Thermal Energy Storage

2009 Assessment of Ice Bear® 30 Hybrid Air Conditioner

1017879

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Technical Update, December 2009

EPRI Project Manager

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PRODUCT DESCRIPTION

This report describes EPRI tests of a thermal energy storage system, the Ice Bear® 30, which is manufactured by Ice Energy Inc. of Windsor, Colorado. Results of two separate tests are included, one at EPRI's Knoxville, TN laboratory and the other a field demonstration site at Volunteer Energy Cooperative (VEC), a TVA distributer, in Decatur, TN. The Ice Bear 30 uses smart integrated controls, ice storage, and a dedicated compressor for cooling. The system is designed to provide cooling to interior spaces by circulating refrigerant within an additional evaporator coil added to a standard unitary air conditioner. The Ice Bear 30 is relatively small size (5 ton), and is intended for use in residential and light commercial applications.

Results and Findings

This report describes:

1) The various subsystems within the Ice Bear 30 system.
2) How the Ice Bear 30 operates.
3) Results of characterization tests.
4) Issues related to application and installation of the system.

Specific information on the application and installation of two Ice Bear 30 thermal energy storage systems are provided; one installed at the laboratory space of the EPRI laboratory facilities in Knoxville, Tennessee and a second installed at the VEC headquarters building in Decatur, Tennessee.

Challenges and Objectives

The objective of this research is to supply data on the performance of thermal energy storage alternative air conditioning technologies applicable for residential and light commercial facilities. This report is intended for utility personnel and technologists who are interested in potential use of thermal storage air conditioning technologies for peak shifting programs. Alternative air conditioning technology is of high interest because of the ability to reduce peak load when both outdoor temperatures are high and the demand on the electric system is high; however, application of such systems is still in its infancy in terms of market acceptance despite multiple demonstrations.

Applications, Values, and Use

Air conditioning technologies combined with thermal energy storage have the potential to provide cooling to office space at a lower cost and with more comfort than traditional systems. This research adds to the data available to utilities and others who may wish to consider the system for peak demand shifting in commercial office space and possibly larger residences.

In the United States, areas of particular potential for application of such systems are those with a large diurnal temperature change (a large difference in day and night temperatures). The high diurnal temperature swing allows the system to discharge the stored ice energy when temperatures are high and to make ice when both the cost for electricity is low and temperatures are low. The process of making ice is more efficient at lower ambient temperatures.

EPRI Perspective

Research was conducted on this technology since it offers potential to enable peak shifting in the small commercial and mass markets. With knowledge of this technology, electric utilities are in a unique position to determine if thermal energy storage systems can help their customers in evaluating and implementing new air conditioning solutions that may be better and more cost-effective than solutions based on traditional technology.

Approach

Primary research was conducted for the report and entailed tests of the Ice Bear 30 in both a laboratory and a field setting. Performance measurement was accomplished by complete instrumentation of a system installed at the EPRI Knoxville, Tennessee laboratory, and an abridged instrumentation system placed in the field test location at the VEC office in Decatur, Tennessee. The goals of the installations and measurements were to verify performance and learn through first-hand experience the installation and operational challenges associated with ice storage technology.

Keywords

Heating Ventilation and Air Conditioning (HVAC)
Energy Efficiency
Peak Load Shifting
Thermal Energy Storage
Ice Storage Systems
Unitary Air Conditioners
Ice Bear

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EXECUTIVE SUMMARY

This report documents research conducted on two Ice Bear 30 Hybrid Air Conditioning systems: one installed in a space within EPRI's Knoxville, Tennessee laboratory facility and the other deployed at a field test site at the Volunteer Energy Cooperative (VEC) in Decatur, Tennessee. The primary goal of the installations was to determine the amount of peak shifting realized by using the Ice Bear 30.

This report describes the various subsystems within the Ice Bear 30 system, their operation, results of characterization tests, and issues related to application and installation. It is an update of continuing work on the subject started in 2008 and builds on last years report: *Thermal Energy Storage: Assessment of Ice Bear 30 Hybrid Air Conditioner.* EPRI, Palo Alto, CA: 2008. 1018509.

As a relatively small thermal energy storage system, Ice Bear 30 offers potential for utilities when widely applied by decreasing the aggregate electric demand during on-peak periods. Ice Bear 30 has the potential to provide indoor cooling during peak demand hours with significantly lower power consumption than a conventional air conditioning system. Anecdotal claims have been made that one Ice Bear 30 can reduce by peak-shifting an electrical load of 5-to-6kW over a multi-hour cooling period.

The Knoxville Ice Bear was installed in the early summer of 2008 and has operated consistently throughout the 2008 and 2009 cooling seasons. Some minor modifications were made to the system, including an upward adjustment of the supply air flow to ~2000 cubic feet per minute (cfm) because of excessive airflow resistance. The Knoxville system, considered a laboratory installation, has a more complete instrumentation package to measure actual cooling capacity delivered through the unitary system and the Ice Bear as well as power consumption to the unitary and Ice Bear components.

The second system was installed at VEC as part of construction of a new wing of the VEC headquarters building. It served as a complimentary field installation of Ice Bear to the Knoxville lab setup. It provided information related to installation and equipment selection for new construction and performance data for an actual field installation. The VEC Ice bear was integrated with a 5-ton split-system, one of five commercial style split-systems serving the new wing of the building. The Ice Bear was installed by the mechanical contractor along with the other building HVAC systems and commissioned by Ice Energy in the early summer of 2009. EPRI, in conjunction with Tennessee Valley Authority, instrumented the system for comparative performance measurement and analysis of load shifting ability.

Findings

The Ice Bear 30 system has shown the ability to maintain space cooling with ice draw both in a cycling and full-load situation. In some cases, the Ice Bear operates with a cooler evaporator, providing somewhat more dehumidification to the space. Power shifting under full load could reach ~5,000 – 5,500 Watts depending on indoor set point and outdoor air temperature.

The systems are quiet and successfully shifted electricity consumption used for cooling from daylight hours to nighttime hours. At the Knoxville location, at 84°F outdoors, when the area thermostat called for cooling, use of the Ice Bear 30 reduced instantaneous electricity consumption from approximately 6.3 kW to approximately 1.0 kW while maintaining the indoor set point temperature. Under approximately full load, the Knoxville Ice Bear 30 system met the manufacturer's claim of providing 30 ton-hours of cooling.

The VEC system also operated properly, successfully shifting load from the daytime peak hours to the nighttime. This system was installed in conjunction with a nominally rated 5-ton Trane commercial split-system, one of 7 split systems totaling 28 tons serving the facility. Throughout the summer months the 5-ton split system never ran at 100% duty cycle, and hence the Ice Bear 30 never had the opportunity to shift a full 30-ton hours of load. Cumulative energy use is presented for two similar weeks, one with the split system only operating and the other with the Ice Bear system operating during peak hours. Average temperatures for the weeks are 74.4˚F and 77˚F respectively for the split-system and Ice bear weeks. Corresponding cumulative energy use was 115.5 kWh and 147 kWh respectively.

Matching Storage Capacity to DX Systems Key

A principle finding of the VEC test is that to take advantage of the full load shifting capabilities of an Ice Bear 30, it should be coupled with a companion air conditioner experiencing at least 5 tons of continuous load during the summer peaking hours.

Testing at VEC showed the Ice Bear 30 had the same ability as in the Knoxville location to effectively shift cooling load entirely off of the unitary system and onto the Ice Bear during a prescribed peak period. However, this installation clearly illustrated that to shift load, there must be load.

Cooling load at the VEC location was significantly below the installed equipment size and significant cycling occurred, even at outdoor temperatures in the low 90°s. 90° plus temperatures are nearing the design balance point and operating duty cycles in the 80-90% range are expected. At VEC, the duty cycle never exceeded 50% meaning that the installed 5-ton split system was never providing, on average, more than 2.5 tons of cooling. This imposes a limit on the level of cooling load, and in turn a limit on how much power can be shifted away from the unitary system onto the Ice Bear. The Ice Bear does not determine loading; it is a slave to the piece of unitary equipment to which it is tied.

When designing an installation for Ice Bear or similar systems, great care must be taken to understand the loading and operating profile of the unitary systems to which Ice Bear will be coupled. Consider the following factors when matching thermal storage to a unitary system:

- The capital cost for Ice Bear remains constant whether it is attached to a low or high duty cycle unitary system, and if coupled to a low duty-cycle system there will be unused load shifting capacity.
- Application for new construction is particularly challenging since there is a tendency to oversize unitary equipment. Cooling equipment is often specified based on rules of thumb or on rudimentary load calculations, and from the system designer's perspective, there is little harm in designing an oversized system and having it operate at less than 100% duty. An oversized system will keep occupants cool, but under-sizing may result in delivering less cooling than occupant's desire when there are very high outdoor air temperatures.

- For retrofit applications in existing buildings there is at least an opportunity to measure the duty cycle of existing equipment, which makes the selection of what unit to couple an ice storage device to a bit simpler. Ice storage systems like the Ice Bear are intended to shift power at the hottest times of the hottest days when air conditioning systems tend to be the most fully loaded.
- Ice Energy offers 5-ton Ice Bear systems to integrate into staged 10-, 15- and 20-ton unitary equipment as a method for ensuring that the ice system is coupled to a fully loaded 5-ton load. The idea being that the Ice Bear would be coupled to the first 5-ton stage of a 10+ ton system. The idea has merit, but a designer must be sure that the installation and the building operating dynamics are such that the chosen 5-ton stage to be coupled with is indeed a stage that is fully loaded. One should not count on the obviousness of an installation, i.e. that something labeled “stage 1” is actually a fully loaded stage. It is risky to depend on generalized deployment plans for such equipment.
- Ice Bear installation was generally straight forward and was carried out by local mechanical contractors with no particular expertise in thermal storage or specific training by Ice Energy. Piping and electrical connections are minimal and in-line with that of standard unitary installations.

2 INTRODUCTION

This report describes the installation, performance, and application of the Ice Bear 30 Hybrid Air Conditioner in a laboratory and in a field test. The Ice Bear 30 is a thermal energy storage (TES) system that uses ice as the storage medium. It is manufactured by Ice Energy, Inc. The terms used in this report – Ice Energy, Ice Bear, and CoolData are registered trademarks (®), and Ice-Ready, Ice-Coil, and Hybrid Cooling are trademarks (™) of Ice Energy, Inc., a manufacturer of thermal energy storage systems located in Windsor, Colorado.

The system is designed to provide cooling to interior spaces by circulating refrigerant within a second evaporator coil added to a standard roof-top air conditioner. The Ice Bear 30 is relatively small sized (5 ton, 30 ton-h) and intended for use in residential and light commercial applications.

The Ice Bear 30 installations documented in this report are at the EPRI Knoxville, Tennessee laboratory and at the VEC headquarters in Decatur, Tennessee.

As a relatively small thermal energy storage system, Ice Bear 30 yields potential for utilities when widely applied by decreasing the aggregate electric demand during on-peak periods. Ice Bear 30 has the potential to provide indoor cooling during peak demand hours with significantly lower power consumption than a conventional air conditioning system. Anecdotal claims have been made that one Ice Bear 30 can reduce by peak-shifting an electrical load of 5-to-6kW over a multi-hour cooling period. This was generally confirmed at the EPRI installation, with the important requirement that the unitary system to which Ice Bear is coupled is operating at full load. If the system is not experiencing full load cooling demand, the ability to shift power decreases. This effect is brought to light in the VEC testing results. EPRI's research is focused on understanding the performance of the Ice Bear 30 system when coupled to a conventional packaged rooftop air conditioner and a commercial 5-ton split-system.

