Next Generation Vending Machine

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ABSTRACT

They're scattered throughout the United States in large cities, suburban areas, and small, rural towns. They often stand alone, but can sometimes be found in pairs and trios. They are commonplace both indoors and outdoors at gas stations, convenience stores, retailers, schools, parks, and office buildings. A total of more than 4 million vending machines dot the countryside, making them nearly as prevalent as the well-known soft drinks they frequently sell. Refrigerated vending machines represent a fertile ground for potential energy savings.

This paper will present laboratory test results of a next-generation high-efficiency vending machine. The proof of concept (POC) machine was designed by Southern California Edison's Refrigeration and Thermal Test Center (RTTC) and built by a major bottling group's manufacturer. It represents a new standard of vending machine energy efficiency, incorporating an intelligent control system, which is also capable of demand response and response to potential dangers of low grid voltage.

Preliminary tests were run without the advanced control system in place. Results show that, when compared to the baseline unit at ambient conditions of 90°F/65%RH, the POC:

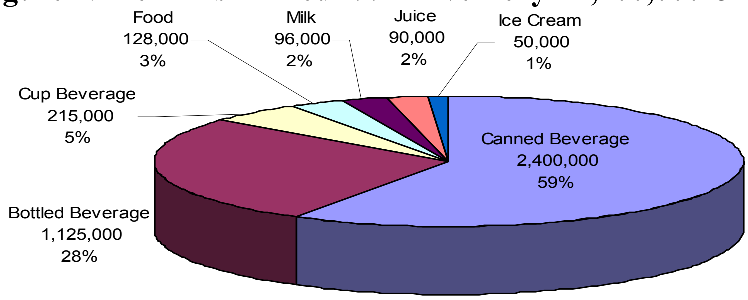
- saved 41% of daily energy use
- reduced peak demand by 56%
- maintained colder product temperatures

Lessons learned from this project will be beneficial to utilities for creating rebate programs, for state and federal energy agencies when establishing standards, for consumers wishing to place vending machines on their property, and for national bottlers and manufacturers who will be able to increase efficiency of their product lines.

Introduction

Refrigerated vending machines are designed to store food and beverages at a prescribed temperature and dispense product in exchange for currency. The U. S. refrigerated vending machine population is approximately 4,100,000, of which about 87% dispense canned and bottled beverages (Figure 1). The average energy usage for a typical vending machine is 3,000 kWh/year and is affected by many factors. (Little 1996)

Figure 1. Total Estimated 1994 Inventory - 4,100,000 Units



Source: Little 1996

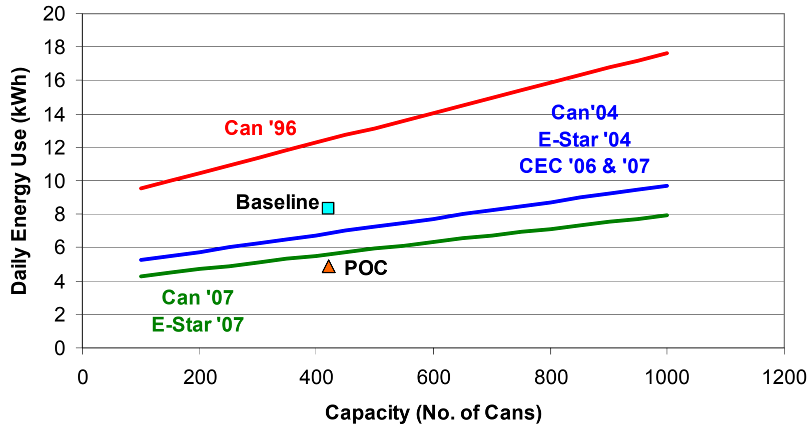
Responsibility for efficiency within the beverage vending industry is a fairly complicated subject because the bottlers (e.g. Coca-Cola and Pepsi) purchase machines from manufacturers and place them as requested by site owners. The site owner gets a small commission from the total sales, but is also responsible for paying the electric bill. This creates a situation in which there is little incentive for vending machine manufacturers to produce energy efficient vending machines. The costs involved with producing a more efficient vending machine often increase the sales price of the machine to non-competitive levels. Therefore, the burden rests on the site owner to ensure a beneficial trade-off between energy efficiency and first cost when selecting a vending machine to purchase.

