FLASTAR: Measured Savings of a Comprehensive Energy Retrofit in a Florida Elementary School

John R. Sherwin, Research Engineer
Danny S. Parker, Principal Research Scientist

Florida Solar Energy Center
1679 Clearlake Rd.
Cocoa, FL 32922-5703

ABSTRACT

This paper describes the final results for the pilot demonstration of the Florida Public Building Loan Concept. This loan program was intended to provide low cost funds to eligible public entities for upgrade of building energy systems. The site was an elementary school in Central Florida which served as the pilot project to demonstrate energy savings in public buildings similar to that achieved by the Texas LOANSTAR program (Verdict et.al., 1990). Termed FLASTAR (Florida Alliance for Saving Taxes and Resources), the study entailed the comprehensive metering of a test site to demonstrate energy savings potential. Over twenty channels of weather and sub-metered energy data have been collected since April 12, 1995. Annual billed energy consumption for the 41,000 square foot facility was approximately 775,000 kWh (60 kBtu/ft^2) or $55,200 in the base year (1994)

aging chillers resulted in 30% reduction to cooling energy use. The second retrofit was occupancy sensor controls for classroom and office lighting which were installed in December 1995. However, post retrofit data showed that metered lighting energy use actually increased after the occupancy sensors were installed. Our data, and that of other projects, suggests that the occupancy sensor retrofit may have increased lighting on-times. Previously school personnel practiced responsible manual switching, but then came to depend on automatic control after the retrofit.

The final project retrofit saw an energy management system (EMS) added in the summer of 1996. The system provided direct digital control (DDC) of the school chiller, air handlers and packaged direct expansion (DX) roof-top cooling systems. The EMS equipment reduced chiller energy use by a further 16% and air handling and DX system energy consumption by 30%.

The project retrofits were found to reduce overall school energy use by approximately 15% or 120,000 kWh per year. The annual energy savings totaled $4,600 at current energy prices, although the retrofits did not significantly impact facility peak load.

INTRODUCTION

This paper describes a pilot project intended to provide low cost funds to eligible public institutions for upgrade of building energy systems. The FLASTAR program (**F**lorida **A**lliance for **S**aving **T**axes **A**nd **R**esources) was modeled after the successful Texas LoanSTAR project [1]. Within that program, funds provided from oil overcharges are loaned to various facilities for building system retrofits. In recent years, the LoanSTAR program has saved the State of Texas some $13.7 million in veri-

Central to the FLASTAR program was the demonstration of real energy cost savings associated with each retrofit measure through comprehensive monitoring [2]. The monitoring covered a time frame to include both pre-retrofit and post-retrofit periods and included those parameters necessary to quantify resulting energy savings.

SITE DESCRIPTION

Fellsmere Elementary School was chosen from a list of several candidate facilities because it was typical of many other Florida elementary schools and was already planning a series of energy saving retrofits under the Institutional Conservation Program (ICP). It was envisioned that the FLASTAR project could piggy-back on the ICP retrofits and reveal much about retrofit performance during a pilot monitoring project.

The school is located in Indian River County, Fellsmere, Florida. The campus is comprised of the original school structure, a new wing addition, and twelve portable classrooms. This study was concerned with only the original structure, which contains 44,241 square feet of conditioned floor space. The monitored facility was built in 1982 and consists of a classroom and administrative wing as well as a cafeteria and kitchen wing. Electricity is the primary source of energy, with liquid propane used for heating and cooking.

The building has an average occupancy of 550 students and staff. Classes are held from 8:30 AM to 3:05 PM daily with faculty and staff hours from 7:30 AM to 4:30 PM. Limited janitorial staff remain until 5 PM. The first day of classes for the fall semester 1996 was August 19.

Table 1 describes the main facility building envelope characteristics excluding the portable classrooms.

HVAC SYSTEMS

The original facility heating, ventilation and air conditioning (HVAC) systems are summarized in Table 2. The system consists of both direct-expansion roof-top heat pumps for the administrative and lobby area and a chilled water system for the rest of the building. The design outside air ventilation rate is approximately 6 cfm/person based on a design occupancy of 500; per occupant ventilation rates are likely higher under average rates of occupancy. The air distribution system consist of five constant velocity air handler units (AHU) which receive return air from the 4" roof plenum with supply air ducted directly to the conditioned space. The supply and return air for the two heat pumps are ducted. At the beginning of the project, most of the equipment was approximately 12 years old and fairly inefficient.