Research Objective

The primary objective for testing Ice Energy's Ice Bear 30 was to determine the amount of peak shifting that can be realized through its application. To accomplish this objective, experiments were conducted at EPRI's Knoxville laboratory in late summer 2008 and continued in the summer of 2009. An additional objective was to perform a field evaluation of Ice Bear operation at an actual building setting. To that end EPRI also performed a field test at VEC in the summer of 2009 where an Ice Bear 30 was installed as a complementary component of a 5-ton split-system air conditioner. This effort was funded and supervised by TVA and the local power distributer, VEC. The field test yielded valuable information on the installation process in a new building and provided initial performance data on a field-installed system.

3
DESCRIPTION OF TECHNOLOGY

Company Overview

Ice Energy Inc. is an energy technology company developing energy storage and advanced cooling and refrigeration products and technologies. The company manufactures and markets a new hybrid air conditioner for residential and commercial applications. Its hybrid cooling system is designed to shift the largest component of residential and commercial demand – air conditioning – from “on-peak” times to “off-peak” periods.

Per Ice Energy Inc., the Ice Bear 30 Hybrid Air Conditioner is the industry's first energy-storage solution specifically developed to reduce the cost of air conditioning for small to medium-sized commercial businesses. Geographical regions that experience large diurnal (day to night) temperature change are target markets for this product. The high diurnal swing allows the system to discharge the stored ice energy when temperatures are high and to make ice when both the cost for electricity is low and temperatures are low. The company further claims that the system can surpass the overall efficiency of conventional equipment in certain diurnal climatic conditions.

Ice Energy has 10 patents, 3 trademarks, and 15 patents in process – all related to the Ice Bear system.

Description of Ice Storage Technology

Thermal energy storage is made practical by the large heat of fusion of water. Heat of fusion is the amount of thermal energy required for a substance to change state from a solid to a liquid or vice versa. One metric ton of water, (one cubic meter) can ideally store 334 MJ, which is equivalent to 317,000 Btu (93 kWh or 26.4 ton-h). In practice, the stored energy is lower because of the mechanisms required to capture the energy. For example, it is difficult to extract energy from a solid block of ice. The energy stored may be 26-ton-hour, but, if the cooling rate is, say, only 1 ton, the system is not practical. To improve the energy transfer rate, typically multiple coils are used and water is used as a working fluid. Nevertheless, the energy density of ice is sufficient so that a relatively compact tank of ice/water can hold enough thermal energy to practically provide cooling.

One of the most widely used air conditioning systems in the world is the “unitary system.” A unitary air conditioning system is a self-contained, factory-built packaged configuration that integrates a cooling plant, air moving equipment (fans), and controls. For commercial buildings, the most commonly applied packaged system is the rooftop air conditioner. The cooling capacity for a typical rooftop package ranges from 5 to 20 tons; however, larger packages with capacities on the order of 200 tons are available.

An operational disadvantage of the traditional packaged system is that the condensing unit must operate to meet instantaneous space cooling loads as they occur. This means that the greatest electrical demand from the system directly coincides with the peak building cooling loads. Unfortunately, it is at this time that the system’s operating efficiency is also at its lowest due to warm outdoor air conditions. The electrical demand for a typical packaged system will generally be greater than 1 kW/ton during peak operating periods and less than 1 kW/ton during off-peak periods.

Description of Ice Bear 30 Hybrid Air Conditioner

An emerging technology that aims to achieve energy and energy cost savings by adding thermal storage capability to these systems is known generically as a unitary ice storage system. One example of such a thermal energy storage system is the Ice Bear 30 by Ice Energy, shown in Figure 3-1. The Ice Bear 30 is a 30 ton-h ice storage unit with a dedicated refrigerant condensing unit (R-410a) and controls. Figure 3-1 shows two different configurations for integrating the ice storage system. The rooftop option shown in Figure 3-1(c) incorporates a separate evaporator (the Ice Energy Ice-Coil™) within a standard rooftop dedicated to the Ice Bear 30. Another option shown in Figure 3-1(d) incorporates an evaporator coil (Ice-Coil™) into an air-handling unit remote from the unit.

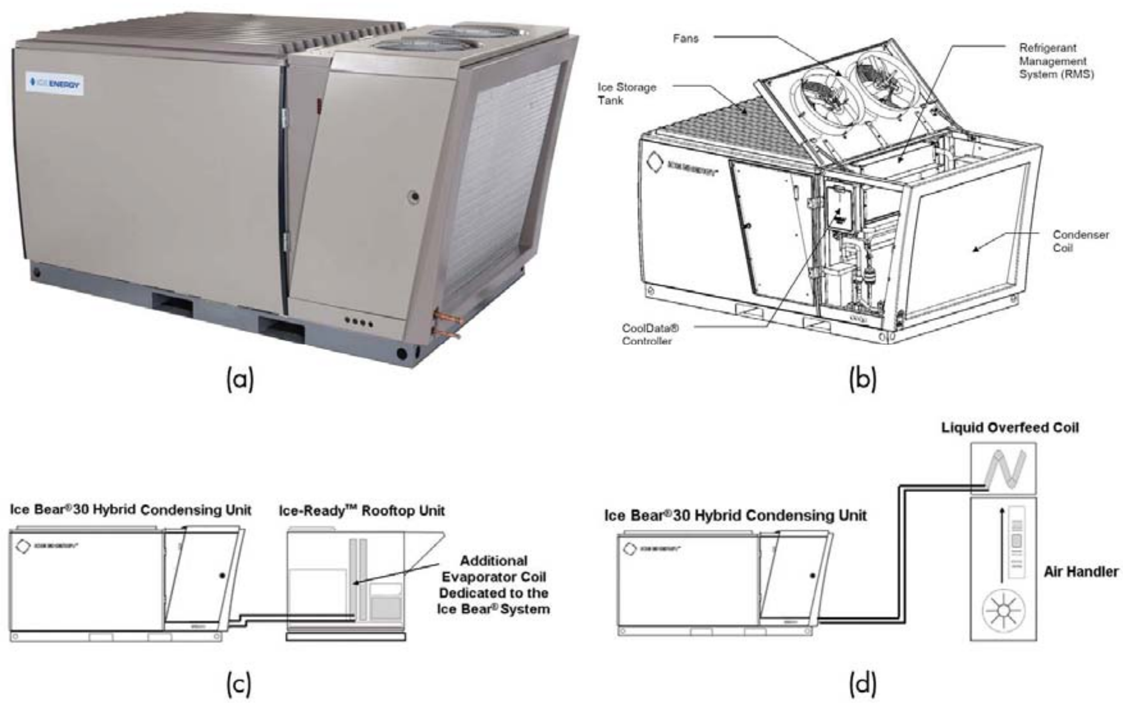

Figure 3-1
Ice Energy Ice Bear Showing (a) & (b) the Ice Bear 30 Condensing Unit and (c) a Rooftop Unit Connection Option, along with (d) a Stand-Alone Unitary Implementation (Courtesy Ice Energy)

When the Ice Bear 30 is joined with an existing air conditioning system, the additional evaporator coil is often easily accommodated because there is room within the air handler cabinet. Additionally, a larger fan option, which is a standard feature from the manufacturer, is used to overcome the added static pressure from the inclusion of the extra coil.

During a charge mode, the self-contained 4.2 ton condensing unit located within the Ice Bear 30 provides high pressure liquid refrigerant to the bottom of a series of vertical, helical coiled heat exchangers (shown in Figure 3-2) immersed in a water tank. Ice forms on the outside surfaces of the coils as the refrigerant evaporates before returning to the compressor suction.

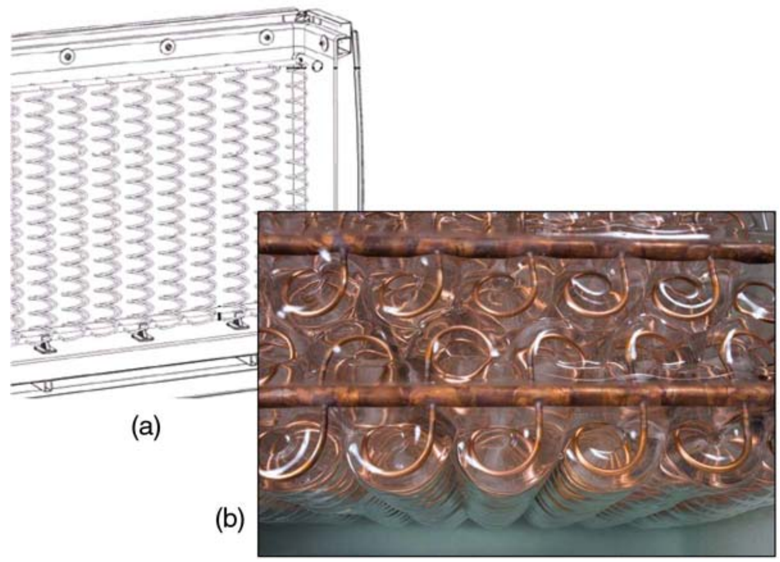

Figure 3-2
Illustration of the Helical Coil Arrangement in Storage Module of the Ice Bear 30 (a) and the Actual Coil Arrangement (b) (Courtesy Ice Energy)

During discharge (during peak electric demand periods), cold liquid refrigerant is circulated to the evaporator coil dedicated to Ice Bear 30. Here the cold liquid refrigerant absorbs heat from the air stream being cooled and dehumidified and evaporates. The refrigerant vapor is returned back to the top of the helical coil heat exchangers where the stored ice causes the refrigerant to condense, thereby melting the ice.

During this discharge cycle, the compressor within the standard air conditioner is turned off and a small pump within Ice Bear 30 is used to circulate chilled refrigerant between the extra coil, shown in Figure 3-3 and the ice tank.

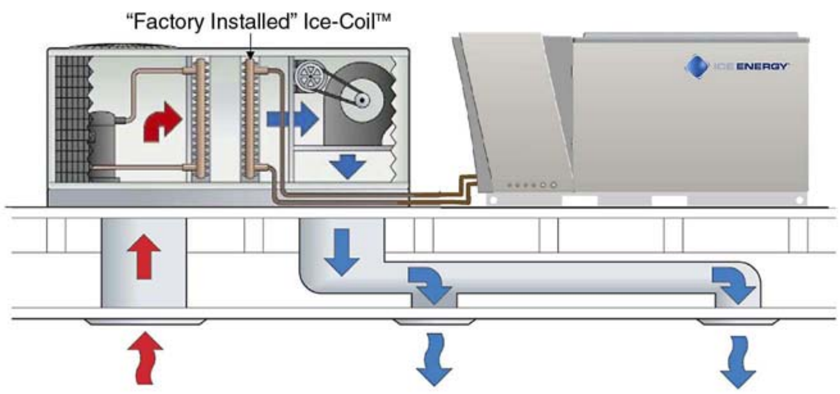

Figure 3-3
Illustration Showing Basic Configuration of an Ice Bear 30 Ice Storage System (Courtesy Ice Energy)

The fan within the standard air conditioner is used to circulate the conditioned air. Thus, the energy consumption during daylight hours is reduced from compressor and fan to just the fan and circulating pump. With the configuration shown in Figure 3-3, no additional controls are necessary. The system works with the existing thermostat. In fact, the addition of the thermal energy is invisible to building occupants. No additional actions are required.

The Ice Bear 30 consists of several key components that are shown in Figure 3-4. A compressor and condenser within the Ice Bear 30 are used to create ice during the nighttime. Use of a separate compressor and condenser enables the combined system (rooftop system and Ice Bear 30) to create ice while at the same time providing cooling to the office or residential space. An on-board refrigerant management system properly sequences the unit's operation during both the charging and discharging modes.