Vending machines can be divided into two main categories; closed-front and glass-front. Closed-front units house products inside a completely opaque insulated compartment. Some models may have a display window where sample products are placed in view, but the products to be vended are contained behind an insulated door and cannot be seen by the consumer. These machines typically have a full-size illuminated advertisement panel on the front. Glass-front units have a transparent panel that enables the purchaser to see the product as it is vended. In this type of machine, the product itself is illuminated and used to attract the purchaser's attention. There are various vending configurations but all machines fit into one of these two categories.

Energy Efficiency Standards

The Canadian Standards Association (CSA) launched the world's first vending machine energy efficiency standard in 1996 with the introduction of CAN/CSA-C804 Energy Performance of Vending Machines. This standard contains both a test procedure for measuring a machine's daily energy consumption and a maximum daily energy consumption level (see Figure 2). The standard was developed with input from various government agencies, manufacturers, bottlers, trade associations, and utilities so that all interested parties could voice their concerns. Machines that qualify under the maximum energy rating are allowed to display a label signifying their status.

Figure 2. Vending Machine Efficiency Standards



In 2004 the United States Environmental Protection Agency (EPA) launched a program similar to the one in Canada. This program allows vending machine manufacturers to attach the EnergyStar label to vending machines which satisfy certain eligibility requirements. The requirements include a maximum daily energy use per unit of capacity, and mandatory inclusion of programmable low power modes so that certain portions of the machine turn off when they are not needed (i.e. lights turn off when there is no traffic, refrigeration system turns off at night, etc.). However, these controls are not required to be programmed when the machine leaves the factory and may never be used.

Following the EPA's lead, the California Energy Commission (CEC), under its Title-20 Appliance Efficiency Standards, instituted energy consumption requirements on vending machines in 2006. This legislation requires all vending machines sold in the state to operate at the 2004 EnergyStar level or better. Very little independent test data is available on vending machine performance. Title-20's maximum allowable energy equation was constructed based on an industry-wide sampling of vending machine manufacturers' published energy consumption data. Results of this project may be used to determine the validity of the energy consumption requirements and enhance the CEC's efforts in developing effective regulations.

Test Design

The vending machine research currently underway at Southern California Edison's (SCE) Refrigeration and Thermal Test Center (RTTC) is broken into two categories, closed-front and glass-front, each of which consists of two phases. The first phase, which is complete, involved testing of vending machines commonly found in the field today. These tests provided insight into the baseline energy use of vending machines under a variety of ambient conditions. It also hinted at shortcomings in their design with respect to energy efficiency. Results of Phase I will be published as part of ASHRAE's 2007 Winter Meeting. The second Phase, currently underway, involves the design and fabrication of a high efficiency POC machine. The POC eliminates the shortcomings observed in Phase I and contains the most efficient combination of commonly available components. After fabrication, the POC will be tested under the same ambient conditions as in Phase I so that efficiency improvements may be quantified. Lessons learned from these investigations will be shared with state and federal government agencies, major manufacturers, beverage bottlers, and SCE customers.

A series of laboratory tests were performed to quantify impacts of realistic ambient conditions on the performance of vending machines. These tests represent a range of scenarios from conditioned office space to extremely hot & dry, and hot & humid weather in the southwestern and southeastern United States. This document reports the results from performance evaluations (Phase II) of a high efficiency POC closed-front vending machine.

Design of POC Unit

In order to improve energy efficiency over the baseline unit, a three-step approach was implemented. Similar strategies apply to all refrigeration equipment.

First, an attempt was made to reduce the cooling load. The compressor must work to remove any heat that enters into the refrigerated space, thus any reduction in cooling load saves compressor energy. Major cooling load sources in vending machines are conduction through the insulated panels, infiltration of warm moist air, heat dissipation from evaporator fan motors, and load associated with restocking warm products.

After the cooling load was addressed, the efficiency of the refrigeration equipment was examined. Standard vending machines have fairly primitive refrigeration systems with little or no "energy efficient" components. All components in the POC were selected based on their efficient operating parameters and enhanced with additional equipment not found in standard machines.