LIGHTING SYSTEM

Interior lighting is predominantly from two-lamp fluorescent fixtures. The primary lamp utilized is theT12 34-W type, but these, along with the aging magnetic ballasts, are inefficient relative to contemporary systems. Table 3 shows the audited lighting systems in the main building.

The installed full connected lighting load is approximately 2.0 W/ft^2. This compares to approximately 1.4 W/ft^2 for more contemporary efficient lighting systems for schools [3]. A change out of the facility lighting system was identified as a potential savings measure for the facility [4].

Table 1
Fellsmere Building Envelope Components

Roof	29,906 ft^2 in main wing; 44,241 ft^2 overall. White single-ply membrane over 2" of lightweight concrete with 2" of rigid insulation on a metal deck. Suspended acoustical tile ceiling located 4" below metal deck. - Overall U-value: 0.095 Btu/ft^2/hr °F
Walls	10,905 ft^2 of gross wall area. Exterior walls consists of 4" brick on 8" concrete block with 1" of rigid insulation behind 1/2" sheetrock interior. - Overall U-value= 0.138 Btu/ft^2/hr-°F
Windows	Fixed tinted single pane glass with following glazed areas by cardinal orientation: NW: 374 ft^2 SW: 104 ft^2 NE: 212 ft^2 SE: 208 ft^2 S: 153 ft^2 E: 153 ft^2 Approximate U-value = 1.04 Btu/ft^2/hr-°F Shading Coefficient = 0.75
Doors	Steel frame doors with U-value of 0.5 Btu/ft2/hr-°F - 270 ft^2 in ten doors
Floor	29,906 ft^2; 4" concrete slab.

Table 2
Summary of Heating, Ventilation and Air Conditioning Equipment at Fellsmere Elementary

Heating Systems	
Administrative offices	Two 5-ton *Trane* split DX heat pumps (Model: RPHB-506)
Remainder	Hydronic 4-pipe system fed by 600,000 Btu liquid propane gas boiler (*Bryan CL-75*) - Two 5 hp circulation pumps
Distribution	Two pipe hot water loop carries water from boiler to AHUs and UVs.
Controls	Boilers and hot water pumps controlled by time clocks.
Cooling Systems	
Administrative offices	Two 5-ton *Trane* split DX heat pumps (Model: *RPHB-506*); EER = ~8.5 Btu/W
Remainder	Two 45-ton air cooled recip. chillers (*Trane CGAA-0506M*); 1.4 kW/ton - Two 20 hp circulation pumps
Distribution	Two pipe chilled water loop carries water from chillers to AHUs and UVs. Hydronic AHUs use a return air plenum. UVs are unducted
Controls	Manual thermostats control AHUs; chillers and pumps on time clock

Table 3
Fellsmere Elementary Lighting System Fixture Characteristics (Main Wing)

Area	F34x4 (159W)	F34x3 (132W)	F34x2 (85W)	F34x1 (44W)	Incand. (75/150W)	Total Watts
Class	0	0	378	4	0	32,306
Library	2	13	39	1	0	5,393
Kitchen	14	29	50	0	0	10,454
Admin.	1	20	26	3	½	5,516
Lobby	2	12	20	32	0/2	5,310
Total	19	74	513	40	1/4	58,979

HISTORICAL SITE ENERGY CONSUMPTION

In 1990 the total electrical consumption for Fellsmere Elementary was 592,320 kWh. By 1994 this had grown to 773,760 kWh representing an average increase in facility electricity consumption of 7% per year. This is due to the steady expansion of the facility associated with addition of a new classroom wind and more portable classrooms. Average monthly peak demand was 248 kW, varying from 149 kW in July during the summer break to 307 kW in September. Heating consisted of the consumption of 951 gallons of propane in 1995. In 1994, energy costs totaled $55,162. The facility's annual energy usage index (EUI) is approximately 60 kBtu/ft^2 or about $1.25/ft^2 when expressed as a normalized cost.[1]

MONITORING PLAN

The FLASTAR monitoring plan was designed to verify energy and cost savings associated with the project retrofits. Secondary objectives included identification of promising O&M opportunities from the metering as well as assessment of Energy Conservation Measure (ECM) performance.