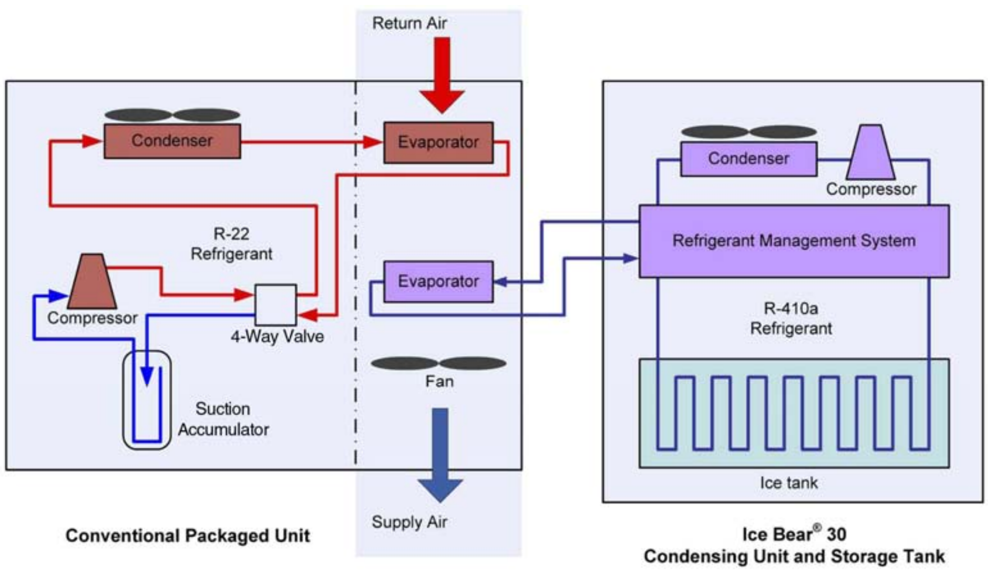

Figure 3-4
Simplified Schematic of the Ice Bear 30

CoolData Controller and Load Shifting

Not shown in the figure above is the Ice Energy remote terminal unit called the CoolData controller, which is used by utilities to schedule and/or control the load shifting window. The CoolData controller also accommodates measurement and validation sensors used to monitor performance of the system and continually optimize the system by adjusting refrigerant flow during ice draw and managing the amount of ice regeneration. This controller, which connects through the Internet to the manufacturer's location, has a built-in web server and data logging. The CoolData controller allows for remote diagnostic of the Ice Bear 30 performance as well as monitoring of the overall system performance.

General Specifications and Performance

The Ice Bear 30 tank capacity is 475 gallons, uses standard tap water, and is commonly filled with a garden hose in about an hour. During the nighttime the system requires between 9 and 11 hours to make ice depending on temperature; the warmer the temperature the longer the time. The Ice Bear 30 tank module can be installed up to 150 feet (pipe length) from the evaporator coil, which is typically placed inside a rooftop unit. The unit weighs 2,500 kg (5,500 lbs) and is 256 cm wide, 152 cm deep, and 122 cm high (101 in, 60 in, and 48 in).

Ice Energy states that Ice Bear 30 is capable of meeting a 5-ton load continuously for a six hour period or a 3-ton load for a 10 hour period during discharging. The flow of cooling between Ice Bear 30 and rooftop unit is fixed at a constant rate, but is controlled using duty-cycle control via a wall mounted thermostat.

Demand Reduction

The daytime demand reduction is a function of the air conditioning unit to which Ice Bear 30 is being compared. Less efficient air conditioning systems, which draw relatively higher power levels, offer greater potential for peak power shifting. The daytime demand reduction equals the power drawn by the air conditioning unit minus both the energy needed to operate the circulation fan and Ice Bear 30 electronics and circulating pump. If the fan within the air conditioner draws 700 W and the Ice Bear 30 requires 300 W to circulate refrigerant, then the power consumption during daytime peak hours would be 1.0 kW. Assuming a total air conditioner load of 6.5 kW during daytime peak hours, the peak demand reduction is 5.5 kW (6.5 kW minus 1.0 kW). If a high efficiency air conditioner is used, the amount of peak reduction could be less, but the actual amount of peak reduction depends on the particular make and model of air conditioner that is being offset by use of Ice Bear 30.

The daytime energy reduction in kilowatt-hours is a function of the building load; the higher the load the greater the kilowatt-hours used to cool the building. In a best case scenario (highest loading), Ice Bear 30 will supply the full 30 ton-h over the course of six to ten hours, depending on the cooling rate. In practice, air conditioners are sized for a design high outdoor temperature, termed the balance point, and deliver less than the maximum rating when the outdoor temperature is below the design temperature.

Ice Energy states that its units are most commonly applied to multi-stage packaged rooftop units, to help insure full utilization of the stored energy on a daily basis. Ice-Ready™ rooftop units with nominal capacities of 10, 15, and 20 tons commonly consist of multiple 5-ton circuits (stages). Although the third stage of these units only operate at design conditions a fraction of the year, the run time of the first stage is , if properly designed, will approach 100% during daily peak cooling periods. Applying the Ice Bear 30 to the first stage of these systems helps to insure full utilization of the stored energy on a daily basis.

4 INSTALLATION

This section includes a brief description of the Knoxville Ice Bear 30 installation, followed by a description of the VEC installation. (For greater detail on the design and installation of the Knoxville Ice Bear system, see the EPRI 2008 Technical Update entitled *Thermal Energy Storage: Assessment of Ice Bear® 30 Hybrid Air Conditioner*, 1018509).

Knoxville System

The Ice Bear 30 system is installed on the north facing wall outside the EPRI laboratory in Knoxville (see Figure 4-1). The Carrier packaged air conditioner is installed on the ground to facilitate access and viewing. Figure 4-2 shows the refrigerant piping between the Ice Bear 30 and the rooftop system.

Figure 4-1
Photograph of Ice Bear 30 at the EPRI Knoxville Campus

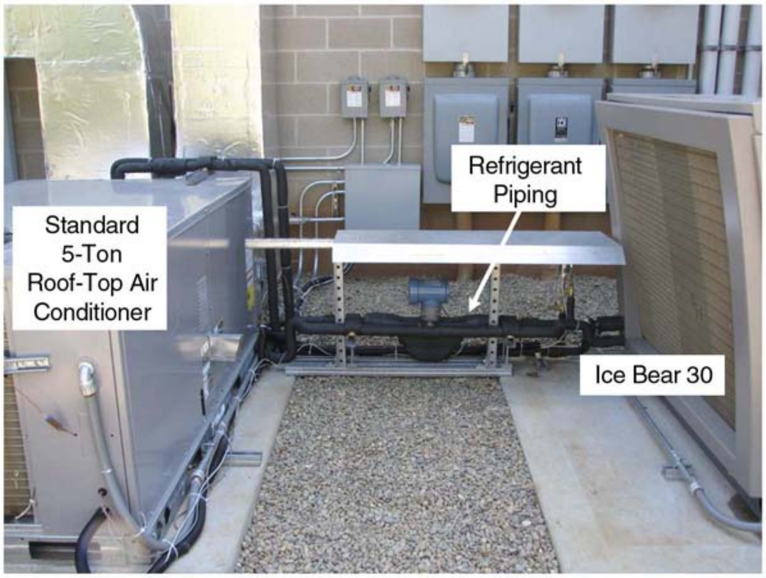

Figure 4-2
Photograph Showing Refrigerant Piping between the Ice Bear 30 and the Rooftop System

The packaged system, retrofitted with a second coil by Ice Energy, is a Carrier single-package rooftop system with model number 48TFF006. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI, formerly ARI) capacity rating is 57,000 Btu/h (4.75 ton). At the AHRI test conditions, the rooftop system consumes 6.7 kW, resulting in an energy efficiency ratio (EER) of 8.51 Btu/Wh (2.49 coefficient of performance or COP). The AHRI seasonal energy efficiency ratio (SEER) is 10.0 Btu/Wh for the model installed at EPRI. The refrigerant used is R-22. The rooftop system refrigerant circuit is entirely independent from the Ice Bear 30 refrigerant circuit, as shown in Figure 3-4 in the previous section.

An east-looking photograph of the interior space cooled by the combined system is shown in Figure 4-3 and a west-looking photograph is shown in Figure 4-4.

Figure 4-3
Photograph (Looking East) of the Interior Space Cooled by the Rooftop Unit and Ice Bear 30

Figure 4-4
Photograph (Looking West) of the Interior Space Cooled by the Rooftop Unit and Ice Bear 30

The supply air ductwork (shown in Figure 4-4) extends to the adjoining warehouse area. Flow of air into the warehouse space is controlled with a manual damper. Cool air into the adjoining area is decoupled from the thermostat providing the ability to manually adjust the thermal load of the room. If the manual damper is wide open the load is greater than five tons. With the damper closed, the load is less than five tons, and the system will cycle.

VEC Installation

At the VEC site, an Ice Bear 30 was coupled to a Trane commercial 5-ton split system. The split system is one of five splits-systems serving a new south wing addition to the VEC headquarters in Decatur, Tennessee. The five air handlers serving the new wing are located in a common mechanical room within the new space. The Ice Bear secondary evaporator was placed in the supply duct approximately 10 feet downstream of the air handler in a horizontal section of duct. Refrigerant piping connecting the coil to the Ice Bear ran for ~15 feet within the mechanical room then through a ~20 foot underground conduit. Total refrigerant line length is on the order of 70-80 feet (round trip). A separate condensate drain was piped from the secondary evaporator coil to a floor drain in the mechanical room. Figure 4-5 and Figure 4-6 show the Ice Bear 30 unit and the secondary evaporator respectively. Nameplate information for the outdoor and indoor split-system components are shown in Figure 4-7 and Figure 4-8.

Figure 4-5
Ice Bear 30 Installed at VEC

Figure 4-6
Secondary Evaporator in Air Handler Supply Duct

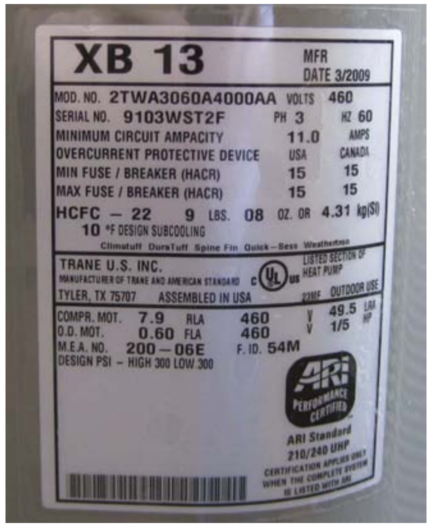

Figure 4-7
Trane 5-Ton Heat Pump Outdoor Unit Nameplate

Figure 4-8
Trane 5-Ton Air Handler Nameplate

The Ice Bear was installed as part of the HVAC system during construction by a local mechanical contractor, the same contractor doing the greater HVAC installation in the building. Installation was generally straight-forward and did not require any unique skills, tools, or personnel. The cost associated with equipment and installation of the VEC Ice Bear, excluding instrumentation, was approximately $24,000. The building was generally complete and the air conditioning systems along with the Ice Bear were commissioned around June 15, 2009. The building had limited occupancy and limited equipment installed through the duration of the 2009 summer cooling season as final construction and building commissioning were completed; as a consequence loading may not be indicative for the future, fully occupied building. The instrumented system will be left in place and plans are to continue logging data through the summer of 2010 to gather further data with the building in a fully occupied state.

