Commercial Ice Machines: The Potential for Energy Efficiency and Demand Response

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ABSTRACT

Ice making machines are ubiquitous in commercial foodservice. Ranging from cube, to nugget and flake-type machines, the installed base represents one of the largest inventories of foodservice equipment. A field study of ice machines in eight restaurants confirmed that the ice production (i.e., compressor operation) was always coincident with utility peak periods. The measured duty cycles, combined with the actual electric load profiles, demonstrated the potential for off-peak operation in addition to energy saving by using more efficient machines. A second field study was undertaken to retrofit an older non– ENERGY STAR® ice machine with an ENERGY STAR® qualified unit. A dramatic (34%) reduction in energy use was documented. Furthermore, the operation of the new machine was completely "locked out" during the utility peak period (i.e., 12 noon to 6 pm) with no impact on the foodservice operation. Because of the intrinsic nature of the insulated ice storage bin, there is no energy used when the machine is not actually making ice. If an existing ice machine has sufficient production and storage capacity to meet the afternoon ice requirement, complete load shifting is a viable strategy. If there is not enough capacity for sustained load shifting over the entire peak period, then some form of automated demand response may be an option for the critical-peak days. Retrofitting existing machines with up-sized ENERGY STAR® qualified ice machines provides a tremendous opportunity for combining energy efficiency with "full-time" demand response.

Introduction

Ice machines are installed throughout the foodservice and hospitality industry, from bars, delis, and restaurants, to hotels and casinos, and other institutional kitchens. Nearly every foodservice operation has at least one ice machine. They also are found in other commercial building types, from offices, laboratories, nursing homes to hospitals. Even supermarkets, with their large refrigeration plants, utilize self-contained ice machines to supply flaked ice for their meat and seafood display. Ranging from cube, to nugget and flake-type machines, together this installed base represents one of the largest inventories of foodservice equipment.

A field study (Karas & Fisher 2007) conducted by the PG&E Food Service Technology Center (FSTC), designated Field Study No. 1 in this paper, characterized the water and energy use of eight individual ice-cube machines in commercial foodservice operations. The study documented the estimated water and energy saving potential that would be realized by replacing a given unit with a more water/energy efficient model. In addition, the measured duty cycles combined with the actual electric load profiles reflected the ice utilization patterns and provided insight into the potential for load shifting (i.e., time-based operation) of each ice machine. In continuation of the first study, a second field investigation (Karas, Cowen & Fisher 2011) was conducted by the FSTC and designated Field Study No. 2 in this paper. The project centered on the replacement of an older non– ENERGY STAR® ice machine with an ENERGY STAR® qualified ice machine of a slightly larger capacity. The goal was to quantify the resulting energy, water and associated utility cost savings as well as the additional electricity cost saving by load shifting ice production exclusively to non–peak utility periods.

Objective

The objective of this ACEEE paper and post analysis of the two field studies is to:

1. Evaluate the potential for non–peak (load shifted) operation or demand-response initiated control of existing ice machines installed in commercial foodservice facilities.
2. Where existing ice machines are not viable candidates for load-shifting or demand response, predict the potential for decreased energy use and the ability for non-peak operation if the ice machines are replaced with ENERGY STAR® recognized ice machines with increased ice making and/or storage capacity.

Types of Ice Machines

The three primary types of ice machines are cube machines, flake machines and nugget machines. Cube ice—distinct portions of clear, regularly shaped ice weighing between 0.17 and 0.5 ounces containing a minimal amount of liquid—is used primarily for keeping drinks cool. Flake ice—irregular chips of ice containing up to 20% liquid—is used primarily for temporary food preservation and in food processing. Nugget ice, also known as chewable ice—small irregular shaped portions of compressed ice chips—is used primarily for keeping drinks cool.

Equipment Subcategories

Ice machines are categorized as self-contained units (SCU), ice-making head units (IMH) or remote condensing units (RCU). Self-contained ice machines are units with the ice maker combined with an integral storage bin. These units are smaller in size than ice making head units and have capacities less than 250 pounds of ice per 24 hours. Ice making head units are modular mechanisms that can be combined with each other on top of a separate storage bin. Head units have capacities ranging from 200 to 1,900 pounds of ice per 24 hours. Storage bins are typically sized to hold 12 hours' worth of ice production. The third category is remote condensing units. Remote condensing units are machines with the condenser mounted in a remote location, typically on the roof.

Energy Efficiency and Performance of Ice Machines

The Department of Energy published two studies that focused on the energy saving potential and R&D opportunities for Commercial Refrigeration. The first study published in 1996 was conducted by Arthur D. Little, Inc. (DOE 1996) while a second study published in 2009 was conducted by Navigant Consulting, Inc. (DOE 2009). Both reports describe the different types of ice making machines and provide insight into design strategies and technologies that could be applied to increase efficiency. Both recognize the fundamental fact that larger machines consume less energy on a per-unit-ice basis than smaller machines. Figure 1 illustrates this performance characteristic using 1994 data from the ARI (now AHRI) database reported in the first DOE study. It is interesting to note that neither study suggested that the replacement of an older ice machine with a new machine of a larger capacity was an energy efficiency strategy to consider. Nor was there any reference by the two studies for the potential to shift the operation of an ice machine to non–peak periods.

