature: 35°F

Wall/Roof/Floor Construction (Insulated Sandwich Panel):
0.06 in. thick steel siding (exterior surface)
6 in. thick polystyrene, R-5/in.
0.06 in. thick steel siding (interior surface)
U-Value: 0.031 $Btu/hr \cdot ft^2 \cdot °F$

Doors:
Number of Doors: 1
Location of Doors: South Wall
Size: 7 ft × 4 ft
0.06 in. thick steel siding (exterior surface)
6 in. thick polystyrene, R-5/in.
0.06 in. thick steel siding (interior surface)
U-Value: 0.031 $Btu/hr \cdot ft^2 \cdot °F$

Occupancy:
- Number of People: 1
- Heat Gain: 450 Btu/hr·person (default value)
- Sensible: 250 Btu/hr·person (default value)
- Latent: 200 Btu/hr·person (default value)
- Occupancy Schedule:
  - One person in walk-in for 4.8 minutes per hour from 8:00am to 6:00pm, Monday thru Saturday
  - One person in walk-in for 2.4 minutes per hour from 10:00am to 6:00pm, Sunday

Infiltration:
- Method: Air Change
- Air Changes per Hour: 0.4 (Heatcraft)
- Infiltration Schedule:
  - 0.4 air changes per hour from 12:00am to 8:00am and 6:00pm to 11:59pm, Monday thru Saturday
  - 0.44 air changes per hour from 8:00am to 6:00pm, Monday thru Saturday
  - 0.4 air changes per hour from 12:00am to 10:00am and 6:00pm to 11:59pm, Sunday
  - 0.44 air changes per hour from 10:00am to 6:00pm, Sunday

Lighting:
- Power Density: 1 W/ft^2 (Heatcraft)
- Total Power: 0.25 kW

Fraction of Light Heat: 0.8
Lighting Schedule:
Lights on for 4.8 minutes per hour from 8:00am to 6:00pm, Monday thru Saturday
Lights on for 2.4 minutes per hour from 10:00am to 6:00pm, Sunday

Refrigerant: R-22

Compressor:
Model: Carlyle 5F20
Type: Semi-Hermetic
Performance: Capacity and Power Maps for 5F20 from eQUEST Library
Rated Performance: 678 lb/hr, 5.190 kW @ 10°F SST, 100°F SDT (Carlyle)

Evaporator:
Model: Krack KR66A-310
System Type: Packaged Variable Volume Variable Temperature (PVVT)
Cooling Capacity: 31,000 Btu/hr (Krack)
Minimum Supply Temperature: 30°F
Cooling Control Range: 5°F
Saturated Suction/Air Temperature Difference: 10°F
Return Air Path: Direct
Rated Supply Flow: 5070 CFM (Krack)
Number of Fans: 6
Total Fan Power: 444 W (0.6 hp)
Fan Schedule: On Continuously