5
INSTRUMENTATION

Following is a brief description of the Knoxville system instrumentation and a complete description of the VEC instrumentation package. (For greater detail on the instrumentation of the Knoxville Ice Bear system (see the EPRI 2008 Technical Update entitled Thermal Energy Storage: Assessment of Ice Bear® 30 Hybrid Air Conditioner, product number 1018509.) Measured points on the Knoxville system are indicated on the schematic drawing Figure 5-1. The primary measurement was air-side cooling capacity of the packaged air conditioner. Temperature and relative humidity were measured in the supply and return ducts and air volume flow was measured in the supply duct. Those five points allow calculation of the air side capacity according to:

$$CoolingCapacity = m_{air} c_{p,air} \left[h_{return}(T, RH) - h_{\sup ply}(T, RH) \right] \quad \textbf{Eq. 5-1}$$

where mass flow is calculated from measured supply air volume flow and the supply air state. c_p, the specific heat of air is treated as a constant. Return and supply enthalpies are calculated from measured values of temperature and relative humidity (RH). On the packaged air conditioner, additional measurements are taken to measure refrigerant-side cooling capacity as a check of the measured air-side capacity. Refrigerant-side capacity is not measurable for the Ice Bear space cooling mode because the refrigerant flowing between the Ice Bear and the secondary evaporator maintains a two-phase component, making measurement of mass flow difficult.

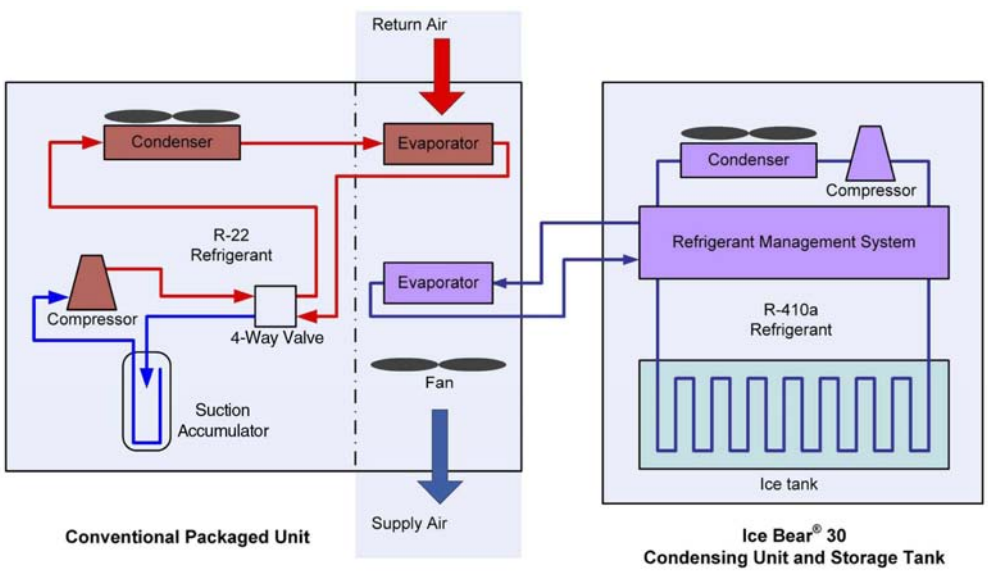

Figure 5-1
Schematic of the Data Acquisition System

VEC System Instrumentation

At the VEC field test, the combined Ice Bear / split-system was instrumented for measurement of comparative air-side performance and for component power consumption. Supply air volume flow was considered to be constant at the rated airflow of 2000 cfm. Since airflow was not measured, no absolute calculation of cooling capacity was made, but comparative measures of cooling capacity between the split system and the Ice Bear are made with an assumed constant air flow of 2000 cfm.

Return air temperature and humidity were measured with a duct mounted Vaisala HMD 60 transmitter with a 12" probe length. The sensor tip was approximately at the center of the duct cross section. The HMD 60 has a humidity measurement range of 0-100% with 2% full scale (FS) accuracy from 0-90% and 3% FS accuracy from 90-100%. Temperature measurement range is -4°F – 176°F (-20°C – 80°C) with accuracy shown in Figure 5-2.

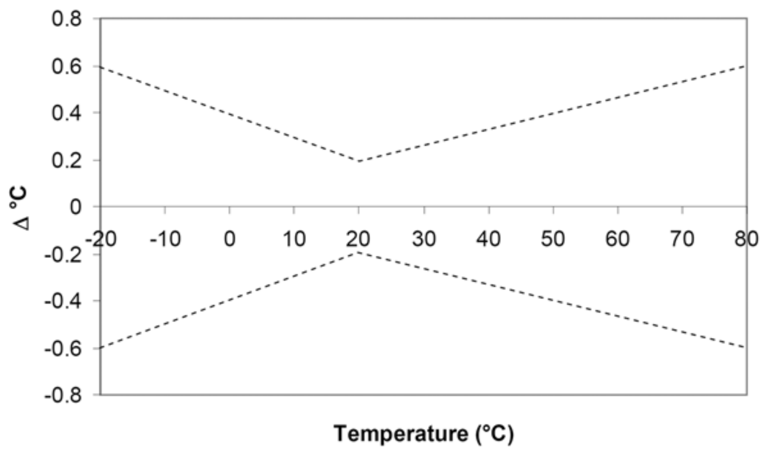

Figure 5-2
Temperature Accuracy of Vaisala HMD 60 Duct-Mount Transmitter

Power was measured at three points: 1) Ice Bear, 2) split-system air handler & 3) split-system outdoor unit. At each point power was measured with a 3-phase WattNode power transducer and associated current transformers (CTs). The CTs and meters were placed in the disconnect boxes serving each of the three pieces of equipment and signal wiring was run out to the data logger. Sensor signals were transmitted onto a local Modbus network and then sent via a Modbus-to-Ethernet gateway to a data acquisition server at EPRI's Knoxville Laboratory. Data could be accessed in real time and was collected into a database for analysis. Figure 5-3 is the graphical user interface (GUI) for the VEC installation.

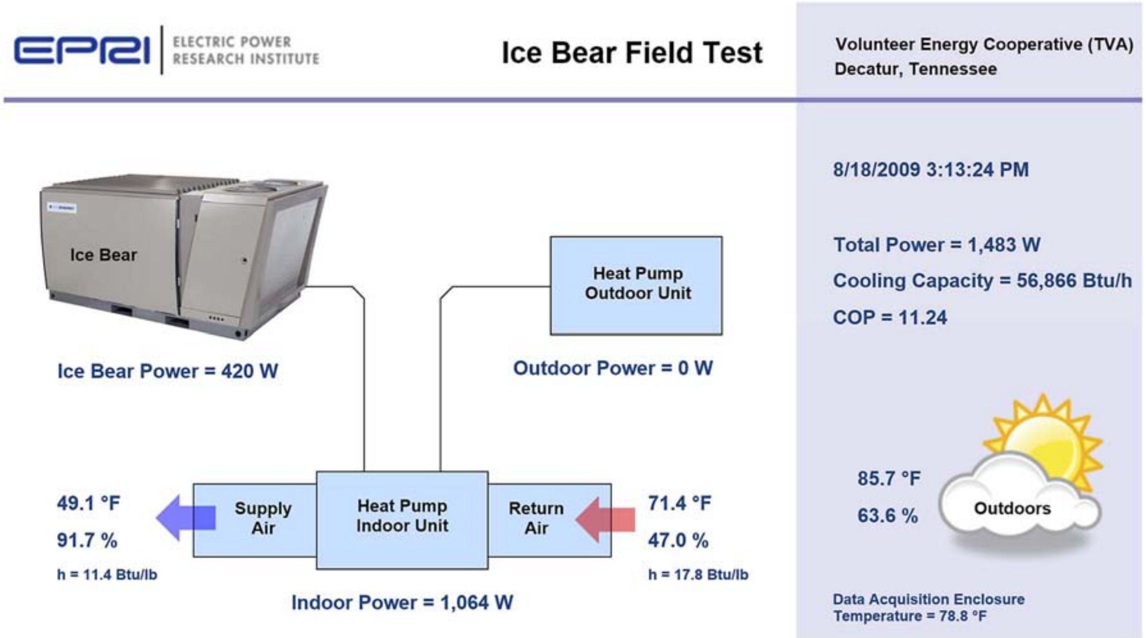

Figure 5-3
Data Graphical User Interface for VEC Installation (Example Operation)

6 CHARACTERIZATION TESTS

Significant testing results were presented in the 2008 EPRI report entitled Thermal Energy Storage: Assessment of Ice Bear® 30 Hybrid Air Conditioner, product number 1018509. Results focused on verifying the amount of cooling provided by the Ice Bear system, which was in line with the claim of ~5-tons and 30 ton-hours, and on the power draw profile of the Ice Bear system. It was recommended by Ice Energy after analyzing the 2008 results that the system could be further optimized by increasing the supply air flow rate to the design value of ~2000 cfm (an increase from ~1650cfm during the 2008 testing). The airflow was increased for the 2009 testing season. Following is a further presentation of results from the Knoxville Ice Bear test installation and a more detailed analysis of results from the VEC installation.

Knoxville System

The Knoxville test setup was flexible enough to allow full load testing at a variety of outdoor conditions. The laboratory and warehouse space served by the Ice Bear system provided a large enough load that at design conditions, cooling was called for continuously. This contrasts with the VEC installation, where relatively low demand for cooling, even during afternoon peak temperatures, caused the split-system/Ice Bear to run at low duty cycle.

The Knoxville system consistently was able to shift nominally 5-tons of cooling load during the designated peak hours of 12:00 noon – 8:00 pm. Measured cooling capacity from both the 5-ton unitary system and the Ice Bear tended to be slightly below 5 tons because return air temperature was in the 70°F range rather than the rating condition of 80°F, as determined by comfort needs of the space. The rating condition of 80°F is intended to mimic a mixed return air temperature including a fraction of hot outdoor ventilation air. The Knoxville system did not have a provision for ventilation air mixing and therefore the unit return air was essentially the actual room air temperature as set on the thermostat.

Figure 6-1 shows ~ 4 days of operation in August 2009 with the Ice Bear shifting peak power between noon and 8:00 pm. Outdoor temperatures on these days peaked in the high 80°s to low 90°s, with the overall outdoor ambient profile shown by the oscillating turquoise line. Power draw by the unitary system trended toward ~7,000 Watts before the Ice Bear engaged, at which point only the supply air blower remained on, drawing 1300 Watts. The Ice Bear averaged ~300 Watts for the refrigerant pump and associated controls during ice draw, making total power used during ice draw ~1600 Watts, or a reduction of ~5,400 Watts. After 8:00pm, ice draw stops and the unitary system re-engages sending system power draw back to the 7kW range. At ~ 9:00 pm, ice regeneration begins and the Ice Bear draws ~ 3,000 - 3,500 Watts until 7:00am or until ice is fully regenerated. The unitary system may run as called for during the ice generation cycle and total power is thus unitary power plus Ice Bear power, making total system power in the range of 10,000 Watts as shown in Figure 6-2.