While technological advancements have facilitated lower energy and water consumption rates, the introduction of an ENERGY STAR® classification for ice machines has provided the industry a catalyst for even greater progress. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) provides a Directory of Certified Automatic Commercial Ice Machines and Ice Storage Bins (AHRI 2012) containing ice harvest rate (i.e., production capacity) and energy and water usage rate data for current models that can be utilized by specifiers and end-users to select water/energy efficient models and by utilities as a basis for financial incentives to promote equipment that is more efficient.

Ice machines have become a recent target of the FSTC based on the potential for energy efficiency and off-peak operation. Figure 2 presents 2012 AHRI data for air-cooled, cube type ice making machines as a comparison to the 1994 plot (DOE 1996). Both Figure 1 and 2 denote the energy use for a 400-lb/24 hr capacity ice machine, one of the most popular sizes of ice machines. The comparison shows a nominal reduction in energy use in the order of 16% between the average ice machine in 2012 compared to 1994. If the capacity of the machine is increased to 600 lb and the best-in-class is selected, the 2012 data reflects a 32% reduction in energy use over the average 400-lb capacity ice machine on the market in 1996. This cursory analysis foreshadows the energy saving projected in Field Study No. 1 and the energy saving that was actually achieved in Field Study No. 2. It also reflects the value that ENERGY STAR® has created and the importance of utility sponsored incentive programs to stimulate early retirement of older ice machines.

Figure 1. Energy Use vs Ice Harvest Rate for Air Cooled, Cube Type Ice Machines (1994 ARI Data – Reference DOE)

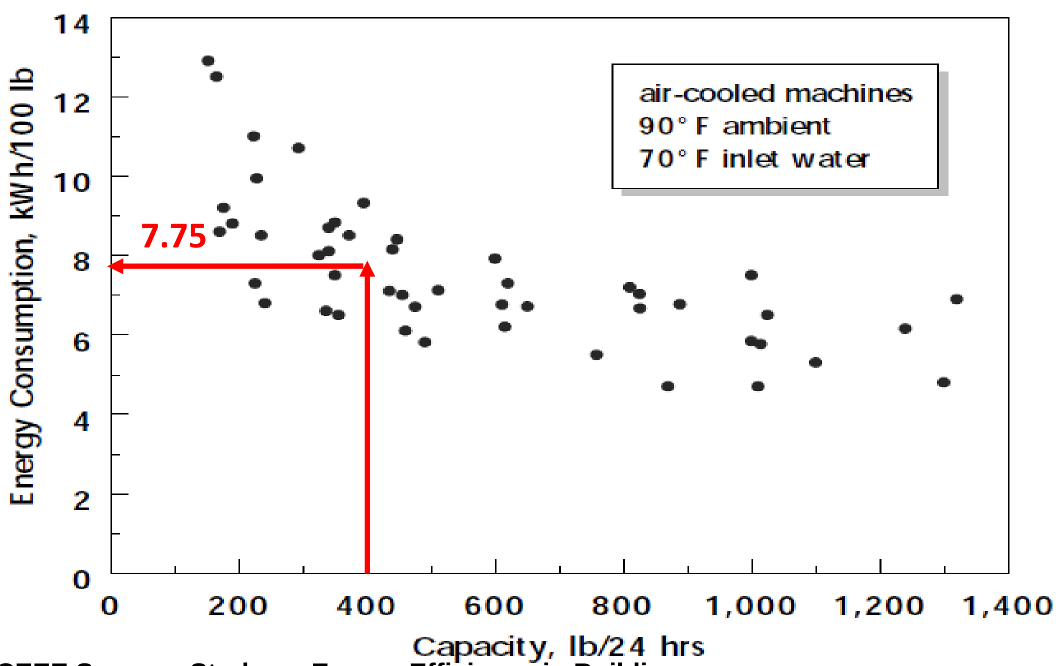
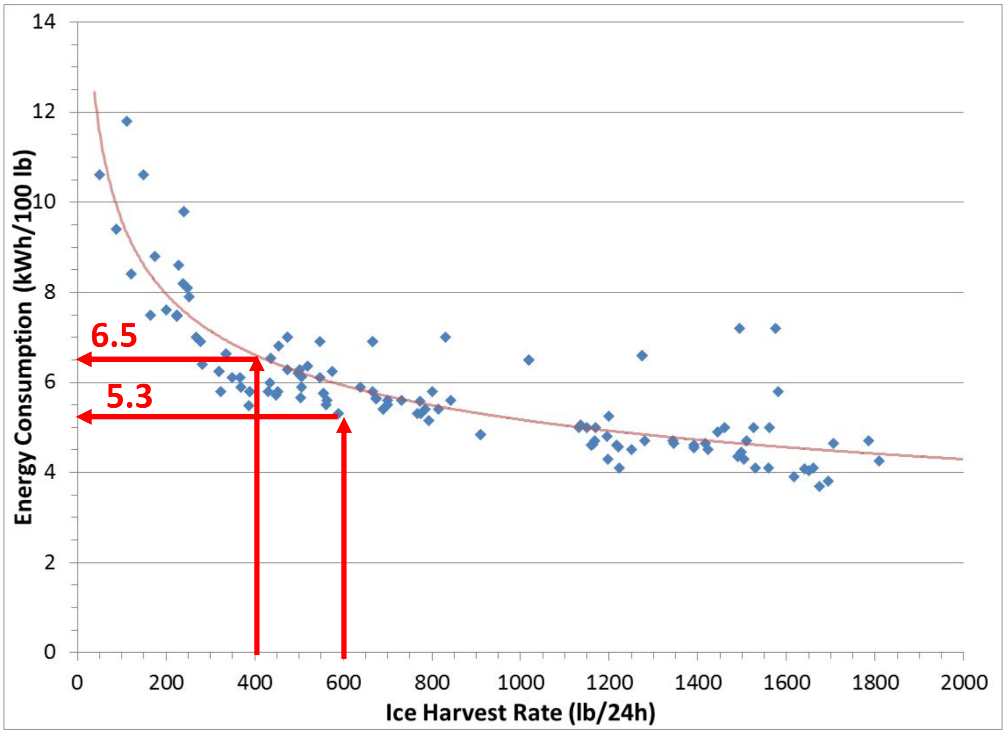