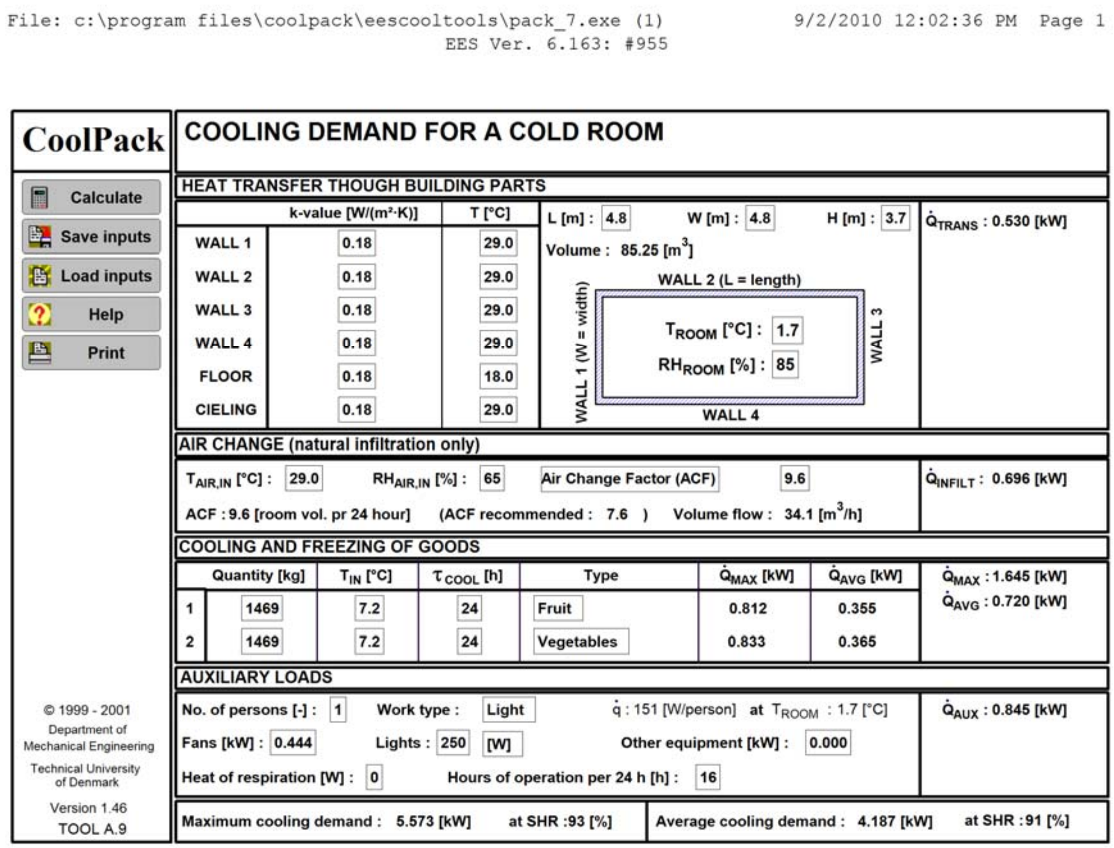
Condenser:
Model: Bohn BRH023
Type: Air-cooled
Rated Capacity: 339,000 Btu/hr @ 30°F Temperature Differential (Bohn)
Number of Fans: 2 (Bohn)
Power per Fan: 1.12 kW (Bohn)
Rated Airflow: 23,000 CFM (Bohn)
Fan Modulation: Cycle On/Off
Refrigerant Pressure Drop: 3 psig (default value)

Product Loading:
Product Type: Fruit/Vegetable
Product Loading: 6480 lb/day (270 lb/hr)
Product ΔT: 10°F
Pulldown Time: 24 hours
Product Specific Heat: 0.79 Btu/lb·°F
Product Heat Load: 2133 Btu/hr

Appendix E: Results from Various Load Calculation Methods for the Prototypical Walk-In Cooler

Input and output data from several load calculation methods are presented below for the Prototypical Walk-In Cooler.

<u>CoolPack (IPU, Denmark):</u>



File: c:\program files\coolpack\eescooltools\pack_7.exe (1)   9/2/2010 12:02:36 PM Page 1
EES Ver. 6.163: #955

CoolPack

COOLING DEMAND FOR A COLD ROOM

Calculate
Save inputs
Load inputs
Help
Print

HEAT TRANSFER THOUGH BUILDING PARTS

	k-value [W/(m²·K)]	T [°C]
WALL 1	0.18	29.0
WALL 2	0.18	29.0
WALL 3	0.18	29.0
WALL 4	0.18	29.0
FLOOR	0.18	18.0
CIELING	0.18	29.0

L [m] : 4.8 W [m] : 4.8 H [m] : 3.7
Volume : 85.25 [m³]
WALL 2 (L = length)
WALL 1 (W = width)
WALL 3
WALL 4
T_{ROOM} [°C] : 1.7
RH_{ROOM} [%] : 85

$\dot{Q}_{TRANS}$: 0.530 [kW]

AIR CHANGE (natural infiltration only)

$T_{AIR,IN}$ [°C] : 29.0 $RH_{AIR,IN}$ [%] : 65 Air Change Factor (ACF) 9.6
ACF : 9.6 [room vol. pr 24 hour] (ACF recommended : 7.6) Volume flow : 34.1 [m³/h]

$\dot{Q}_{INFILT}$: 0.696 [kW]

COOLING AND FREEZING OF GOODS

	Quantity [kg]	T_{IN} [°C]	τ_{COOL} [h]	Type	$\dot{Q}_{MAX}$ [kW]	$\dot{Q}_{AVG}$ [kW]
1	1469	7.2	24	Fruit	0.812	0.355
2	1469	7.2	24	Vegetables	0.833	0.365