[1] The applicable utility rates from Florida Power and Light Company (GSD-1, effective April 1, 1995) are $0.03868/kWh and $7.61 per kWD (above 10 kW).

The fundamental metering plan summary was as follows:

- Whole building energy consumption was to be metered in the facility. Sub-metering was determined by the specific end-uses to be affected by the anticipated ECMs. Other pertinent data such as chilled water mass flow and space and ambient weather conditions were to be obtained at the site.
- The required data acquisition equipment and sensors were selected and calibrated to meet the established project research objectives. The metering equipment was then successfully configured, calibrated and installed.
- A data acquisition plan called for the daily transfer of data from the site to FSEC for data archival and plotting. Based on our experience, this was imperative to provide the maximum reliability in obtaining metered data.

The monitoring plan for Fellsmere Elementary School, centered around the 1992 energy audit report [4]. The schedule of retrofits indicated in the report included replacement of the current HVAC chillers, motion sensor control for lighting, the addition of an energy management system and change out of the facility lighting equipment. The metering equipment was configured and calibrated in early March, and installed by April 11th, 1995.

Power Consumption

Metering of power consumption was approached at three levels. The first level was direct metering of 15-minute electricity use of the overall facility. This measurement was obtained by a pulse output from the total power meter provided by the local utility.

The second level of power metering examined any consumption outside of the space considered for retrofit. This included portable classrooms, a separate new wing of classrooms, and exterior lighting. Each of these were sub-metered so that the retrofit building's energy use could be properly isolated. The third level concerned those individual systems inside the retrofit area which included the chillers, the lighting, air handlers, and any supplemental space conditioning systems. Miscellaneous loads were derived by subtracting of all monitored loads from that of the total facility.

The lighting system serving all the classrooms, cafeteria/auditorium, and administrative offices is divided among four electrical breaker panels located in various mechanical rooms around the school. To isolate lighting loads, all of these panels were individually sub-metered and linked back to the central data logger in a main mechanical room near the rear of the school.

The school had no formal energy management system (EMS) save conventional manual thermostats and clock timers whose operation depended on the diligence of site maintenance personnel. The effectiveness of a modern comprehensive EMS system was to be quantified by monitoring reductions in air handler power consumption and chiller run times.

The site used five constant volume air handlers which were sub-metered at two locations within the monitoring areas. In addition to the air handlers and central chiller system, the school also used two, 5-ton direct expansion air conditioning systems located on the roof above the administrative offices. These were monitored since it is anticipated that the EMS system would affect their operation and both units were slated for replacement.

HVAC Performance

The post retrofit evaluation of the current HVAC system was accomplished by calculation of a coefficient of performance for the school's chillers. This was calculated by using the ratio of heat energy rejection to energy input. Heat transfer is obtained by the product of the system mass flow and the differential temperature measurement of the return and supply chilled water lines. Energy input for the chillers were recorded by watt-hour transducers, one for each of the two chillers. Temperature and humidity data from the building core were also recorded from the interior of the building. This was used to determine relative comfort levels within the facility before and after the retrofits.

Temperature, Humidity, and Insulation

Six temperature measurements were taken at the research site. One is contained in the roof-top weather station for recording ambient temperatures, another samples the interior space conditions, and four are used for characterizing HVAC performance (this includes a primary and redundant differential pair on the supply and return chilled water loop). All were taken as double-ended readings using type-T copper-constantan thermocouple wire.

There were two humidity measurements. One monitored interior space conditions and the other was located in the weather station for ambient conditions. Both were obtained using thin film capacitive type instruments. The site weather station is made up of a pyranometer, hygrometer, and thermocouple with gill plate solar radiation shield mounted on the school roof-top.

Flow

Mass flow monitoring for the HVAC system's chilled water loop is accomplished via an insertion type, paddle wheel flow meter installed in June of 1995. These meters feature six-blade, non magnetic impellers with published accuracy of ±1% of full scale. Prior to installation, the meter were sent to Texas A&M's Energy Systems Laboratory for calibration specific for the site pipe size.