Figure 2. Energy Use vs Ice Harvest Rate for Air Cooled, Cube Type Ice Machines (2012 AHRI Data – FSTC Analysis)



National Ice Machine Inventory and Energy Load Estimate

The 1996 DOE study estimated the 1993 installed base of ice machines at 1.2 million units, with 1993 shipments of 188,000 units. The 2009 DOE study reported a 2008 inventory of 1.5 million with 2003 annual shipments of 197,000 units. Both inventory estimates were based on the assumption of one ice machine per foodservice facility, which was then applied to 201 foodservice establishments in the first study and 283 establishments in the second. If we assume a 7 to 10 year life (also referenced by both DOE studies), then the replacement unit sales alone would suggest that the inventory is well in excess of 2 million. The North American Association of Food Equipment Manufacturers (NAFEM) reported sales in 2008 of 216,000 units (NAFEM 2008).

From another back-of-the-envelope angle, the FSTC inventoried 93,000 commercial and institutional foodservice facilities in California in 2010. (Zabrowski and Mills. 2010). With California representing approximately 10% of the U.S. market, the nominal number of foodservice facilities is in the order of one million. Recognizing that many foodservice operations have more than one ice machine, the total inventory of ice machines in foodservice facilities should exceed one million units by a good margin. An unpublished inventory of ice machines compiled by the FSTC as an adjunct to the referenced PIER study estimated 155,000 ice machines in California foodservice operations. Adding in the other commercial and institutional sectors that utilize ice machines, it is plausible that the total ice machine inventory in the U.S. is in the 2.5 to 3 million range. For the purpose of this paper and high level energy load projection, the authors have assumed an installed base of 2.5 million ice machines in the U.S.

The first DOE study projected the electricity used by the 1.2 million ice machines at 9.4 TWh/yr. The second DOE study estimated that electricity consumption of the 1.5 million units to be 8.1 TWh/yr. The second study reported an energy use of 5,429 kWh/yr per unit to calculate the nationwide use. Prorating the second DOE study estimate of 8.1 TWh/yr for an inventory of 2.5 million units, the annual electricity consumed by ice machines in the U.S. is estimated to be in the order of 13.5 TWh/year. With average power consumption in the range of 1000 watts per 500 lb ice machine capacity, the authors estimate the peak demand of 2.5 million units to be in the order of 2,500 MW. The associated reduction in electricity generation by shifting the operation of ice machines to non–peak periods would be very significant.

Field Study No. 1

The FSTC selected eight restaurant sites based on convenience of location, ease of measurement, and cooperation of the owners. Water and electrical energy usage data was collected from each ice machine for a period of approximately one month. Water consumption was measured with a single-jet paddlewheel turbine water meter installed at the inlet line of each machine and used in tandem with an electronic data logger that recorded time-stamped pulses from each meter. An energy data logger was installed in the circuit breaker panel feeding each machine to record power and energy consumption.