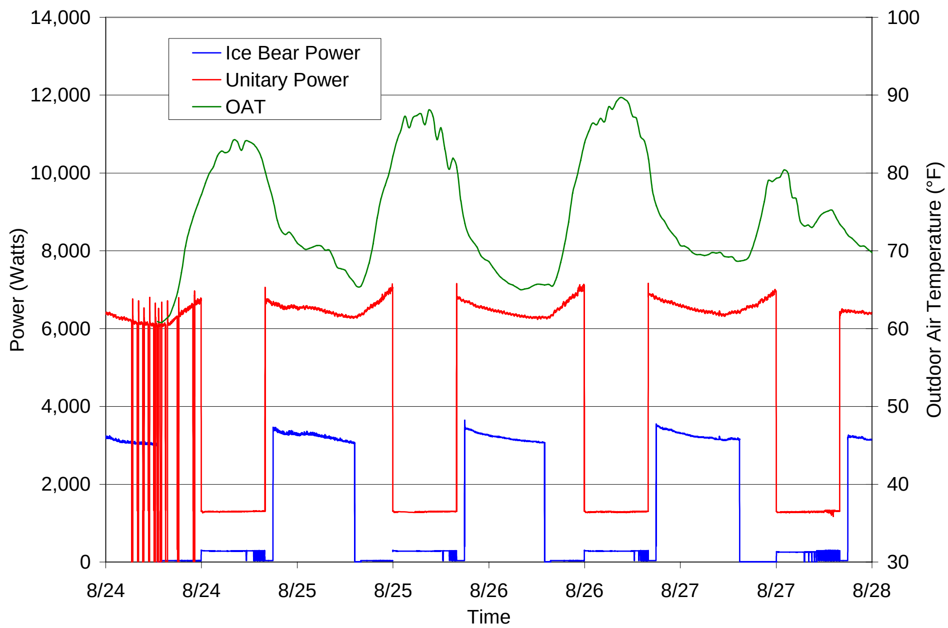

Figure 6-1
Knoxville Ice Bear 4-day Operating Profile, August 24-27 (OAT -> Outdoor Air Temperature)

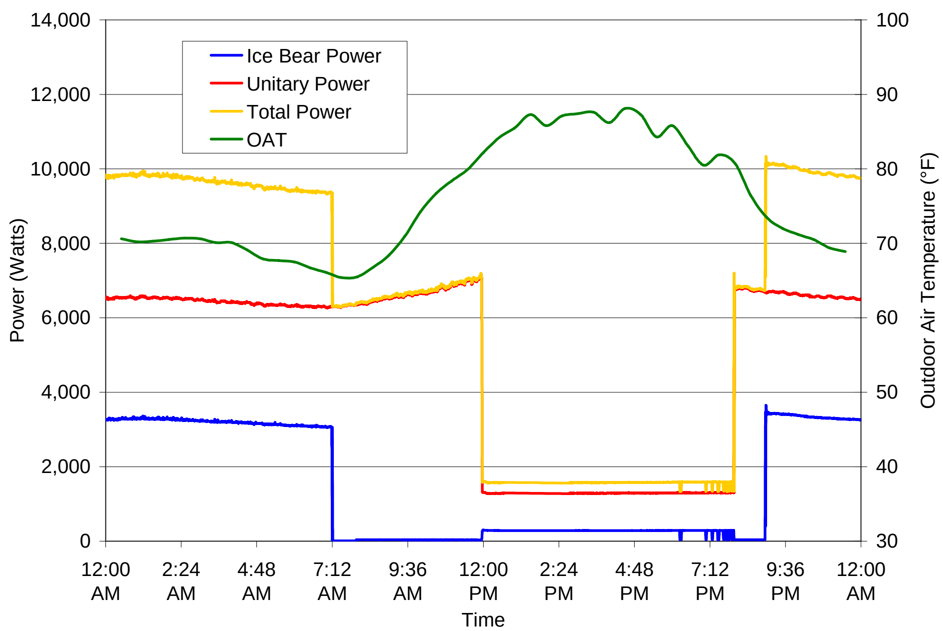

Figure 6-2
Knoxville Ice Bear One-Day Operating Profile, August 25, 2009

Return and supply air temperatures for a daily operating profile on August 25 are given in Figure 6-3. During the nighttime hours, return air temperature averages ~ 68°F and then slowly warms to ~70°F during the day. Supply air temperature generally tracks the return air. Direct expansion (DX) system cooling capacity decreases with rising outdoor ambient temperature and can cause the supply air temperature to increase relative to the return air temperature. With ice storage, dependence on outdoor temperature is removed and supply air temperature can remain constant relative to return air temperature, in effect providing a cooler equivalent evaporator coil. This has advantages for dehumidification where a colder evaporator coil will produce supply air at a lower dew point and in turn provide for a dryer space. However, assessing the dehumidification advantage depends on the specific equipment used and the operating and control protocols that are followed in an actual building.

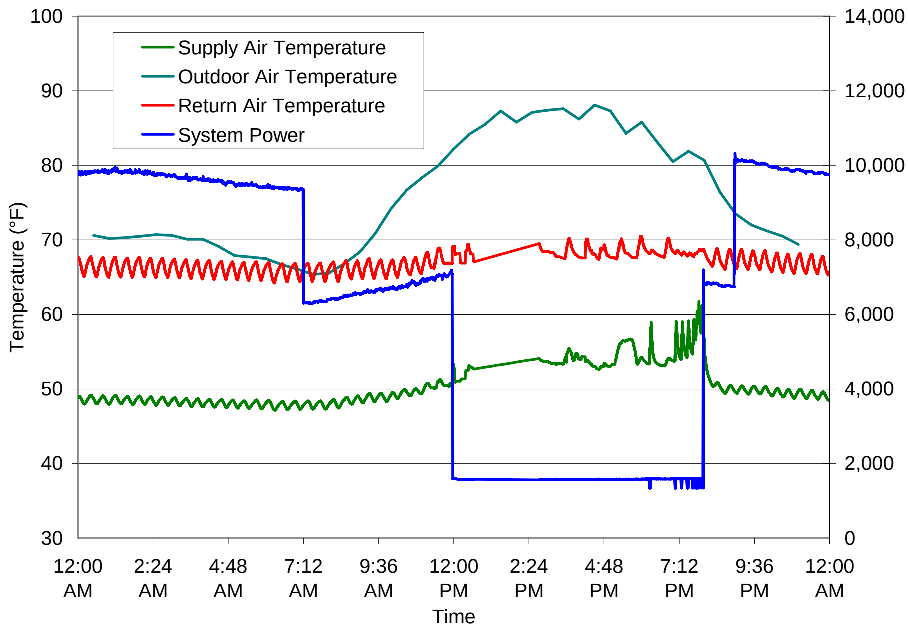

Figure 6-3
Knoxville Ice Bear One-Day Supply Air Temperature Profile

VEC System

The VEC Ice Bear 30 was allowed to operate naturally according to the protocol established at installation. Peak was defined nominally as 12:00 noon – 7:00 pm daily, during which cooling was provided by ice draw and the associated split-system did not operate, except for the indoor blower. Normal split system cycling occurred before and after the peak period as called for by the system thermostat. Figure 6-4 shows a typical operating cycle of the Ice Bear system over the course of two summer days. It shows total power consumption of the Ice Bear and the split-system, whether operating coincidentally or exclusively. Average power draw for the split system when cycled on is 4.8 – 5.5 kW. Relative duty cycle can be inferred by the spacing of the vertical power draw lines (tighter spacing indicates a higher duty cycle).

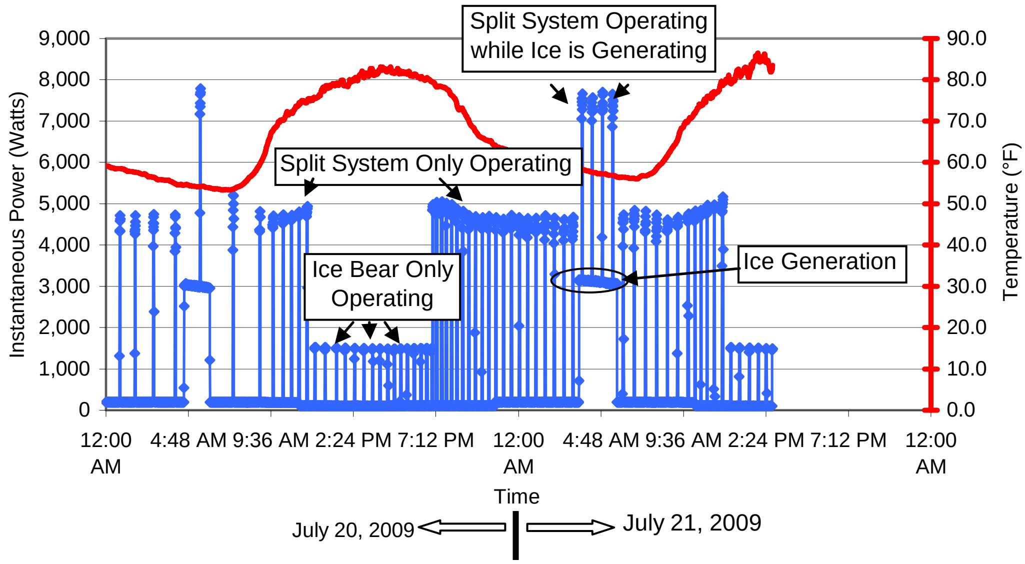

Figure 6-4
VEC Ice Bear / Split-System Operating Profile

Ice Bear is operating exclusively from noon to 7:00 pm on 7/20/09 with a maximum power draw of ~1600 Watts (combined Ice Bear refrigerant pump and indoor blower power). Operation remains below a 100% duty cycle and cycling continues in a similar pattern to the split-system. Outdoor ambient temperature peaked at ~83°F which is below the design maximum, which limited load on the system and gave rise to a relatively low duty cycle. It is shown in further data however, that even at higher outdoor temperatures the system is never fully loaded and duty cycle never reaches 50%. Low duty cycle caused by low load has the effect of limiting the aggregate effectiveness of stored cool energy.

During the evening hours ice is regenerated according to an internal algorithm of the Ice Bear and based in part on the use pattern of the previous day. Ice used during the peak hours of July 20 are regenerated the following morning starting around 3:30 am. Power draw by the Ice Bear during regeneration is approximately 3.1 kW continuously until regeneration is complete. Ice regeneration has no impact on the accompanying split system and it is permitted to provide cooling as called for by the thermostat, which is seen as the high vertical lines on Figure 6-4.

The rate of energy use is highest at night when ice is generated and cooling called for, and it is lowest during ice draw. This is illustrated in Figure 6-5 where the rising sloped pink line showing total cumulative energy used is overlaid on a single day Ice Bear/split-system operating cycle. Steeper slope indicates a higher rate of energy consumption.

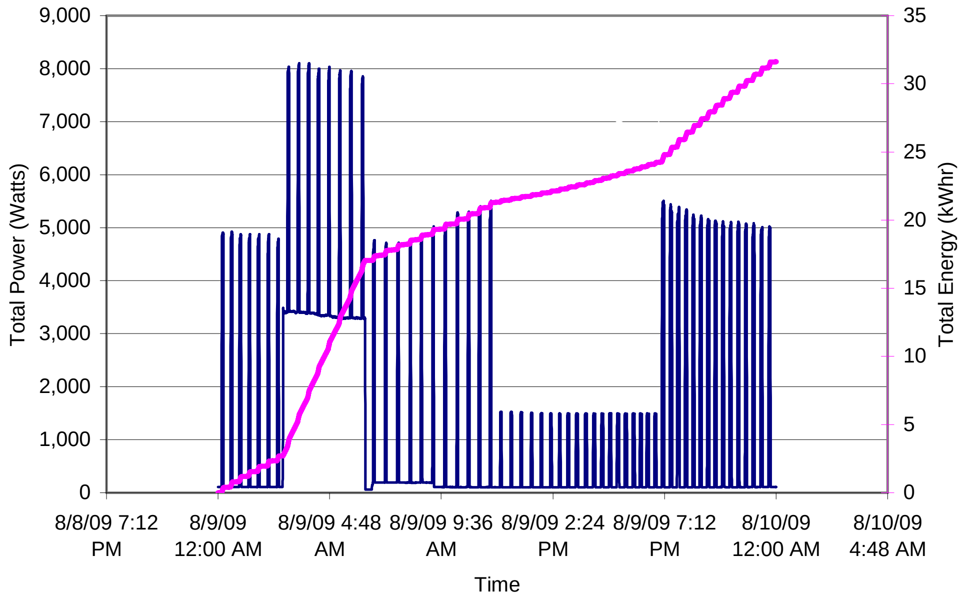

Figure 6-5
VEC Ice Bear/Split System Operating Profile and Energy Use Rate

The following three graphs Figure 6-6, Figure 6-7 and Figure 6-8, profile the 30-minute average power characteristics of various components of the Ice Bear and the split system. The VEC building is relatively lightly loaded on the days shown with split system duty cycle averaging ~25-50%. This range was typical for the majority of the summer, indicating that the nominal 5-ton system was oversized for the existing building load. Building load may change as it becomes fully occupied and filled with additional equipment. As well, summertime peak daily temperatures were slightly below normal for 2009; peak ambient temperature on the days shown ranged from 88° to 91°F.