$\dot{Q}_{MAX}$: 1.645 [kW]
$\dot{Q}_{AVG}$: 0.720 [kW]

AUXILIARY LOADS

No. of persons [-] : 1 Work type : Light $\dot{q}$: 151 [W/person] at T_{ROOM} : 1.7 [°C]
Fans [kW] : 0.444 Lights : 250 [W] Other equipment [kW] : 0.000
Heat of respiration [W] : 0 Hours of operation per 24 h [h] : 16

$\dot{Q}_{AUX}$: 0.845 [kW]

Maximum cooling demand : 5.573 [kW] at SHR :93 [%] Average cooling demand : 4.187 [kW] at SHR :91 [%]

Department of Mechanical Engineering
Technical University of Denmark
Version 1.46
TOOL A.9

Using the *CoolPack* software from IPU, Denmark, a maximum cooling demand of 19,000 Btu/hr (5.573 kW) was calculated for the prototypical walk-in cooler.

Refrigeration Load Calculator (Emerson Climate Technologies):

Emerson Climate Technologies
Refrigeration Box Load Analysis
Sep-27-10

General Information	
Project Title:	Walk-In Cooler Test
Designed By:	
Project Location:	Los Angeles, GA
Address:	
City / State:	Los Angeles, GA
Zip Code:	
Phone:	
Fax:	
Load Estimation Method:	Detailed

Design Conditions	
Weather City:	Los Angeles, GA
Latitude / Longitude:	33.92N / 118.4W
Elevation (ft):	105
Standard Pressure (psia):	14.6
Outdoor Design DB/WB (°F):	80.4 / 64.5
Application:	Walk-In Cooler
Box Location:	Indoors
Dimensions:	15.75'L x 15.75'W x 12.0'H
Insulation (Walls and Ceiling):	6" Molded Polystyrene
Insulation (Floor):	6" Molded Polystyrene
Box Shape:	Rectangular
Surrounding Air DB/WB (°F):	90.0 / 75.1
Box DB/WB (°F):	35.0 / 31.4
Box to Evap. TD (°F):	10.0
System Run Time (hr):	16

Refrigeration Load	
Total Load (Btu/hr):	19,674
Safety Factor (%):	10

Product Load	
Load (Btu/hr):	86,586

Infiltration Load	
Air Change Method (Btu/hr):	2,358

Glass Door Load	
Glass Doors (Btu/hr):	--

Miscellaneous Load	
Lighting (W/ft²):	1
Motors (HP):	0.08
People:	1
Equipment:	0

Condensing Unit: Emerson Climate Technologies	
Model:	F3AD-B151-CFV-020
Refrigerant:	R-22
Number of Units:	1
Evaporator Temp. (°F):	25
Capacity (Btu/hr):	11,300
Power (W) / EER (Btu/Wh):	1,550 / 7.3
Size:	24.0"L x 18.3"W x 16.3"H
Liquid Conn. Size/Type:	3/8", Flare
Suction Conn. Size/Type:	7/8", Sweat
Electrical:	208/230V / 60Hz, 1 Phase
Max. Fuse Size (Amps):	20
Min. Circuit Ampacity:	14.2

Condensing Unit Features: F3AD-B151-CFV-020	
Accumulator:	--
Condenser End Covers:	Yes
Conduit:	Yes
Fan Guard:	Yes
Filter-Drier:	--
Pressure Controls:	Yes
Receiver:	Yes
Shut Off Valves:	Yes
Sight Glass/Moisture Indicator:	--
Liquid Solenoid Valve:	--
Fan Cycle Control:	Yes
Discharge Line Thermostat:	Yes
Variable Speed Fan Control:	--
Performance Alert Diagnostics:	--
Liquid Injection:	--
Vapor Injection:	--
Defrost Timer:	--
Water Valve:	--
Crank Case Heater:	--
Oil Separator:	--
UL Status:	Yes

Evaporator: Russell (Type: Air Defrost)	
Model:	AA28-134B
Box to Evap. TD (°F):	10.0
Capacity (Btu/hr):	14,400
Air Flow Rate (ft³/min):	1480
Fin Density (fins/in):	8
Electrical:	208/230V / 60Hz, 1 Phase / 2A
Size:	45-1/2"L x 15"W x 15-1/4"H

Defrost Heater: Russell (Type: Air Defrost)	
Power (W):	--
Electrical:	--

TXV: Emerson Climate Technologies	
Model:	HFES-1-HC
Type:	Balanced Port

Using the *Refrigeration Load Calculator*, a total load of 19,674 Btu/hr was calculated for the prototypical walk-in cooler.