This field study successfully characterized the water and energy use of the eight individual ice-cube machines operating in commercial food service operations. The study documented the water and energy saving potential that would be realized by replacing a given unit with a more water/energy efficient model. The measured average and peak duty cycles, combined with the actual electric load profile, provide insight into the potential for non-–peak operation of each ice machine. Although the results could not normalized for ambient air and water temperatures to match, field test results showed that most machines compared well with AHRI listed consumption rates, with only three of the eight machines showing significant differences (Figure 3). In general, the results of this study provide utilities and end users with increased confidence in using AHRI data shown in Figure 2 to estimate energy use for a given ice machine application. In that vein, Figure 4 illustrates the energy saving that could be realized from replacing the existing ice machines in the field study with a similarly sized best-in-class ENERGY STAR® unit based on the Consortium for Energy Efficiency Tier 3 air-cooled high-efficiency performance specifications (CEE 2006). For three of the machines, savings in the range of 2,300 kWh per year would be realized, and one machine demonstrated the potential to save close to 6,000 kWh per year.

Of significance to the objective of this paper was the fact that the load profile for all of the eight machines showed that they operated extensively during the utility peak period (12 pm to 6 pm) as ice was being drawn while most of the machines were shutting off at night (12 am to 6 am) with a full bin. Three of these machines would be straightforward candidates (i.e., with peak duty cycles below 70%) for a simple time clock based control (Figure 5). Another three of the machines monitored are in the “maybe” category with average duty cycles below 70% but with peak duty cycles up as high as 90% (Figure 6). These higher duty cycle machines may be candidates for a demand response program where they could be overridden on days where the restaurant experienced a high demand for ice. Two of the ice machines were simply undersized, with average duty cycles greater than 80% and peak duty cycles of 100% (Figure 7). In other words, on heavy-demand days for ice, these machines never shut off.

Figure 3. AHRI vs. Field Measured Energy Consumption per 100 lb Ice Produced

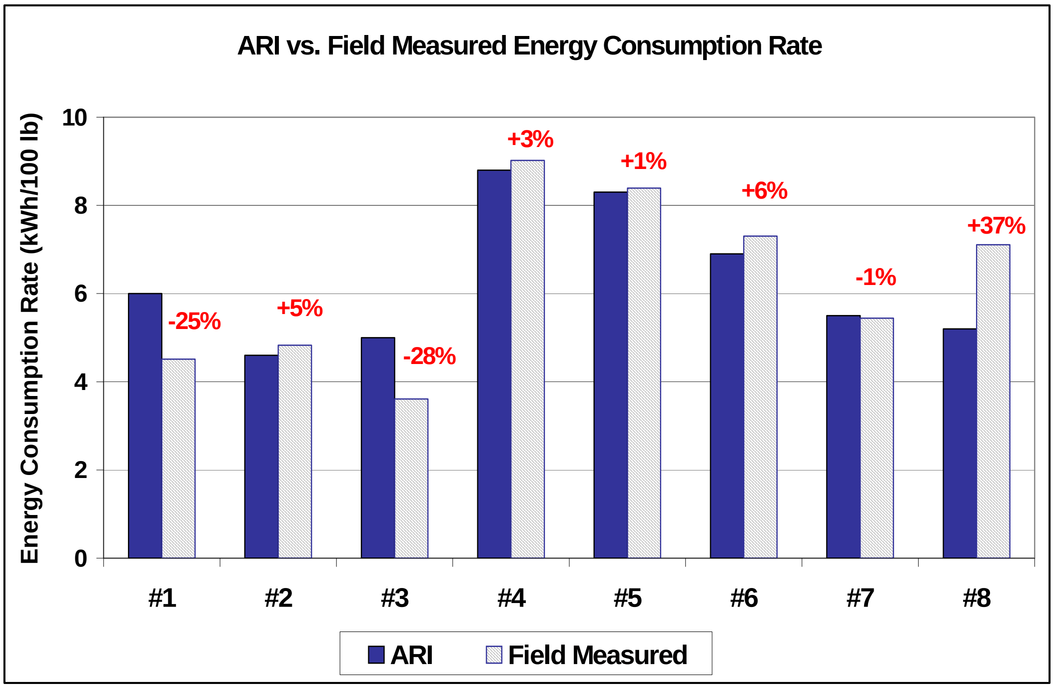
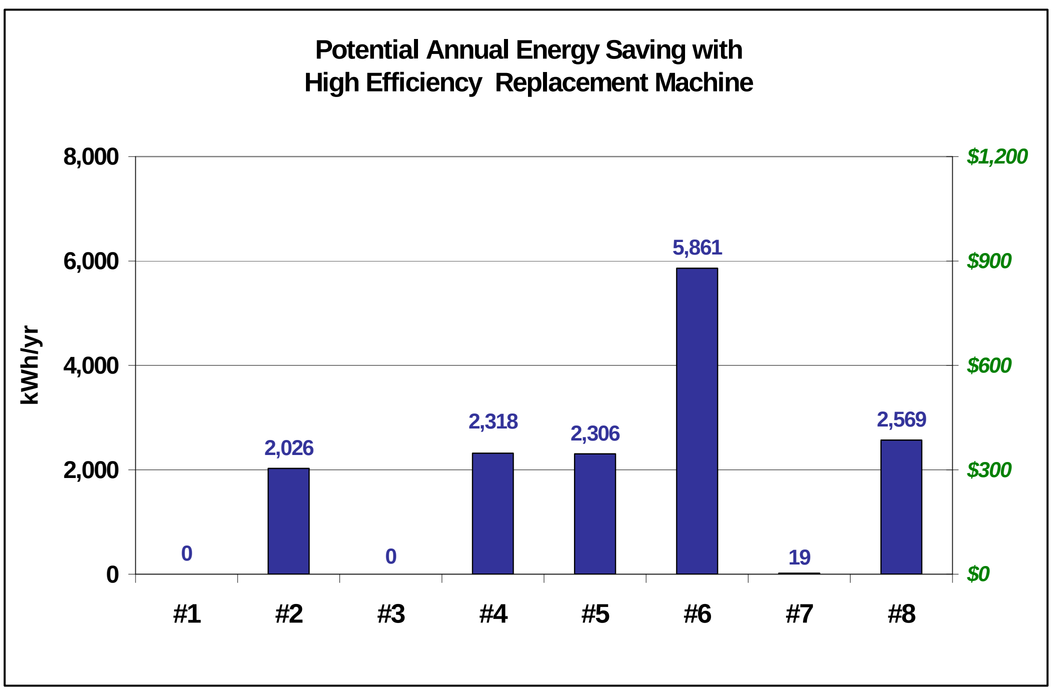