Ice bear was programmed to provide cooling through ice draw from 12:00 noon through 7:00pm and to begin ice regeneration at 9:00pm. Ice regeneration continues until the tank is fully recharged and is dependant on the amount of capacity used during the previous day. When ice draw begins, the compressor and outdoor fan of the split system are turned off, as seen by the red line on Figure 6-6. Figure 6-7 is a close-up of the same data for August 13.

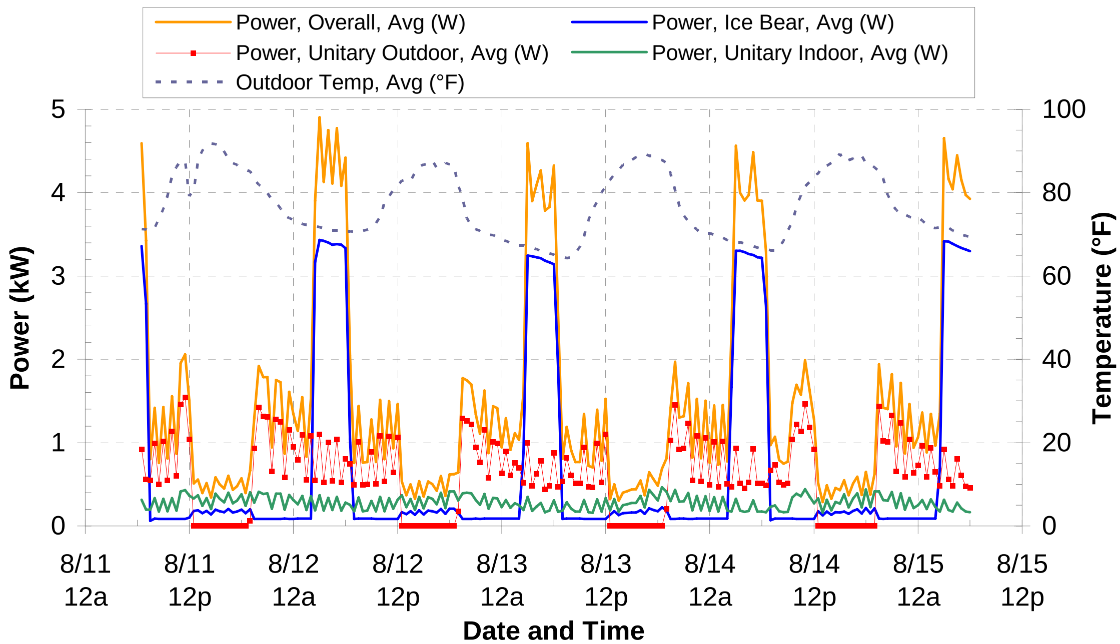

Figure 6-6
Multi-Day Operating Cycles of VEC Ice Bear System

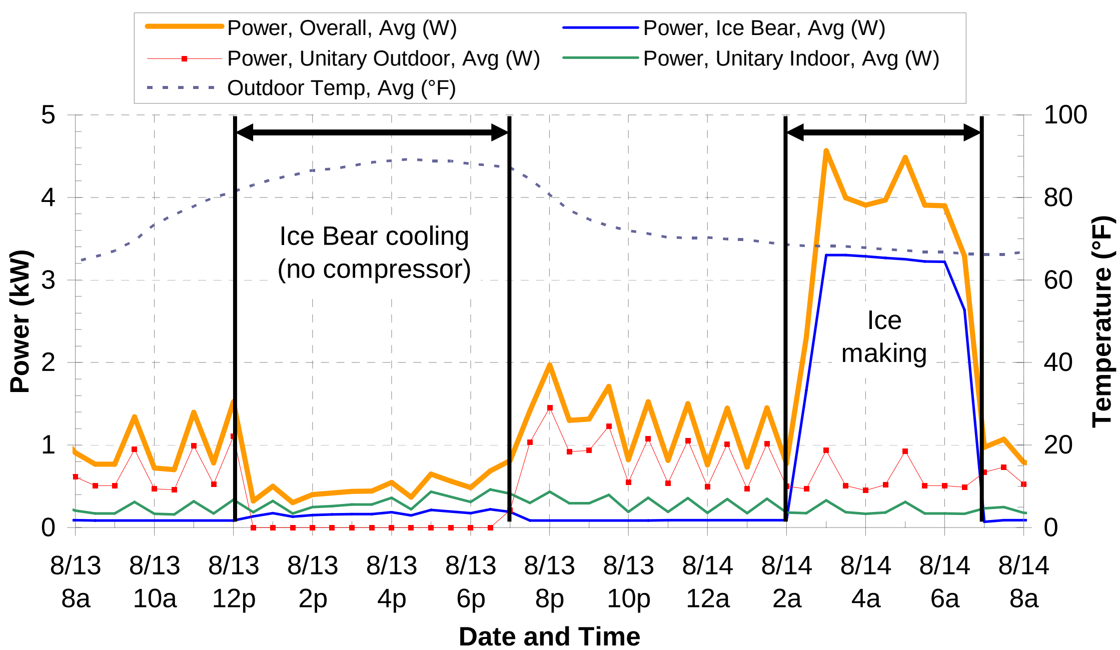

Figure 6-7
VEC Ice Bear / Split-System Aggregate Power Draw Profile

For the week of August 24 – 28, the Ice bear was turned off and the split-system was allowed to operate independently, providing all cooling to the building. Figure 6-8 shows similar 30-minute average power draw for the split system, with total system power shown by the thick gold line. Power draw tracks outdoor temperature and has a maximum with peak daily outdoor temperature. Also noticeable is that 30 minute average peak power is relatively low, never breaking 3.0 kW. This is because the 5-ton system is cycling and is never fully loaded. The blue circled section of the total power line on August 25 is blown up in Figure 6-9, with the % duty cycle added as the green line. As the graph indicates, duty cycle never exceeds 50% and averages close to 40% during the hot afternoon hours. Continuous power draw from 12:00 noon through 8:00 pm on August 25 is plotted in Figure 6-10, revealing cycling behavior even at outdoor temperatures approaching 89°F.

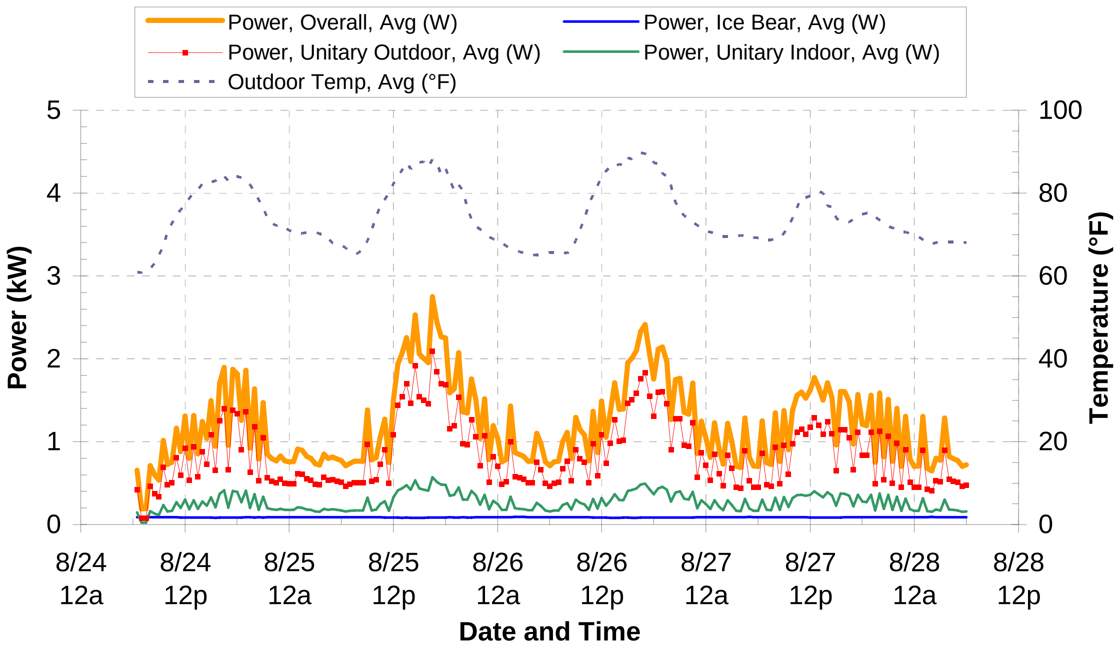

Figure 6-8
Multi-Day Operating Cycles of VEC Split System

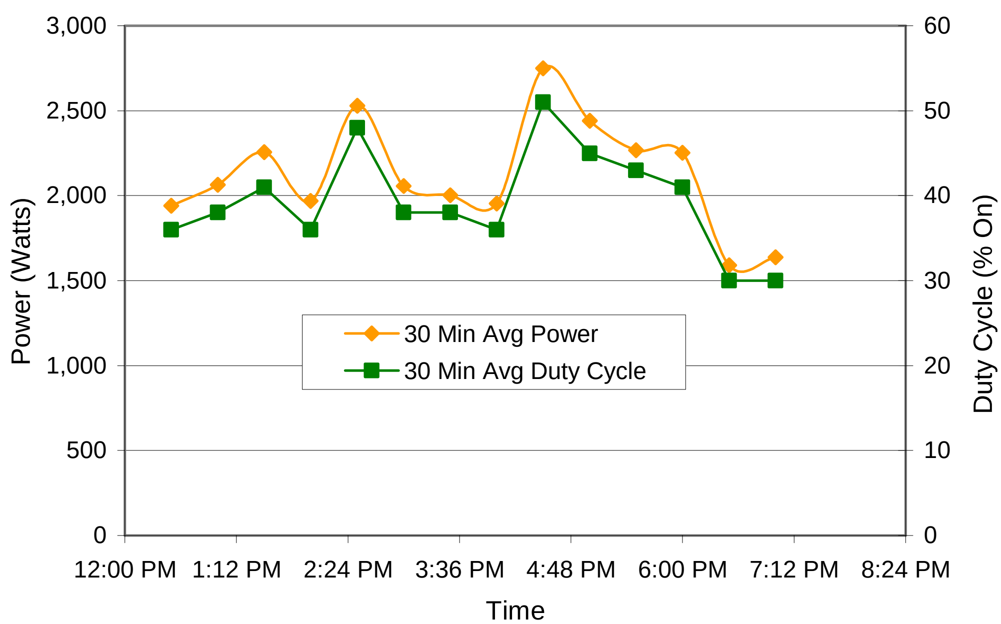

Figure 6-9
August 25, 30-Minute Average Power and Duty Cycle—Split System Only Operating