To achieve the maximum benefit from efficient components, they must operate cohesively. Hence, the next step was to develop a centralized control system. This system integrates all components to take advantage of their individual energy efficient functions.

Following the steps outlined above, the RTTC developed POC specifications for the most efficient vending machine. Engineers from the vending machine manufacturer reviewed the specifications to ensure that they would be practical for a unit in the field. They also provided advice on the fabrication difficulties associated with some of the proposed energy efficiency measures.

Due to time constraints and limited manufacturing capabilities, the shell of the manufacturer's most efficient closed front vending machine was used as the starting point for this project. Therefore, some changes included in the POC are a result of the evolution of the manufacturer's product line since the baseline unit had been manufactured. However, some proposed improvements had to be removed from the specifications because the difficulty of fabrication would increase. For example, although it was a goal to increase the amount of insulation all the way around, the insulated panels could not be modified without making major changes to the assembly line machinery. On the other hand, the thickness of the insulated door had increased since the baseline was built, so the door was thicker by default.

Energy Efficient Components

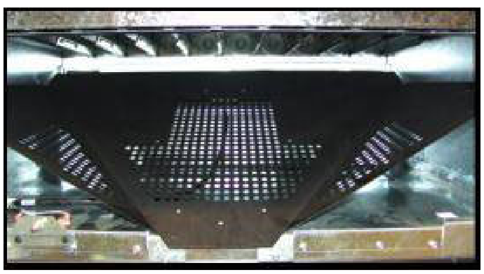
The specifications went through several rounds of review and revision before the final version could be completed. The following is a description of the components that were included in the final product.

Lighting. The advertisement panel is illuminated by two 5 foot super T-5 fluorescent lamps rated at 30 watts each. An electronic ballast consuming 7 Watts resides in the door frame. The baseline lighting system contains two 5 foot T-12 lamps consuming 50 watts each.

Reflective coating. Reduction of cooling load is the most important part of reducing energy consumption of refrigeration equipment. A highly reflective coating typically utilized on rooftops was applied to all exterior surfaces of the machine. The coating reflects solar radiation, thereby reducing the conduction of heat through the insulated panels.

Delivery chute. Standard vending machines have a delivery chute fabricated from a solid piece of sheet metal. This creates an extreme blockage in airflow circulating through the refrigerated cabinet. The evaporator fan and coil sit directly underneath the chute. The fan pushes air up through a plenum in the rear of the cabinet. When it reaches the product, the cold air comes forward into the product stacks and gradually makes its way back to the chute. In the baseline unit, the only path for return air to reach the fan was through two small openings at the front corner of either side of the cabinet. By punching holes in the chute (Figure 3), air is free to circulate back to the fan. This will reduce the power requirements of the evaporator fans and also the heat they dissipate into the space.

Figure 3. Delivery Chute with Improved Circulation (Left) and Tangential Variable-Speed Evaporator Fans (Right)



Evaporator fan. Typical vending machine air distribution systems use two propeller fans to circulate the cold air. In the baseline machine the fans were rated at 46 Watts. The propeller fans were replaced with a pair of tangential fans coupled to DC motors with variable-speed capability (Figure 3). The motors only draw 11W, 24% of the power consumed by the standard motors and the fans are better-suited to this application. Unlike the standard fans, air flow can remain constant across the entire width of the coil. Additionally, the 90° throw angle allows a smoother transition between horizontal air flow through the coil and vertical flow up the back of the case. A plenum directing air through the coil and into the fan was also included to further improve airflow.

Condenser fan. In the baseline unit, a condenser fan powered by a single-speed shaded-pole motor was situated between the coil and compressor. It was replaced with an integrated ECM motor / fan unit capable of variable speed operation. Variable speed enables the controller to take advantage of the ambient air temperature to float the head pressure, which in turn reduces stress on the compressor. Additionally, a shroud was added to direct air through the entire width of the coil and increase its heat transfer effectiveness.

Compressor. All standard vending machines contain small hermetically-sealed reciprocating compressors. In the POC machine, a new model of variable speed compressor was used. It is the first deployment of a second-generation model line and contains an integrated inverter and control hardware. The controller algorithm uses a thermostat input to determine when cooling is needed and was developed for drop-in replacement of existing single-speed vending machine compressors.