Figure 4. Energy Savings with an Upgrade to Energy Star

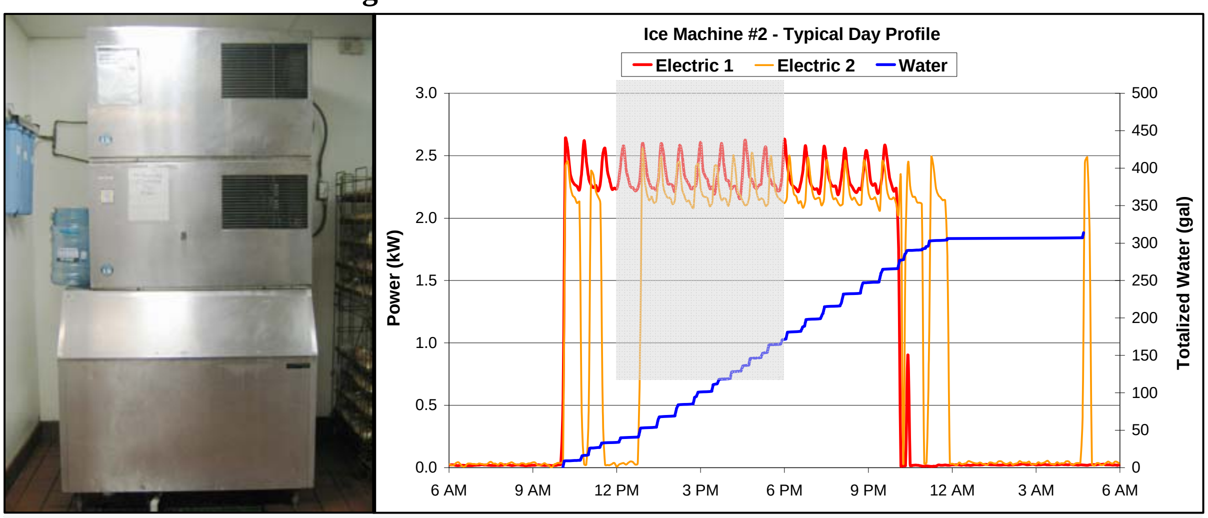


Load Shift Example from Field Study No. 1

In an effort to quantify the energy cost saving benefits that might be realized by a customer, the ice machine designated #2 in the study (Figure 5) was used as the basis for a load-shift example (without actually being implemented in the field) and an ASHRAE seminar presentation (Cowen 2010). Located in a full-service restaurant that is open for lunch and dinner seven days a week, this ice-cube machine configuration utilized one bin with two stacked air-cooled ice making heads with remote condensers. The average electrical consumption was 55.4 kWh/day with a coincident peak demand of 4.83 kW. This translated to a projected annual electricity cost of $3,172 applying the PG&E E-19 time-of-use rate schedule (PG&E).