Calc-Rite Load Program (KeepRite Refrigeration):

NATIONAL REFRIGERATION & AIR CONDITIONING CANADA CORP.
KeepRite Refrigeration
159 Roy Boulevard (P.O. Box 2020)
Brantford, Ontario
Canada, N3T 5Y6
Contact Name:
Telephone: (519) 751-0444 / 800-463-9517
Ext:
Fax: (519) 753-1140
Email: info@k-rp.com
Internet: www.k-rp.com

Calc-Rite LOAD PROGRAM By KeepRite

CUSTOMER INFO

,
,
Telephone:
Fax:
Contact:
Ext:
E-Mail:

JOB INFO

Reference:

Description:

Ambient Temp:	90	ºF	Length:	15.8	ft
Box Temp:	35	ºF	Width:	15.8	ft
Box Location	Outdoors		Height:	12	ft
			System Run-Time:	16	hrs

WALL LOAD

See details on page 2.

Total Wall Load: 3286 BTU/h

PRODUCT LOAD

See details on page 2.

Total Product Load: 5751 BTU/h

INFILTRATION LOAD

Average Infiltrating Air Temperature. 90 ºF

ESTIMATED INFILTRATION

Usage	Regular	
Infiltration Load 1:	3940	BTU/h

ESTIMATED BY DOOR OPENINGS

Number Of Doors:	1	
Average Door Width:	4	ft
Average Door Height:	7	ft
Hours Open Per 24 Hours:	0.8	hrs
Ventilation RH:	55	%
Infiltration Load 2:	2513	BTU/h

ESTIMATED BY VENTILATION RATE

Ventilation Rate:	0	cfm
Ventilation RH:	55	%
Infiltration Load 3:	0	BTU/h

Number Of Glass Doors:	0	Load:	0	BTU/h
Number Of Dock Doors:	0	Load:	0	BTU/h

Total Infiltration Load: 2513 BTU/h

Estimated based on door openings.

MISCELLANEOUS LOAD

LIGHTING	1	W/sq.ft.	249.64	W	2	hrs
MOTORS	6		0.1	Hp	24	hrs
PERSONNEL			1		0.8	hrs
FORKLIFTS			0		0	hrs

OTHER LOADS

0	W	0	hrs
0	W	0	hrs
0	W	0	hrs
0	W	0	hrs

Total Miscellaneous Load: 6651 BTU/h

REQUIREMENT SUMMARY

Load Requirement + 10 % 20021 BTU/h

Cond. Unit Amb:	95	ºF
Box Temp:	35	ºF
Design TD:	10	ºF
Refrigerant Type:	R-22	
Cond. Unit Location:	Outdoors	

CONDENSING UNIT SELECTION

Number Of Condensing Units:	1	
Condensing Unit Type:	K (Semi-Herm Copeland)	
Condensing Unit Voltage:	208-230 / 3 / 60	
Cond Temp:		ºF
Condensing Unit Model No:	K300M8-HT3A	
	25330	BTU/h

UNIT COOLER SELECTION

Number of Unit Coolers:	1	
Unit Cooler (Evaporator) Type:	Med Profile - Med Temp AD 6FPI	
Unit Cooler Voltage:	208-230 / 3 / 60	
Unit Cooler Model No:	No Unit Selected	
	0	W

SYSTEM BALANCE

Total System Capacity:	0	BTU/h
TD:	0	ºF
S.S.T.:	0	ºF

Equipment selection is sized to meet capacity requirement solely from data and conditions provided by the user

Page 1 of 2 C:\Program Files\NationalRefrigeration\KeepRite\Calc-Rite\JobFiles\ARTI eQUEST Example.lck 9/27/2010 1:14:26 PM

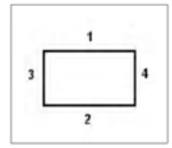
Calc-Rite LOAD PROGRAM By KeepRite

Reference:

Description:

WALL LOAD

SHAPE	**Rectangular**
Volume:	**2995.68** ft³
Total Wall Load:	**3286** BTU/h



	Type	Length ft	Height / Width ft	Section Area ft²	Thickness in	Insulation	K - Factor	External Temp ºF	Wall Load BTU/h
1	Wall	15.8	12	189.6	6	Expanded Polystyrene (extruded)	0.2	94	559
2	Wall	15.8	12	189.6	6	Expanded Polystyrene (extruded)	0.2	94	559
3	Wall	15.8	12	189.6	6	Expanded Polystyrene (extruded)	0.2	94	559
4	Wall	15.8	12	189.6	6	Expanded Polystyrene (extruded)	0.2	94	559
5	Floor	15.8	15.8	249.64	6	Expanded Polystyrene (extruded)	0.2	55	249
6	Ceiling	15.8	15.8	249.64	6	Expanded Polystyrene (extruded)	0.2	99	798

PRODUCT LOAD

	Product	Type	Weight lb	Entering Temp ºF	Final Temp ºF	Pull-Down Time hrs	Spc. Heat Above Btu/lb.	Spc. Heat Below Btu/lb.	Product Load BTU/h
1	Produce, Vegetables	Beans, snap	6480	45	35	24	0.94	0.57	5751
2									0

Total Product Weight: **6480** lb **Total Product Load:** **5751** BTU/h

C:\Program Files\NationalRefrigeration\KeepRite\Calc-Rite\JobFiles\ARTI eQUEST Example.lck 9/27/2010 1:14:27 PM

Using the *Calc-Rite Load Program*, a load requirement of 20,021 Btu/hr was calculated for the prototypical walk-in cooler.

Heatcraft Load Estimate Form:

HEATCRAFT Worldwide Refrigeration

Refrigeration Load Estimate Form (for rooms above 32°F) Bulletin Above32-05

Estimate for: **Estimate by:** **Date:**

Basis for Estimate

Room Dimensions: Width 15.8 ft. Length 15.8 ft. Height 12 ft.
Volume: (L) 15.8 x (W) 15.8 x (H) 12 = 2996 cu. ft.
Ambient Temp 85 °F. (Corrected for sun load) — Room Temp 35 °F. = 50 °F. T.D.

Note: Tables can be found in Engineering Manual, H-ENG-2

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Insulation	Inches	Type
Ceiling	6	POLYSTYRENE
Walls	6	POLYSTYRENE
Floor	6	POLYSTYRENE

Product Load

(a) 6480 lbs./day of SNAP BEANS to be reduced from entering temp. of 45 °F. to 35 °F. Temp. Drop 10 °F.
(b) ____ lbs./day of ____ to be reduced from entering temp. of ____ °F. to ____ °F. Temp. Drop ____ °F.

Miscellaneous

Motors (including all blower motors) 0.6 HP
Ground Temp. 65 (Table 21)
Lights (assume 1 watt/sq.ft.) 250 Watts
No. of people 1

1. Transmission Loads

Ceiling:	(L) 15.8 x (W) 15.8	x Heat Load 45	(Table 1)	= 11234
North Wall:	(L) 15.8 x (H) 12	x Heat Load 45	(Table 1)	= 8532
South Wall:	(L) 15.8 x (H) 12	x Heat Load 45	(Table 1)	= 8532
East Wall:	(W) 15.8 x (H) 12	x Heat Load 45	(Table 1)	= 8532
West Wall:	(W) 15.8 x (H) 12	x Heat Load 45	(Table 1)	= 8532
Floor:	(L) 15.8 x (W) 15.8	x Heat Load 45	(Table 1)	= 11234

2. Air Change Load

Volume: 2996 cu. ft. x 9.5 Factor (Table 4) x 1.86 Factor (Table 6) = 52939

3. Additional Loads

Electrical Motors: 0.6 HP x 75000 BTU/HP/24 hr. = 45000
Electrical Lights: 250 Watts x 82 = 20500
People Load: 1 People x 21480 BTU/24 hrs. (Table 12) = 21480
Glass Door Load: 0 Doors x 19200 BTU/Door/24 hr. = 0

4. Product Load: Sensible (Product Load Figured @ 24 hr. Pulldown*)

(a) 6480 lbs./day x 0.91 Spec. Heat (Table 7) x 10 °F. Temp Drop = 58968
(b) ____ lbs./day x ____ Spec. Heat (Table 7) x ____ °F. Temp Drop = 0
*For product pulldown time other than 24 hrs. figure 24 hr. load x (24/Pulldown Time)