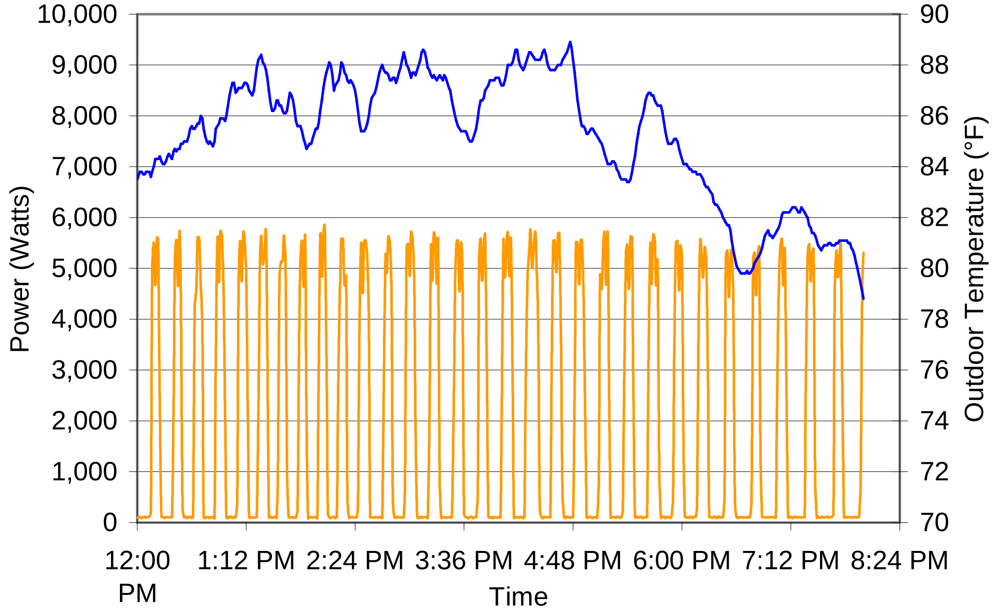

Figure 6-10
Split-System Instantaneous Power Draw—Split System on August 25, 2009

The next several figures illustrate the effect of the time interval of power measurement on the measured shifted power. With a thirty minute average power measurement, the cycling nature of system power draw is mostly blurred and power shifting at any time tends toward the longer term average. In Figure 6-11 30-minute average power draw of ~400-600 Watts is shown for the overall system during ice draw and ~1500 – 2800 Watts for the split-system without ice. Calculated 30-minute average shifted power is shown in Figure 6-12 as the difference between the two lines in the previous figure. 30 minute shifted power ranges from ~1000 Watts - ~2400 Watts in a somewhat steady pattern, with a loose tie to outdoor ambient temperature.

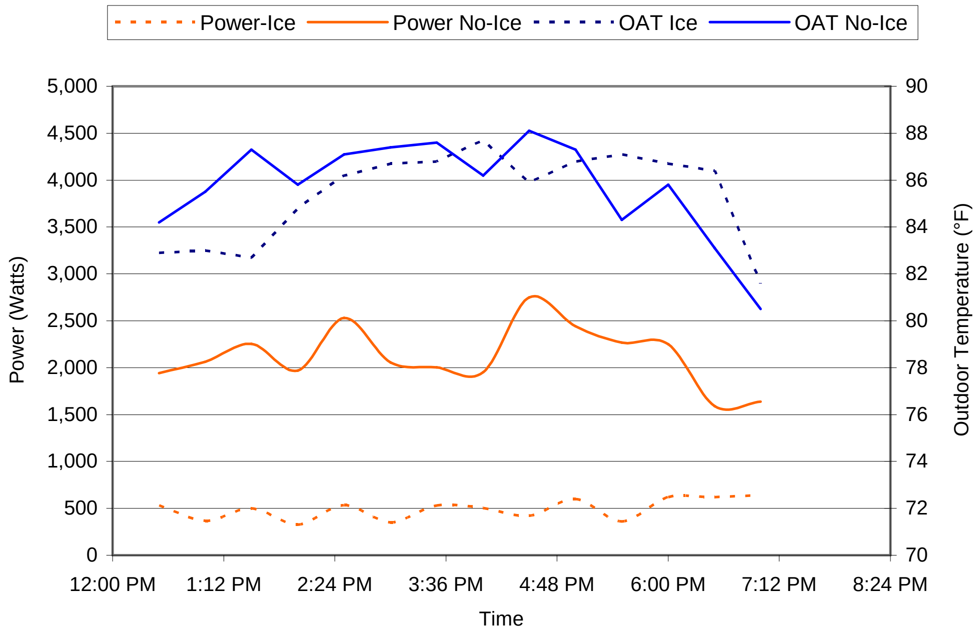

Figure 6-11
Comparative 30-Minute Average Power Draw for Split System (8/25/09) and Ice Bear (8/12/09) Operation at Similar Outdoor Air Temperatures (OAT)

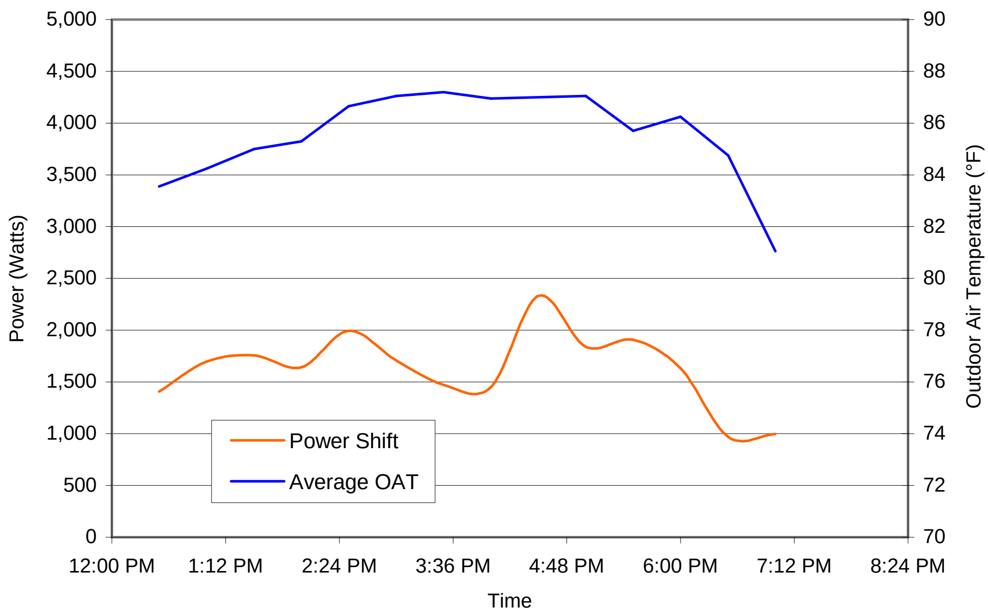

Figure 6-12
30 Minute Average Shifted Power Comparing Ice Bear (8/12/09) vs. Split System (8/25/09) Operation at Similar Outdoor Air Temperatures (OAT)

Figure 6-13 and Figure 6-14 respectively show the same data as the previous two graphs, though at a 1-minute calculated interval rather than 30-minute interval. Whereas the 30-minute interval was long enough to average away most of the cycling effect on power draw, a one minute interval fully captures the cycling and power draw reflects that. In Figure 6-13, the split system draws ~5,600 – 5,700 maximum Watts during an on cycle and the Ice Bear system draws ~1,600 – 1,700 Watts for an equivalent cycle. Figure 6-14 is a graph of the power shifted as calculated over one-minute intervals. Maximum power shifted is approximately 5,500 Watts, but there are significant periods of zero shift and some periods of apparent negative shift. This is data for a single unit; the addition of more units, even with the same operating duty cycle, would tend to wash the data toward the trend seen in the 30-minute average calculations. However, this illustrates that duty cycle, as determined by building load, is one of the most important operating parameters to consider when deploying an energy storage product.

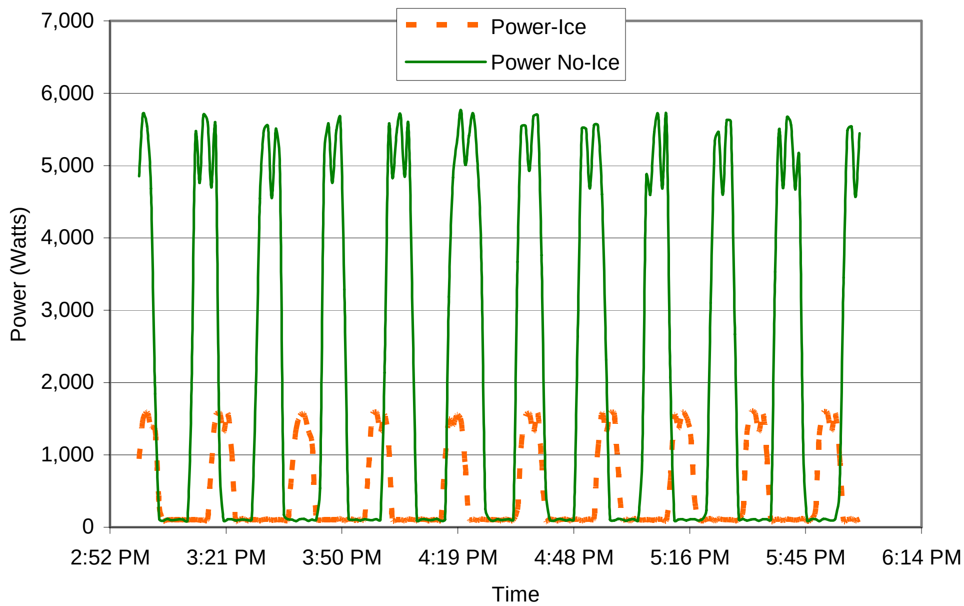

Figure 6-13
Instantaneous Power Draw for Split-System (8/25/09) and Ice Bear (8/12/09) Operation at Similar Outdoor Air Temperatures (OAT)

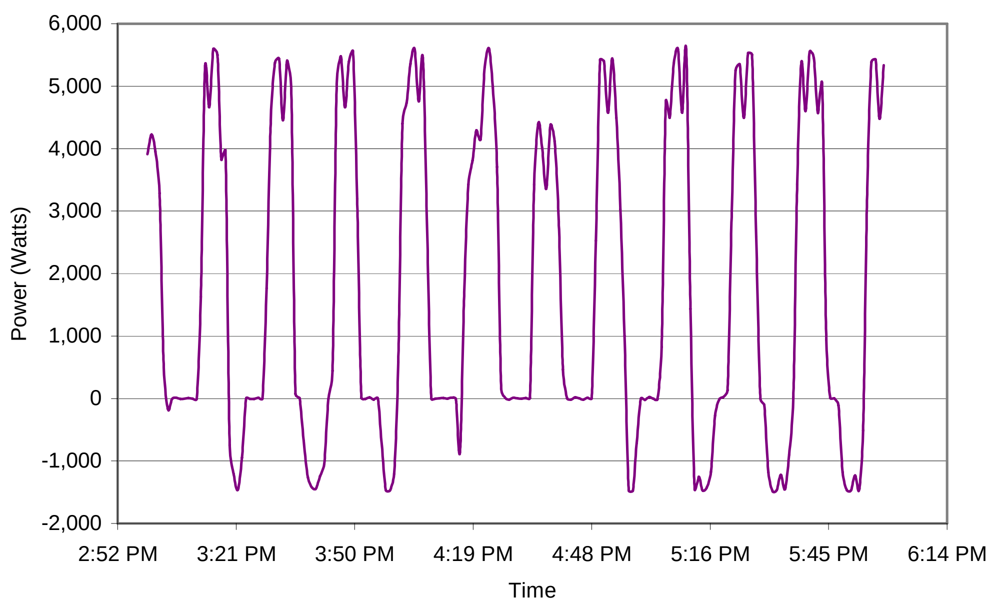

Figure 6-14

Instantaneous Shifted Power Comparing Ice Bear (8/12/09) vs. Split System (8/25/09) Operation at Similar Outdoor Air Temperatures

Energy Use

Cumulative energy is shown along with the corresponding daily temperature profile in Figure 6-15 for the split system operation over the five day period, August 24-28. A similar 5-day profile is shown for Ice Bear (system) total cumulative energy along with the corresponding daily temperature profile is given in Figure 6-16. The two graphs are lastly overlaid in Figure 6-17. Total energy consumed by the split-system over 8/24 – 8/28 is 115.5 kWh at an average temperature of 74.4˚F. Total energy consumed by the Ice Bear system over 8/11 – 8/15 is 147 kWh at an average temperature of 77.0˚F.