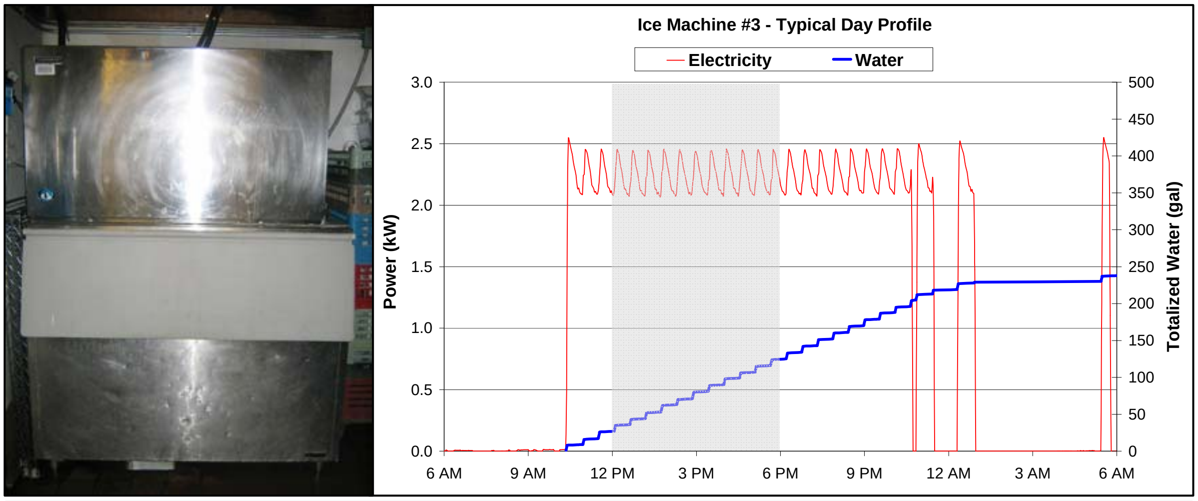
With a measured average duty cycle of 50% and a maximum of 65%, it was assumed that it would be possible to shift operation of this ice machine exclusively to non-peak periods (before noon and after 6 pm). By moving the operation of the ice machine to mostly off-peak periods (night time operation) and applying the same E-19 rate schedule, the energy cost savings were calculated to be $355—with demand charge savings yielding an additional $839. By using a simple time clock to control the operation of the ice machine, this restaurant would see an annual cost saving of $1,194, or a 38% reduction in the total electricity cost, bringing it from $3172 to $1,978. The potential exhibited by this cost saving example became the catalyst for a second field study where the FSTC actually replaced an existing ice machine with a slightly larger and more efficient machine to confirm our load-shifting theory.

Figure 5. Load Profile of Ice Machine #2.



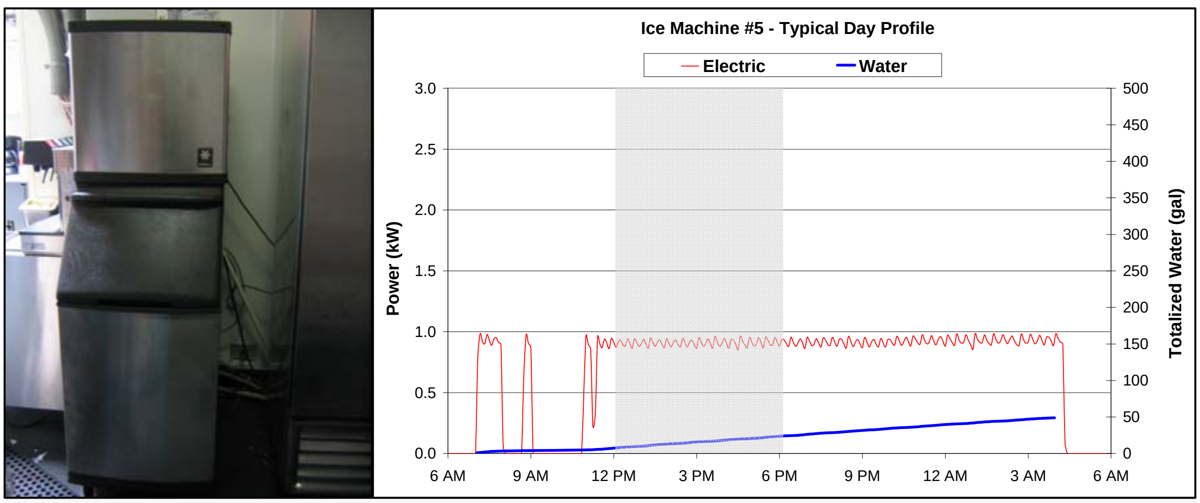
1130 lb/24 hr x 2 capacity, Avg. duty cycle = 50%, Max. duty cycle = 65%, Load shift: YES

Figure 6. Load Profile of Ice Machine #3.



1130 lb/24 hr capacity, Avg. duty cycle = 60%, Max. duty cycle = 91%, Load shift: MAYBE

Figure 7. Load Profile of Ice Machine #5.