PROJECT MILESTONES

The summary below provides a brief chronology of project milestones:

- April 1995: Data acquisition system configured and installed at the site.
- July 1995: Mass flow meter was added to chilled water loop.
- Sept. 1995: First ECM. Existing twin 45-ton chillers replaced with a single, 100 ton screw chiller.
- Jan. 1996: Operation of the new chiller retrofit under full occupancy. Installation of a second ECM: occupancy sensors installed during Christmas break.
- April 1996: Review of operation with the occupancy sensors; tuning of controls. O&M recommendations.
- July 1996: Installation of the Energy Management System (EMS). Assessment of the occupancy sensor ECM.
- July 1997: Retrofit of lighting system with T8 lamps and electronic ballasts.

MONITORED ENERGY CONSUMPTION

Figure 1 depicts the total facility 15-minute electrical demand over the entire monitoring period. Average monthly electrical demand is shown as green horizontal lines. The figure also notes the installation of each retrofit. Total energy consumption averaged 64,480 kWh per month in 1994 prior to our monitoring study. After all the scheduled retrofits were completed, the average monthly use dropped to 54,896 kWh per month – an overall energy savings of about 15% relative to the base year.

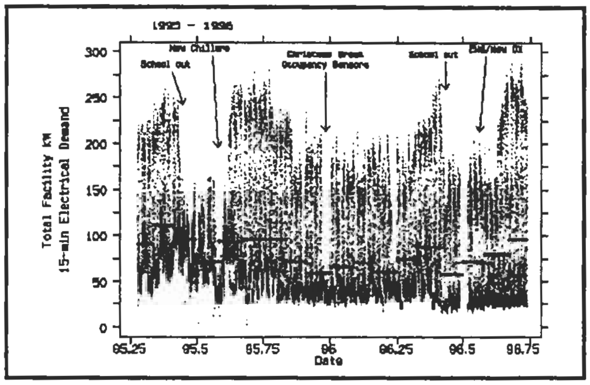

Figure 1. Total facility electrical demand over 18-month study period.

The impact of the EMS retrofit is not so nearly evident at the peak load demand as it is at the lower end of the scale where it is obvious that there are many more recent hours with a facility demand less than 50 kW. The general trend is an increasing concentration of data points at low consumption or "off" levels. Since the HVAC systems represent a large percentage of the total load, the installation of the new chiller and EMS seem to have produced the greatest impact.

Figure 2 details the sub-metered end uses from electricity consumption data taken at the site from July through September of 1996. The school is composed of the main school building, with an attached new wing and portable classroom areas. The category marked "other" represents refrigeration, cooking loads and miscellaneous end-uses such as computers, office equipment, exit lighting, and water coolers. Nearly one third of the total energy consumption at Fellsmere is dedicated to "other" and portable classroom energy use.

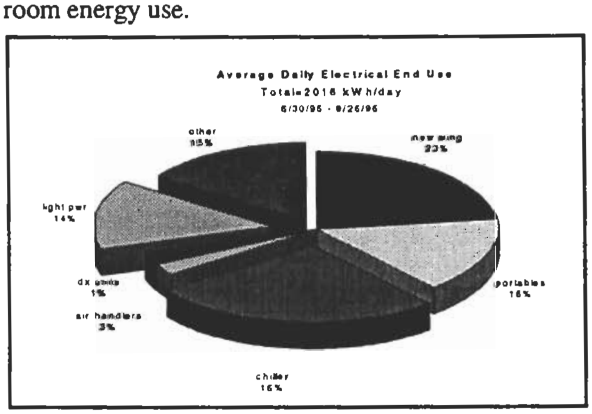

Figure 2. Summary of quarterly electrical end-use at FLASTAR site.

The energy demand of the 12 portables is particularly interesting since this represents the fastest growth of educational floor space in Florida.[2] Figures 3 and 4 detail these loads. The portable classrooms demand an average of 14.9 kW over the monitored period (360 kWh/day). Figure 4 shows the expected hat-shaped time use demand profile, but also reveals a significant amount of energy use during early morning and evening hours. This is attributed to air conditioning being often left operating during unoccupied periods. The graph also shows evidence of resistance heat use during cold winter mornings. These data suggest that portable classroom energy use might be an important area where some form of energy management could be employed.