Liquid to suction heat exchanger. A liquid-to-suction heat exchanger allows heat in the refrigerant entering the evaporator to be transferred into the suction gas. This results in cooler refrigerant entering the evaporator with the inherent ability to absorb more heat from the air. In the baseline unit, a crude liquid-to-suction heat exchanger was employed by soldering the suction and liquid lines together. For the POC, a tube-in-tube type of heat exchanger commonly used on commercial ice machines was included. Here, the liquid line is suspended and completely immersed in the suction line through two and a half turns of a vertical coil.

TXV. Vending machines typically use a capillary tube to control refrigerant flow through the system. Thermostatic expansion valves (TXVs) are much more adept at precisely controlling refrigerant flow, but standard TXVs are not available in the small size needed for vending machines. An innovative pulsating TXV suitable for the required capacity range was implemented.

Evaporator and condenser coils. The coils in the baseline unit were small standard fin-and-tube coils. By increasing the coil heat transfer effectiveness the overall system efficiency is greatly improved. Both new coils were constructed to stretch across the entire width of the cabinet to take advantage of as much heat transfer surface area as possible. In addition, the inner surfaces of the tubing were enhanced with a helical cross groove pattern. This pattern creates turbulence in the refrigerant and increases the heat transfer effectiveness between the refrigerant and the coil material. The evaporator coil utilizes copper tubing and aluminum fins while the condenser is comprised of copper tubing and copper fins.

Controls. For all of theses components to work together in an efficient fashion, a control system was needed. A control strategy was developed to take advantage of the variable speed capabilities of the compressor and fans, demand response capabilities, and low voltage response. The controller was designed in LabVIEW for laboratory testing so that all variables could be adjusted to determine the most efficient operating scheme. Unfortunately, due to time constraints, the control system could not be incorporated for this round of testing. Instead, a simple thermostat on/off switch was used in conjunction with the compressor's drop-in control algorithm. A third phase of the project is currently underway and will look at the impact of incorporating the control system.

Test Protocol

All tests were carried out in accordance with ASHRAE Test Method 32.1-1997. However, this set of tests was intended to be a trial run for the POC machine, so only a minimal number of sensors were installed. The instrumentation installed was not sufficient to conduct a true ASHRAE 32.1 test.

ASHRAE Test Method 32.1 requires that the vending machine under test be installed as recommended by the manufacturer. It must be placed six inches in front of a vertical wall or partition that extends at least twelve inches beyond the top and sides of the machine to restrict air circulation. Air velocity in the test chamber is not to exceed 50 fpm in the vicinity of the vending machine. The Test Method contains three separate test procedures (ASHRAE 1997):

- Energy consumption test—determines the stabilized daily and unit product energy consumption of the vending machine operating in standby.
- Vend test—determines how much cold product a machine will deliver when products are vended at a rate of two per minute, three hours after a half full machine is refilled with hot product.
- Recovery test—determines the product temperature recovery time of a vending machine when loaded with hot product.

A summary of conditions required for these tests is shown in Table 1. While all three tests are important for manufacturers and bottlers to rate the performance of their machines, the RTTC tests focused on only the energy consumption test.

Table 1. Test Conditions Required by ASHRAE Test Method 32.1-2004

Test Condition	Energy Consumption Test (Results shown in this paper)	Vend Test (Not conducted)	Recovery Test (Not conducted)
Air Temperature	90 ± 2°F and 75 ± 2°F	90 ± 2°F	90 ± 2°F
Relative Humidity	65 ± 5% for 90°F test and 45 ± 5% for 75°F test	65 ± 5%	65 ± 5%
Reloaded Product Temperature	-----	90 ± 1°F	90 ± 1°F
Beverage Temperature	36 ± 1°F Throughout Test	33 - 40°F Final Temperature	33 - 40°F Final Temperature
Average Beverage Temperature (for pretest)	----	36 ± 1°F Pretest Conditions	36 ± 1°F Pretest Conditions

The scope of this project went beyond the specified ASHRAE test conditions. After a 24 hour stabilization period, the unit was tested at the ambient conditions shown in Table 2 for 24 hours. All test room parameters were monitored to ensure compliance with the ASHRAE test standard.