275 lb/24 hr capacity, Avg. duty cycle = 83%, Max. duty cycle = 100%, Load Shift: NO

Field Study No. 2

The test site for this field study was chosen because it had an older model, average-sized ice-cube machine with 380 lb production capacity with 310 lb bin capacity and was assumed to have an ice consumption rate low enough to facilitate sustained peak load shifting. After consultation with the equipment supplier and facility owner, the research staff had confidence that the replacement machine with a 410 lb production capacity with a 430 lb bin capacity could be shifted to operate entirely during non–peak times.

Both ice machines evaluated in the field study were air-cooled, ice-making-head (i.e., the condensing unit and ice-making mechanism with evaporator plate are housed in a single enclosure that is placed over a separate ice storage bin) ice-cube makers. The existing ice machine was confirmed to be in proper working order and had the condenser coil filter cleaned prior to testing. The machine was instrumented with an energy meter, water meter and data loggers and was monitored for a period of three weeks. It was then replaced with the new, ENERGY STAR® machine, which was also instrumented and monitored for three weeks. For each machine, the average ice harvest weight, production capacity (under field conditions) and duty cycle were determined. Average harvest weight per cycle was determined by weighing the ice production through six cycles.

The new machine was then switched to non–peak period operation. This machine featured computerized control, which was programmed for ice production only between the hours of 6:00 pm to 12:00 am. The unit was then monitored for an additional week while confirming adequate daily ice production as well as ice accessibility (i.e., a comfortably reachable ice height in the bin) while load shifted.

Results of Ice Machine Replacement

The existing ice machine exhibited an energy consumption rate of 6.54 kWh per 100 lb of ice, an average cycle power of 1.05 kW, a duty cycle of 64%, a water use rate of 28.0 gal/100 lb of ice and a calculated field ice production capacity over a 24-hour period of 390 lb. The replacement ice machine operated with an energy consumption rate of 4.34 kWh per 100 lb of ice and an average cycle power of 0.89 kW, representing a 34%, 2.2 kWh per 100 lb reduction in energy and a 15%, 0.16 kW reduction in power. The duty cycle was 37%, reflecting a 42% run time reduction. The calculated ice production capacity was 497 lb per 24 hours, and water use was 24.0 gal/100 lb, a 4.0 gal/100 lb, 14% reduction. Overall, the increase in efficiency of the new ice machine over that of the existing machine translated to an annual energy and water cost saving of $303 for this small foodservice operation that was not on a time-of-use rate.

Load Shifting Success

The replacement of the existing ice machine with the higher efficiency machine resulted in a 0.16 kW, 15% load reduction—from 1.05 kW down to 0.89 kW. Operated with load shifting, the new machine effectively reduced the facility’s on-peak load by the entire 1.05 kW. Figure 8 shows the power profile of the old machine, and Figure 9 shows the power profile of the new machine with load shifting, each highlighting the machine’s non–operating state over the utility peak period. The power profile of the new ice machine shown in Figure 9 confirms a successful load shift strategy, with no schedule override needed. In this example, even with no afternoon ice production, the machine and bin combination were proven to have ample ice supply at all times.

Figure 8. Existing Ice Machine Power Profile: Normal Operation

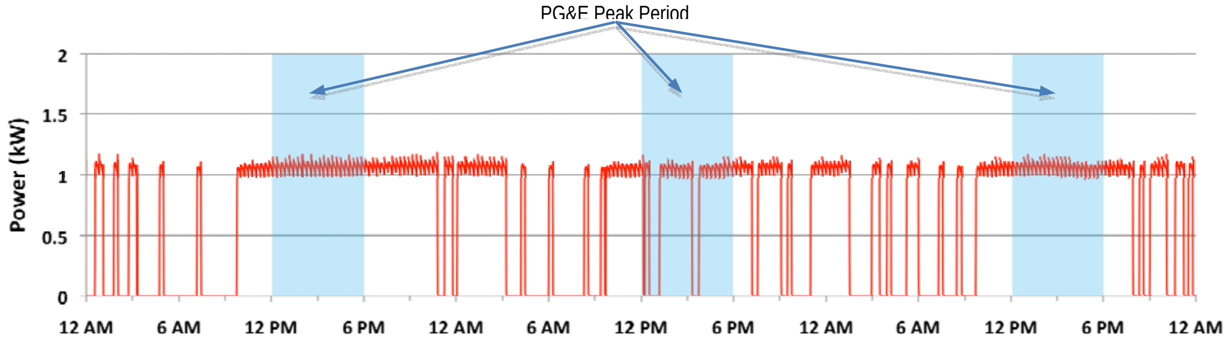
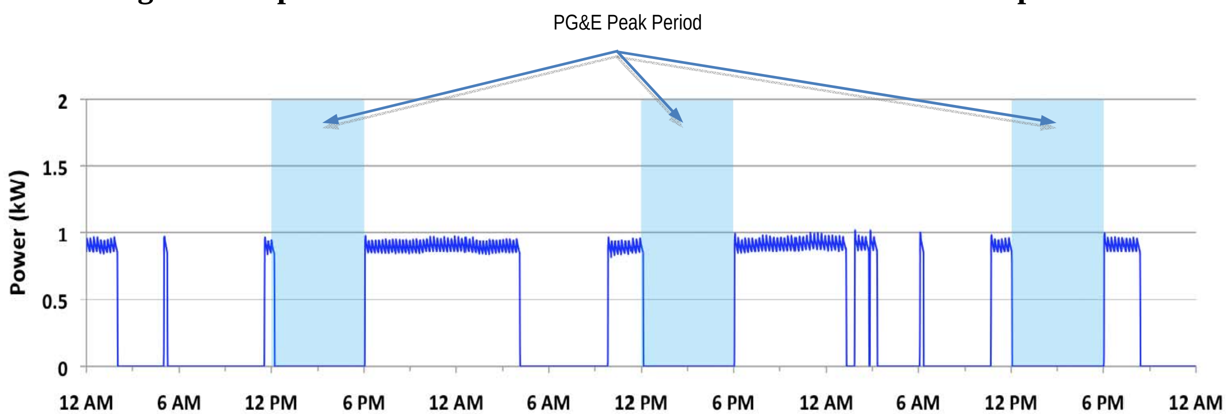