5. Product Load: Respiration*

(a) 6480 lbs. stored x 4.6 BTU/lbs./24 hrs. (Table 8) = 29808
(b) ____ lbs. stored x ____ BTU/lbs./24 hrs. (Table 8) = 0
*For consideration of previously loaded product, a multiplier of (5) is normally applied to the daily product load (Line #4)

Total Refrigeration Load (1+2+3+4+5) BTU/24 hrs. 285291
Add 10% Safety Factor 28529
Total with Safety/Factor BTU/24 hrs. 313820

Divide by No. of Operating Hrs. (16) to obtain BTUH Cooling Requirement 19614

Equipment Selection

Condensing Unit: Qty. Model No.
Unit Cooler: Qty. Model No.
System Capacity BTU/hr.

2175 West Park Place Blvd. • Stone Mountain, GA 30087 • 770.465.5600 • Fax: 770.465.5990 • www.heatcraftrpd.com

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Using the Heatcraft Load Estimate Form, a cooling requirement of 19,614 Btu/hr was calculated for the prototypical walk-in cooler.

Appendix F: Derivation of AHRI 1250 Method-Of-Test Compressor Run Time

AHRI Standard 1250 Equations

Nomenclature

The symbols and subscripts used are as follows (AHRI 2009b):

AWEF:	Annual Walk-in Energy Factor, Btu/W·h
$BL(t_j)$:	Heat removed from walk-in box that does not include the heat generated by the operation of refrigeration systems, W·h
$B\dot{L}H(t_j)$:	Non-equipment related walk-in box load during high load period, Btu/h
$B\dot{L}L(t_j)$:	Non-equipment related walk-in box load during low load period, Btu/h
CR:	Compressor run time expressed as a percentage of the total hours in a year
$E(t_j)$:	System energy consumption at t_j , W·h
j:	Bin Number
n_j:	Bin hours, hr
$\dot{q}_{ss}(t_j)$:	System steady state net refrigeration capacity at t_j , Btu/h
t_j :	Bin temperature, ˚F

Annual Walk-in Energy Factor Definition

The Annual Walk-in Energy Factor (AWEF) as defined in the AHRI Standard 1250/1251 (AHRI 2009b, 2009c) is a ratio of cooling capacity, not including the energy usage of the evaporator fans, to the energy used by the system. The values that serve as inputs for this ratio correspond to a year period of usage.

$$AWEF = \frac{\sum_{j=1}^{n} BL(t_j)}{\sum_{j=1}^{n} E(t_j)} \qquad \text{Equation 15 (AHRI 2009b, 2009c)}$$

The variable *BL* is a function of the bin temperature, t_j. It is defined by the following equation.

$$BL(t_j) = \left[0.33 * B\dot{L}H(t_j) + 0.67 * B\dot{L}L(t_j)\right] * n_j \qquad \text{Equation 16 (AHRI 2009b, 2009c)}$$

Box Load High and Low Definitions

Walk-in box high load and low load conditions are defined differently based on whether the unit is a cooler or a freezer and whether its condenser is indoors or outdoors.

<u>Cooler, Condenser Indoors</u>

$$B\dot{L}H(t_j) = 0.7 * \dot{q}_{ss}(90°F) \qquad \text{Equation 1 (AHRI 2009b)}$$

$$B\dot{L}L(t_j) = 0.1 * \dot{q}_{ss}(90°F) \qquad \text{Equation 2 (AHRI 2009b)}$$

<u>Cooler, Condenser Outdoors</u>

$$\dot{BLH}(t_j) = 0.65 * \dot{q}_{ss}(95°F) + 0.05 * \dot{q}_{ss}(95°F)(t_j - 35)/60 \qquad \text{Equation 3 (AHRI 2009b)}$$

$$\dot{BLL}(t_j) = 0.03 * \dot{q}_{ss}(95°F) + 0.07 * \dot{q}_{ss}(95°F)(t_j - 35)/60 \qquad \text{Equation 4 (AHRI 2009b)}$$

<u>Freezer, Condenser Indoors</u>

$$\dot{BLH}(t_j) = 0.8 * \dot{q}_{ss}(90°F) \qquad \text{Equation 5 (AHRI 2009b)}$$

$$\dot{BLL}(t_j) = 0.4 * \dot{q}_{ss}(90°F) \qquad \text{Equation 6 (AHRI 2009b)}$$