Table 2. Summary of Test Scenarios for POC Closed-Front Vending Machine

Test Scenarios		1	2	3	4
Ambient Condition	Temperature	75°F	90°F	115°F	130°F
	Relative Humidity	45%	65%	45%	15%

Data Acquisition

Due to time limitations, which precluded full integration of the controller hardware and algorithms, a minimalist instrumentation plan was deployed with knowledge that a more thorough follow-up testing would occur after the controls were enabled. Therefore, although the instruments deployed for this round of testing are capable of high accuracy and are regularly calibrated, for the most part there were no redundant sensors to guard against random errors. However, using engineering intuition and results form previous vending machine tests, it was verified that all sensors were reading within expected ranges.

Edison engineers reviewed the data initially on site at the RTTC to ensure that the control parameters were within range. In the event that any of the control parameters fell outside acceptable limits, the problem was flagged. In such cases, test runs were repeated until the problem was corrected. Table 3 depicts all the monitoring channels used in this project.

Table 3. RTTC POC Closed-Front Vending Machine Monitoring Points

Measurement (# of sensors)		Measurement (# of sensors)
Room Air Properties		**Refrigerant Temperature**
Room Temp*		Compressor Suction Temp
Room RH (2)*		Accumulator Out Temp
Room Dew Point		Filter In Temp
Internal Air Properties		Filter Out Temp
Evaporator Air Inlet Temp		Evaporator Ref Out Temp
Evaporator Air Outlet Temp		TXV In Temp
Product Temperature		TXV Out Temp
NTBV Product Temp*		**Pressure**
Electrical		Discharge Pressure
Compressor Power		Suction Pressure
Total Power*		

* Required by ASHRAE 32.1.

Test Facility

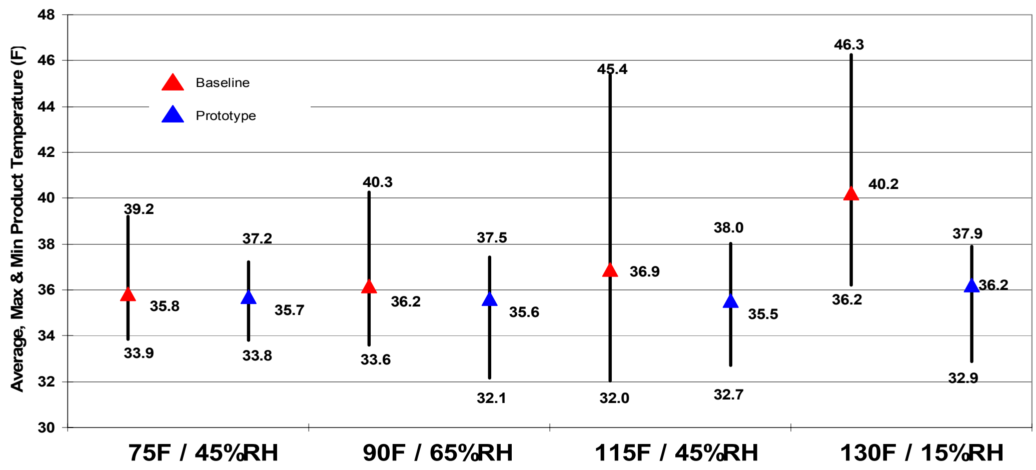
Both the baseline and POC vending machines were tested in environmental test chamber #4 of the RTTC. This room maintained precise temperature and humidity levels by using a state of the art heating, cooling, humidification, and controls systems.

Discussion of Results & Conclusion

Vending machine performance is typically evaluated in two ways: its ability to keep the next-to-be-vended (NTBV) product at a specified temperature and the energy consumed to satisfy the temperature requirement. Results from the four 24-hour energy consumption tests at different ambient conditions are presented in this section and allow a closer look into the operational characteristics of the POC machine. Also included are comparisons with performance of the baseline unit under the same ambient conditions.