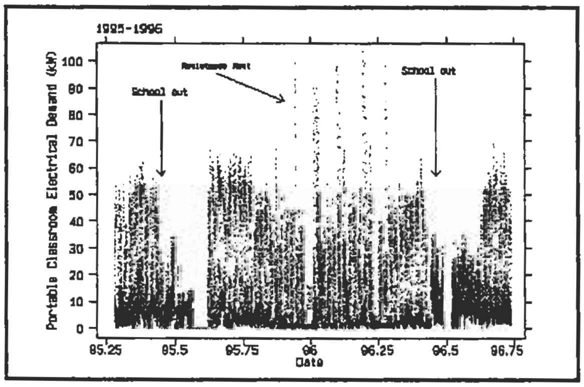

Figure 3. Time series plot of portable classroom electrical demand over entire monitoring period.

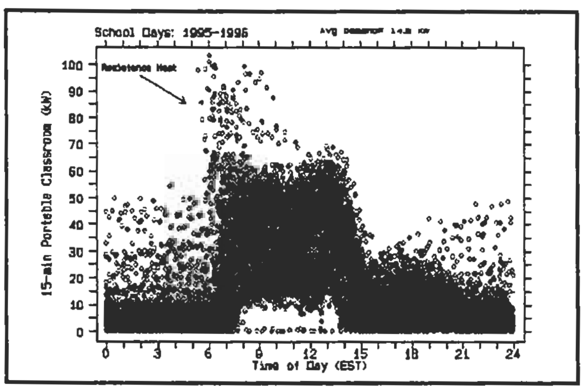

Figure 4. Portable electric demand profile over period.

Chiller Retrofit

As seen from Figure 2, the HVAC systems account for about 16% of the facility electrical energy consumption. In late July 1995 the facility chillers were changed out. This improvement replaced two reciprocating type condensing units with a single high efficiency screw type counterpart. Comparison of the pre and post retrofit data over time frames with similar ambient and interior temperatures show some pronounced reductions in chiller electrical energy use. As illustrated in Figures 5 and 6, these savings were 19% and 45% for school and non-school days, respectively. Regression analysis of the new system (Figure 7) resulted in an installed performance of 1.21 (±0.001) kW/ton as installed, which is within the range of specifications.

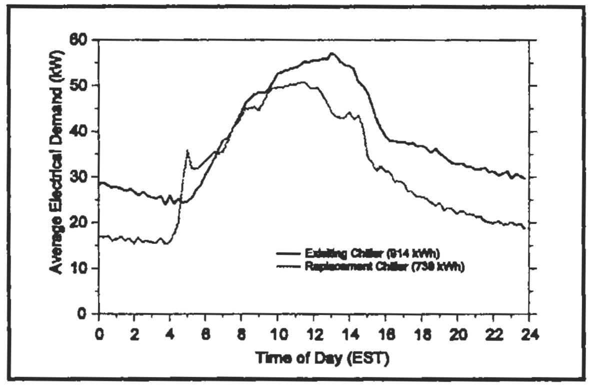

Figure 5. Comparative chiller demand profiles for all school days, April 12 - November 15, 1995.

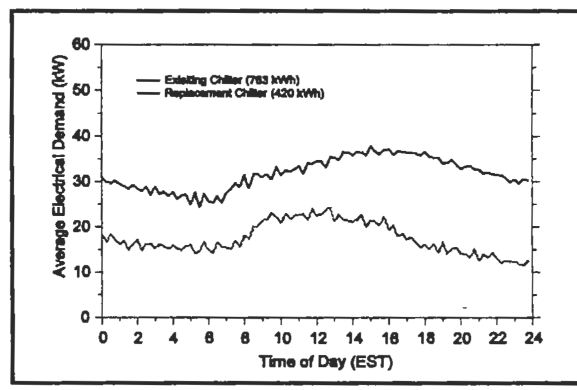

Figure 6. Comparative chiller demand profiles for all non-school days, April 12 - November 15, 1996.