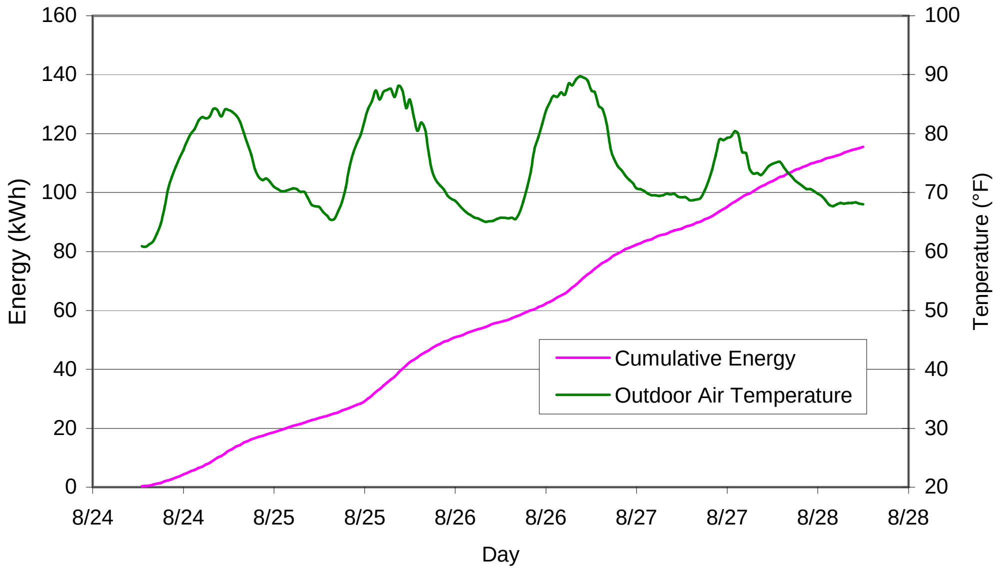

Figure 6-15
Split System Cumulative Energy over the Period 8/24 – 8/28, 2009

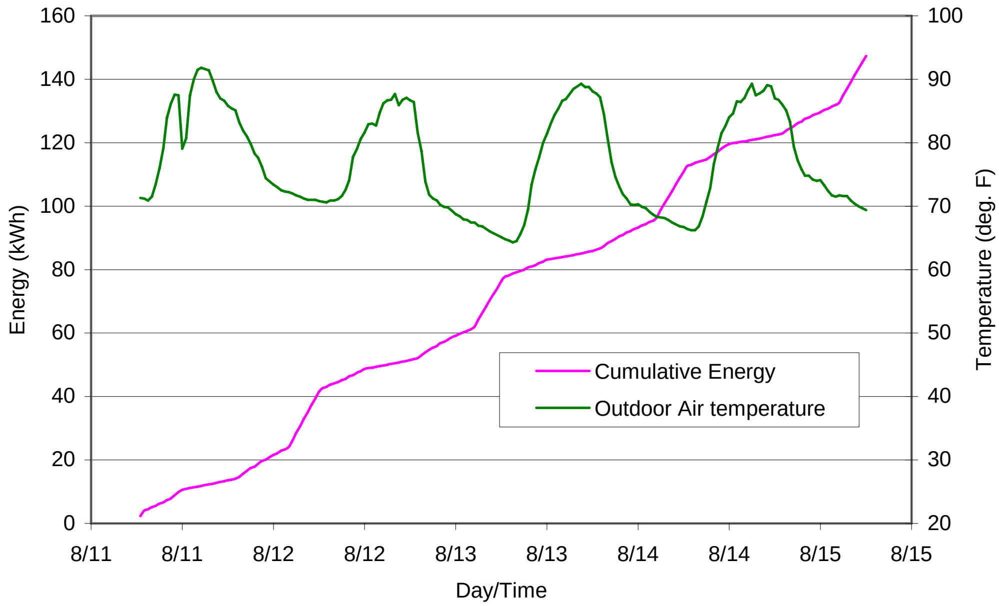

Figure 6-16
Ice Bear System Cumulative Energy over the Period 8/11 – 8/15, 2009

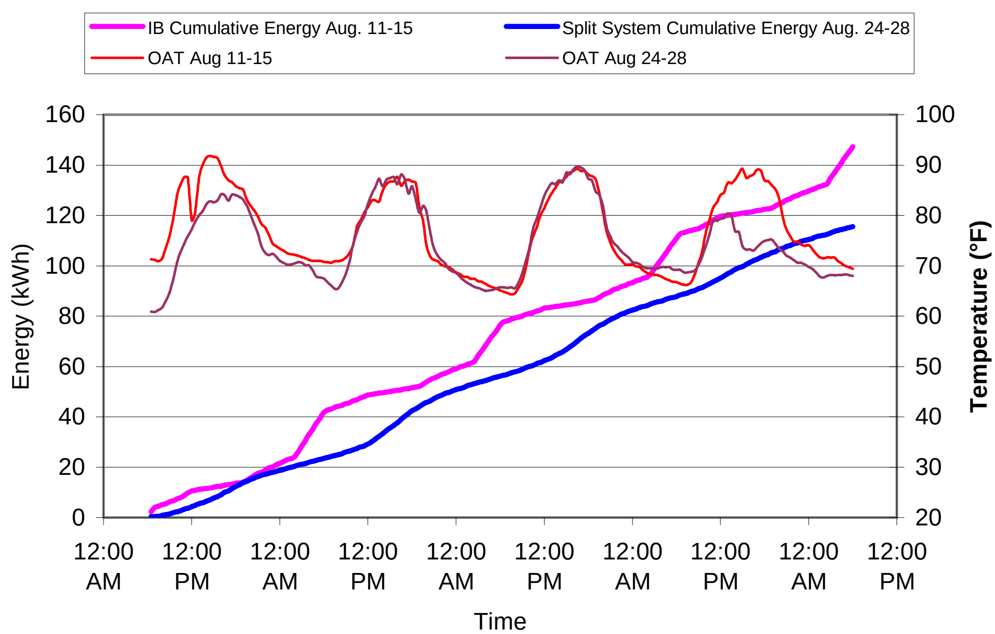

Figure 6-17
Overlaid Cumulative Energy Consumption, Ice Bear and Split-System over a Similar 5-Day Period

7 CONCLUSION

The Knoxville Ice Bear was installed in the early summer of 2008 and has operated consistently throughout the 2008 and 2009 cooling seasons. Some minor modifications were made to the system, including an upward adjustment of the supply air flow to ~2000 cfm because of excessive airflow resistance. The Knoxville system has shown the ability to maintain space cooling with ice draw both in a cycling and full-load situation. In some cases, the Ice Bear operates with a cooler evaporator, providing somewhat more dehumidification to the space. Power shifting under full load could reach ~5,000 – 5,500 Watts depending on indoor set point and outdoor air temperature.

Occupants of the space have no way to know if the unitary system or the Ice Bear is providing cooling at any moment. The systems both operate from the same standard internal thermostat that is set by an occupant in the usual way.

A second system, installed at VEC was part of construction of a new wing at their headquarters building. It was integrated with a 5-ton split system, one of five commercial style split systems serving the new wing of the building. The Ice Bear was installed by the mechanical contractor along with the other building HVAC systems and commissioned by Ice Energy in the early summer of 2009. EPRI, in conjunction with Tennessee Valley Authority, instrumented the system for comparative performance measurement and analysis of load shifting ability.

Tests at VEC showed that the Ice Bear had the same capability as in the Knoxville location to effectively shift cooling load entirely off the unitary system and onto the Ice Bear during a prescribed peak period. However, an important lesson from this installation is that in order to shift load, there must be load. Cooling load at the VEC location was significantly below the installed equipment size and significant cycling occurred, even at outdoor temperatures in the low 90°s. 90° plus temperatures are nearing the design balance point and operating duty cycles in the 80-90% range are expected.

At VEC, the duty cycle never exceeded 50%, meaning that the installed 5-ton split system never provided, on average, more than 2.5 tons of cooling. This imposes a limit on cooling load, and in turn how much power can be shifted away from the unitary system onto the Ice Bear. The Ice Bear does not determine loading; it is a slave to the piece of unitary equipment to which it is tied.

When designing an installation for Ice Bear or similar systems, great care must be taken to understand the loading and operating profile of the unitary systems to which Ice Bear will be coupled. The capital cost for Ice Bear remains constant whether it is attached to a low or high duty cycle unitary system, and if coupled to a low duty-cycle system part of the investment will be wasted on unused load shifting capacity. This is a particular challenge for new construction since cooling equipment is often specified based on rules of thumb or on rudimentary load calculations and there is also a tendency to oversize unitary equipment for a space.

In an optimal design, systems run at a 100% duty cycle at design outdoor air temperature (generally around 95°F) and at temperatures below design outdoor air temperature they operate as a reduced duty cycle as demanded by thermostatic control. Being that systems operate at reduced duty cycle over the majority of design operating conditions, there is minimal harm, in the equipment specifier's eyes, to over design the system. It will after all, simply operate at less than 100% duty cycle to a slightly higher outdoor temperature. Building occupants will hardly know the difference. Conversely, if a system is designed too small, it will operate at 100% duty-cycle at a lower design temperature, above which it will be unable to maintain the set point temperature in the space, generally triggering the ire of occupants. For this reason there is a bias toward slight over sizing of DX cooling equipment.

In existing buildings (retrofit applications) there is at least an opportunity to measure the duty cycle of existing equipment, which makes the selection of what unit to couple an ice storage device to a bit simpler. Ice storage systems like the Ice Bear are intended to shift power at the hottest times of the hottest days when air conditioning systems tend to be the most fully loaded. When considering or designing such a system, considerable care should be focused on the correct choice of which DX systems are candidates for coupling to ice storage.

Ice Energy offers 5-ton Ice Bear systems to integrate into staged 10-, 15- and 20-ton unitary equipment as a method for ensuring that the ice system is coupled to a fully loaded 5-ton load. The idea being that the Ice Bear would be coupled to the first 5-ton stage of a 10+ ton system. The idea has merit, but a designer must be sure that the installation and the building operating dynamics are such that the chosen 5-ton stage is indeed a stage that is fully loaded. One should not count on the obviousness of an installation, i.e. that something labeled "stage 1" is actually a fully loaded stage.

The principal lesson is that like many types of equipment, proper, competent engineering must guide an installation in order to access a systems' full potential.

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