Figure 4 depicts the average NTBV product temperature over the entire duration of each test. During all tests the POC unit was able to maintain a 36°F NTBV product temperature. Overall, the POC closed-front vending machine showed marked improvement over the baseline unit under all ambient temperature conditions. Product temperatures were maintained when the ambient temperature rose above 115°F; a task which the baseline unit failed to achieve (Figure 4).

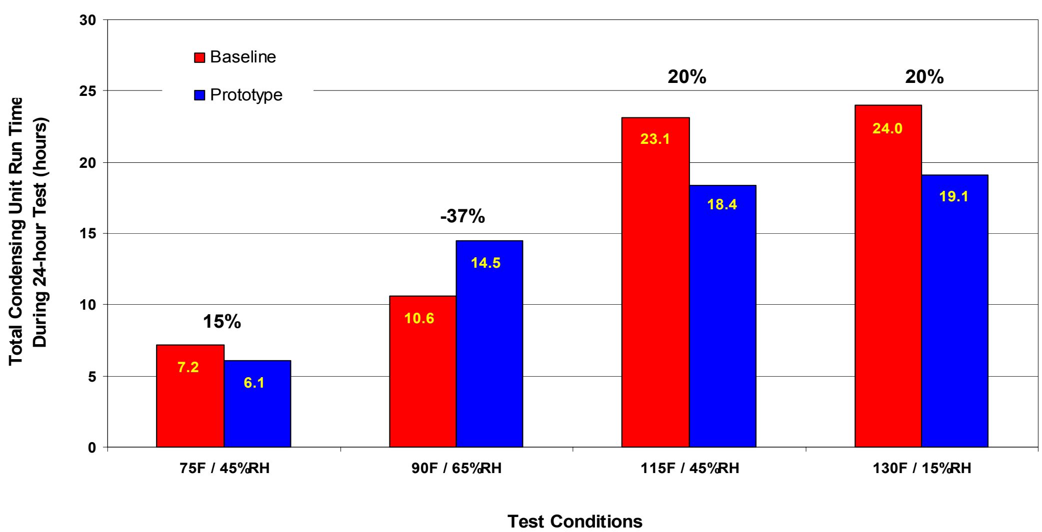
Figure 4. Comparison of Baseline and POC NTBV Temperatures



As the ambient temperature increased, the condensing unit had to run for a longer period of time to attempt to satisfy the cooling load (

Figure 5). The run time increased from 6.1 hours in the 75°F test to 19.1 hours in the 130°F test.

Figure 5. Comparison of Total Condensing Unit Run Time over a 24-Hour Test Period for both the Baseline and POC Units



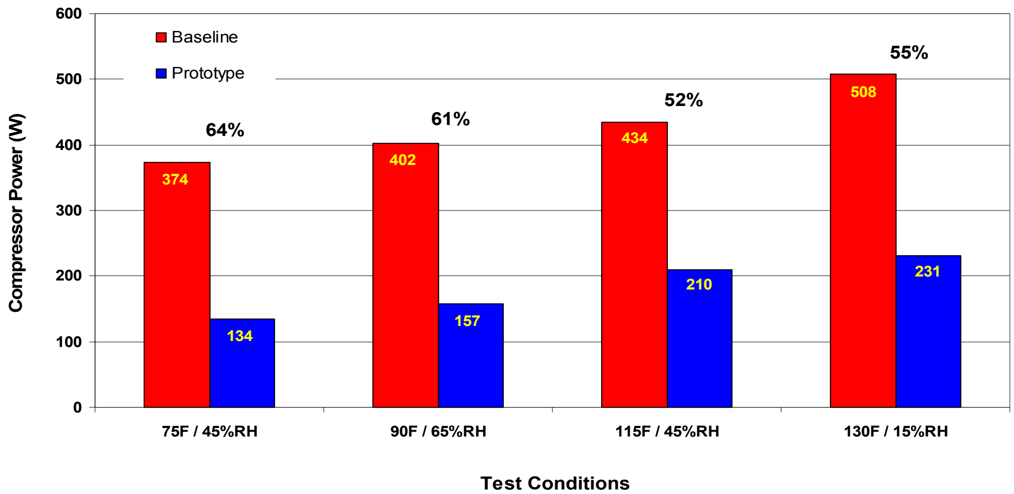
The variable speed compressor allows the refrigeration system to meet cooling capacity requirements in a much different fashion than a single speed compressor. Condensing unit run time for the POC unit was significantly less than the baseline except under the 90°F ambient condition (Figure 5). The fact that it cycled off during the high temperatures implies that, due to cooling load reductions, the variable speed compressor did not reach its full cooling capacity.