<u>Freezer, Condenser Outdoors</u>

$$\dot{BLH}(t_j) = 0.55 * \dot{q}_{ss}(95°F) + 0.25 * \dot{q}_{ss}(95°F)(t_j + 10)/105 \qquad \text{Equation 7 (AHRI 2009b)}$$

$$\dot{BLL}(t_j) = 0.15 * \dot{q}_{ss}(95°F) + 0.25 * \dot{q}_{ss}(95°F)(t_j + 10)/105 \qquad \text{Equation 8 (AHRI 2009b)}$$

System Steady State Net Refrigeration Capacity Definition

The system steady state net refrigeration capacity definition varies based on the bin temperature being analyzed.

If $t_j \leq 59°F$

$$\dot{q}_{ss}(t_j) = \dot{q}_{ss}(35°F) + \left(\dot{q}_{ss}(59°F) - \dot{q}_{ss}(35°F)\right)\frac{t_j - 35}{59 - 35} \qquad \text{Equation 18 (AHRI 2009b)}$$

If $t_j > 59°F$

$$\dot{q}_{ss}(t_j) = \dot{q}_{ss}(59°F) + \left(\dot{q}_{ss}(95°F) - \dot{q}_{ss}(59°F)\right)\frac{t_j - 59}{95 - 59} \qquad \text{Equation 20 (AHRI 2009b)}$$

AHRI 1250 Method-of-Test Compressor Run Time

Compressor Run Time Definition
The compressor run time at bin temperature, t_j, is defined as follows:

$$CR(t_j) = \frac{BL(t_j)}{n_j * \dot{q}_{ss}(t_j)} \tag{4}$$

Combining Standard 1250 equation 16 and equation (4):

$$CR(t_j) = \frac{\left(0.33 * \dot{BLH}(t_j) + 0.67 * \dot{BLL}(t_j)\right) * n_j}{n_j * \dot{q}_{ss}(t_j)} \tag{5}$$

This is simplified by cancelling out the bin hours, n_j, which appear in the numerator and denominator.

$$CR(t_j) = \frac{0.33 * \dot{BLH}(t_j) + 0.67 * \dot{BLL}(t_j)}{\dot{q}_{ss}(t_j)} \tag{6}$$

The annual compressor run-time is then calculated by performing the following summation over the 8760 hours that make up one year.

$$CR = \frac{\sum_{j=1}^{n} CR(t_j) * n_j}{8760} \tag{7}$$

Combining equations (6) and (7) the annual compressor run time is as follows:

$$CR = \frac{1}{8760} \sum_{j=1}^{n} \frac{0.33 * \dot{BLH}(t_j) + 0.67 * \dot{BLL}(t_j)}{\dot{q}_{ss}(t_j)} * n_j \tag{8}$$

Compressor Run Time : Condenser Indoors

<u>Cooler, Condenser Indoors</u>
For the indoor condenser, Standard 1250 assumes a constant ambient bin temperature (t_j) of 90˚*F* for all 8760 hours in the year (n_j=8760). Therefore, box load high, box load low, compressor run time, and the system steady state net refrigeration capacity are all evaluated at the constant ambient bin temperature (t_j) of 90˚*F*.

The annual compressor runtime (equation (8)) can then be simplified as follows:

$$CR = \frac{1}{8760}\sum_{j=1}^{n} \frac{0.33 * \dot{BLH}(90°F) + 0.67 * \dot{BLL}(90°F)}{\dot{q}_{ss}(90°F)} * 8760 \tag{9}$$

Cancelling out the constant 8760 and combining Standard 1250 equations 1 and 2 with equation (9):

$$CR = \frac{0.33 * 0.7 * \dot{q}_{ss}(90°F) + 0.67 * 0.1 * \dot{q}_{ss}(90°F)}{\dot{q}_{ss}(90°F)} \tag{10}$$

Simplifying equation (10) by cancelling the net refrigeration capacity to arrive at the annual compressor runtime:

$$CR = 0.33 * 0.7 + 0.67 * 0.1 = 29.80\% \tag{11}$$

<u>Freezer, Condenser Indoors</u>
Using the same procedure as outlined in equations (9) through (11) the freezer (with indoor condenser) compressor run time can be derived. Standard 1250 equations 5 and 6 are utilized in place of Standard 1250 equations 1 and 2.

$$CR = 0.33 * 0.8 + 0.67 * 0.4 = 53.20\% \tag{12}$$

Compressor Run Time : Condenser Outdoors
The complexity of the outdoor condenser equations for box load high and box load low can be attributed to the variation in compressor run time based on the ambient conditions. When the outdoor ambient temperature is low the compressor will run less than it would at higher ambient temperatures for the same refrigeration load. To determine the compressor run time percentage for a cooler or freezer with an outdoor condensing unit, hourly bin data must be applied.