Figure 9. Replacement Ice Machine Power Profile: Load Shifted Operation.



Discussion and Conclusions

Ice machines represent one of the few pieces of electrical equipment in a restaurant that can be turned off for a significant period of time within the context of demand response without compromising the foodservice operation in terms of throughput, temperatures within the space or refrigerated cavity, or lighting levels. Thanks to the ice storage bin, ice machines have the ability to make ice during periods of the day that are not coincident with the either usage of ice or the utility peak. However, the length of time that a given machine can be turned off is a function of its capacity (both ice making and storage) with respect to the demand for ice within the foodservice facility. This measure of capacity is directly reflected by the duty cycle of the ice making machine on a given day. And as shown by Field Study No. 1, the duty cycle can vary greatly from one ice machine installation to another.

Larger capacity ice machines are inherently more energy efficient than lower capacity units. When considering only capacity, a general sizing guideline has been to choose a unit that would operate with an average duty cycle of 75% based on the ice harvest rate and the assumed daily ice requirement, which balances machine size and cost with the reserve capacity needed for high-demand days. When energy consumption is also taken into consideration, a higher capacity model with higher efficiency might be justified. What is also apparent from the data shown in Figure 2 is that, for a given capacity of ice machine, the range in energy use can vary significantly and that prudent selection of an ice machine using the AHRI data is a viable energy saving strategy.

If an existing ice machine has sufficient production and storage capacity to meet the afternoon ice requirement, complete load shifting can be achieved as confirmed by Field Study No. 2. If there is not enough capacity for sustained load shifting over the entire peak period, then some form of automated demand response may be an option for the critical-peak days. Retrofitting existing machines with up-sized ENERGY STAR® qualified ice machines provides a tremendous opportunity for combining energy efficiency with "full-time" demand response.

The potential to shift the operation of ice machines off of peak utility periods is significant. In many cases, an existing ice machine will have adequate capacity to accommodate load shifting with a simple time clock or built-in control. However, without monitored data, including both duty cycle and load profile, it is very difficult to predict whether a given ice machine is a candidate for load shifting or demand response.

In the foreseeable future, it is conceivable that all ice making in commercial facilities will be during non–peak periods, and in many cases, during the off-peak hours of the night. This potential can be realized within a relatively short period of time if utilities and energy efficiency organizations develop and promote load-shifting or demand response guidelines and programs.

Recommendations

Utilities and energy efficiency agencies need to work with ice machine manufacturers to determine eligibility of a customer's ice machine for load shifting, demand response or replacement to a larger capacity machine. This will require a low-cost instrumentation package capable of measuring power and plotting the load profile. Working with manufacturers, a dedicated effort needs to be directed towards the development of hardware and software that will interface with a signal from an electric utility within the context of a demand response program. Utilities need to consider incentive programs within their energy efficiency program portfolio, their demand response program, or both.

From an end-user perspective, purchasing a new ice machine with the intention of operating it solely off of peak requires that it and the storage bin be properly sized to provide sufficient ice reserve supply during busy hours. It is therefore important to seek advice from the manufacturers, their representatives, or other consultants to determine the appropriate machine/bin size. Whether in new or existing facilities, the potential to combine peak demand reduction with overall energy/water saving through the purchase and installation of a new, high-efficiency ice machine presents an attractive energy and water cost-saving opportunity.

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