Compressor power consumption showed a slight increase as the ambient temperature increased (Figure 6). The total vending machine used 244 watts at 75°/45% and 330 watts at

130°/15%, an overall increase of 86 watts (35%). The compressor was responsible for 55-70% of the unit's total power demand.

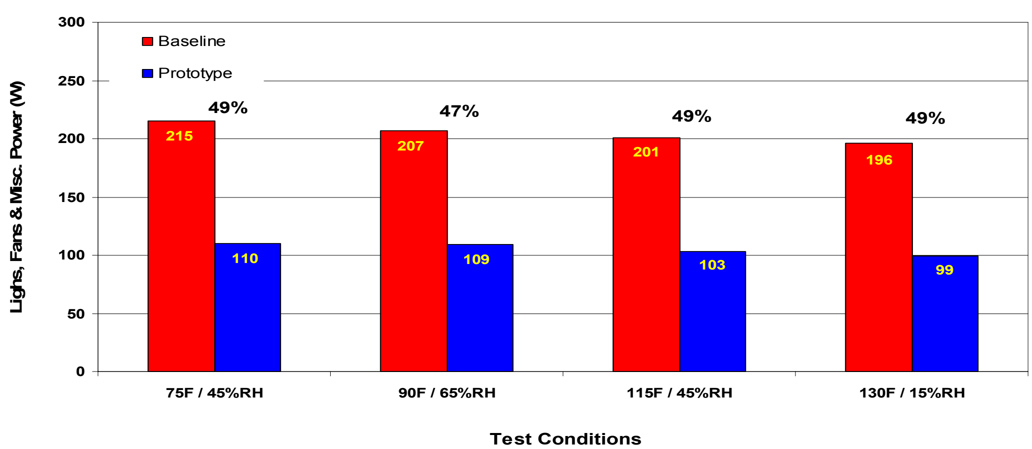
The compressor is by far the largest power consumer in the unit but the variable speed compressor showed a drastic reduction in power demand from the baseline (Figure 6). Under all test scenarios, the compressor demand was at least 52% less than the single speed baseline compressor.

Figure 6. Comparison of Compressor Power Demand over a 24-Hour Test Period for both the Baseline and POC Units



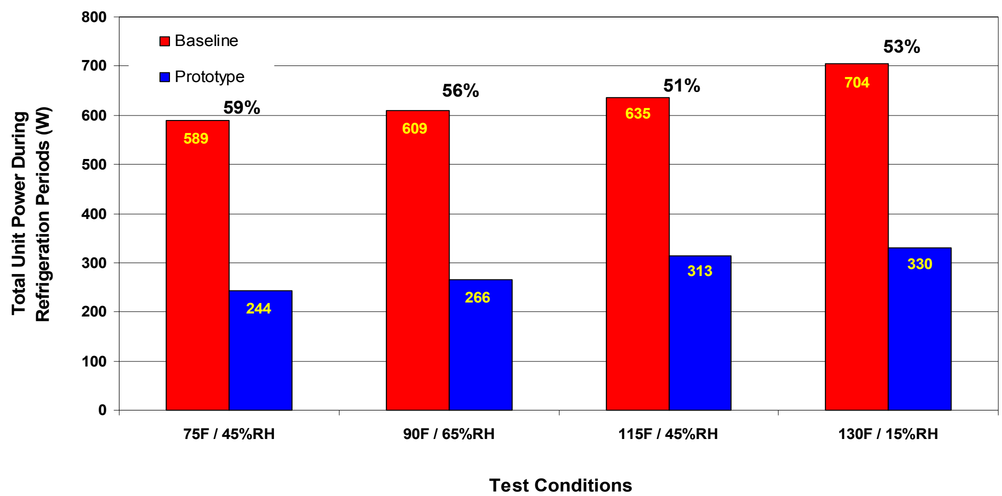
Power demand of the evaporator fan, condenser fan, lighting and miscellaneous equipment generally did not deviate as the ambient conditions changed. Improvements to the lighting system, fans, and other components cut their combined demand nearly in half for all test conditions (Figure 7). Similar to the baseline unit, there was only a slight decrease as the ambient temperature increased. Note that the POC unit did not have any money handling equipment installed. In the baseline unit the money handler demand was approximately 7 Watts, so its omission is relatively insignificant.