<u>Cooler, Condenser Outdoors</u>
Equation (8) is combined with Standard 1250 equations 3 and 4 to arrive at the following:

$$CR = \frac{1}{8760}\sum_{j=1}^{n} \frac{0.33 * \left(0.65 * \dot{q}_{ss}(95°F) + 0.05 * \dot{q}_{ss}(95°F)\frac{t_j - 35}{60}\right) + \ldots}{}$$

$$\ldots \frac{0.67 * \left(0.03 * \dot{q}_{ss}(95°F) + 0.07 * \dot{q}_{ss}(95°F)\frac{t_j - 35}{60}\right)}{\dot{q}_{ss}(t_j)} * n_j \tag{13}$$

The equation can be simplified as follows:

$$CR = \frac{1}{8760}\sum_{j=1}^{n} \frac{0.33*\left(0.65+0.05*\frac{t_j-35}{60}\right)+0.67*\left(0.03+0.07*\frac{t_j-35}{60}\right)}{\dot{q}_{ss}(t_j)}\dot{q}_{ss}(95°F)*n_j \qquad (14)$$

$$CR = \frac{1}{8760}\sum_{j=1}^{n} \frac{0.2346+0.0634*\frac{t_j-35}{60}}{\dot{q}_{ss}(t_j)}\dot{q}_{ss}(95°F)*n_j \qquad (15)$$

The net refrigeration capacity is a function of the bin temperature as noted in equation (15). For bin temperatures less than or equal to 59˚*F* Standard 1250 equation 18 is applied:

$$\dot{q}_{ss}(t_j) = \dot{q}_{ss}(35°F) + \left(\dot{q}_{ss}(59°F) - \dot{q}_{ss}(35°F)\right)\frac{t_j-35}{59-35} \qquad \text{Equation 18 (AHRI 2009b)}$$

Likewise, Standard 1250 equation 20 is applied for bin temperatures greater than 59˚*F*:

$$\dot{q}_{ss}(t_j) = \dot{q}_{ss}(59°F) + \left(\dot{q}_{ss}(95°F) - \dot{q}_{ss}(59°F)\right)\frac{t_j-59}{95-59} \qquad \text{Equation 20 (AHRI 2009b)}$$

The calculation of the compressor run time percentage is accomplished by evaluating equation (15) and Standard 1250 equations 18 and 20 at the bin temperatures and corresponding bin hours, based on the TMY-3 weather data of Kansas City, Missouri (Table 35), as defined in Standard 1250.

<u>Freezer, Condenser Outdoors</u>

Using the same procedure as outlined in equations (13) through (15) the compressor run time for the freezer (with condenser outdoors) can be derived as follows (Standard 1250 equations 7 and 8 are utilized in place of Standard 1250 equations 3 and 4):

$$CR = \frac{1}{8760}\sum_{j=1}^{n} \frac{0.282+0.25*\frac{t_j+10}{105}}{\dot{q}_{ss}(t_j)}\dot{q}_{ss}(95°F)*n_j \qquad (16)$$

Again, this equation is summed over the weather data bin temperatures and corresponding bin hours for Kansas City, Missouri, and Standard 1250 equations 18 and 20 are used to define the net refrigeration capacity at each bin temperature analyzed.

Table 35. Temperature Bins and Corresponding Bin Hours (AHRI 2009b)

Table D1. Bin Temperatures and Corresponding Bin Hours for AWEF Calculation

Bin Temperature (˚F)	Bin Hours (h)
100.4	9
95	74
89.6	257
84.2	416
78.8	630
73.4	898
68	737
62.6	943
57.2	628
51.8	590
46.4	677
41	576
35.6	646
30.2	534
24.8	322
19.4	305
14	246
8.6	189
3.2	78
-2.2	5