Figure 7. Comparison of Lights, Fans and misc. Power demand over a 24-Hour Test Period for both the Baseline and POC Units



The total unit power increased by 86 Watts as the ambient temperature changed from 75°F to 130°F (Figure 8). In the baseline unit, this increase was 115 Watts. When comparing the total unit demand to the POC under the same operating conditions, it was reduced by 51 to 59% for all scenarios.

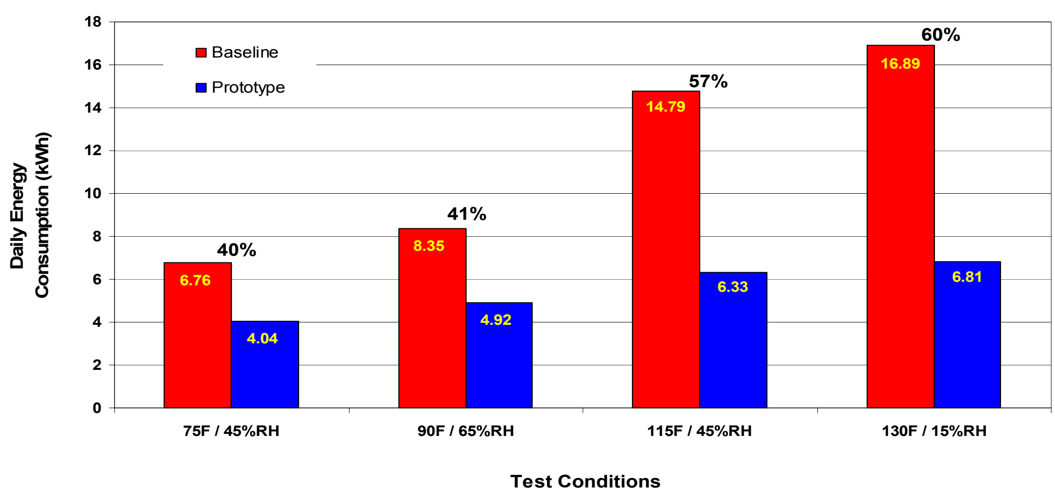
Figure 8. Comparison of Total Unit Power Demand over a 24-Hour Test Period for both the Baseline and POC Units



Energy consumption of the POC rose by 69% as the ambient conditions changed from 75°/45% to 130°/15% (Figure 9). This was caused both by the increased compressor power demand and increased condensing unit run time observed as the ambient temperature rose.

Daily energy consumption of the POC unit remained below 6.9 kWh for all tests (Figure 9). As the ambient temperature increased, energy consumption increased by 2.77 kWh (69%). The baseline unit performed less satisfactorily, showing an increase of 10.13 kWh (150%). Energy savings at the same test condition ranged from 40% to 60%.

Figure 9. Comparison of Total Daily Energy Consumption for both the Baseline and POC Units



These tests have shown that the strategy of reducing cooling load and incorporating energy efficient components into a vending machine was successful in maintaining better control of product temperatures while reducing electric demand and energy consumption. Although the instrumentation plan was very limited, the most important variables were monitored to gage the POC unit performance. A subsequent set of tests will monitor performance with the control system in place. It is anticipated that additional energy savings will result from implementing this final segment of the initial strategy.

Clearly, the POC unit outperformed the baseline unit under all ambient conditions. Comparing the POC's daily energy usage with equivalent capacity 2004 EnergyStar (or 2006 CEC Title 20) performance data indicates that the POC consumes 28% less energy (see Figure 2).

Findings from this project are anticipated to play an instrumental role in enhancing the California Appliance Efficiency Standards as well as the Department of Energy's work addressing the Energy Policy Act of 2005. Furthermore, SCE is exploring venues through which the information from this project can be included in statewide energy efficiency incentive programs.

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