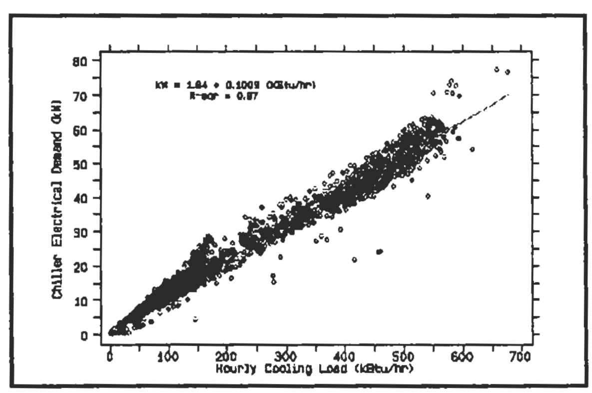

Figure 7. Regression of new chiller electric demand against chilled water cooling load.

[2] Indicative of this trend, two portables were added to Fellsmere in the summer of 1995.

Similar analysis (Figure 8) performed on the pre-retrofit data showed the performance of the original chillers to be 1.66 (±0.002) kW/ton as opposed to the original factoring specification of 1.24 kW/ton. This likely indicates degradation in the performance of the old system over the life of its operation. This improvement from the new chiller represents a net increase in chiller performance of 27% over the monitoring period where both the electrical and thermal energy data was available.

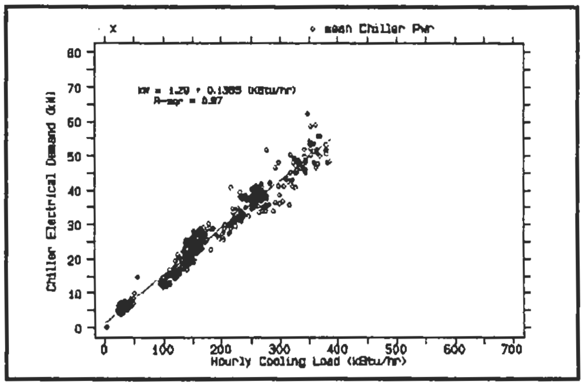

Figure 8. Regression of existing chiller electric demand against chilled water cooling load.

Given the low interior air temperatures maintained in the facility during 1995, we conducted a brief analysis to examine the sensitivity of the measured chilled water loads to outdoor temperature and interior temperature set point. Figure 9 shows a comparison between the average measured chilled water loads (kBtu/hr) and the measured temperature difference between the interior and outdoor temperature on all school days lagged by one hour. The chilled water load shows the expected surge at its 5:30 AM start-up with a fair degree of correlation between outdoor temperature difference and total loads. The sudden drop off in loads at 3 PM reflects the end of daily classes. Comparison of lighting electricity use also showed correspondence with chilled water loads. A simple multiple regression indicated that the interior-ambient temperature difference and measured lighting energy use explained 92% of the variation in hourly chilled water loads:

kBtu = 181.2 + 9.21 (ΔT) + 3.281 (Lighting kW)
[34.3] [9.16] [9.03]

R^2 = 0.919

F(2,96) = 519.92

Where:

kBtu = measured average chilled water load in 15-minute interval (1000 Btus)

ΔT = measured interior to exterior temperature difference one hour previous (°F)

Lighting kW = measured lighting electrical demand (kW)

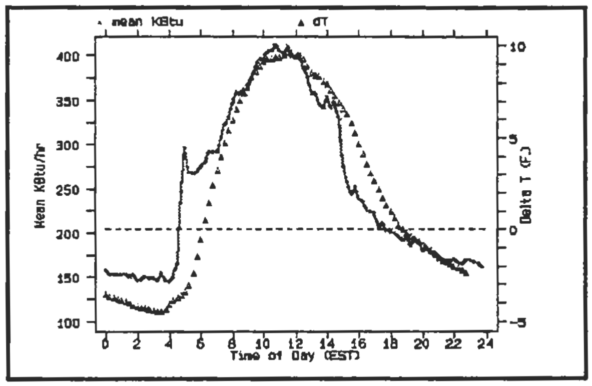

Figure 9. Comparison of average measured chilled water load and temperature difference between interior and outdoor temperatures.

The t-statistics for the coefficients are given in brackets; much of the remaining variance is likely due to occupancy and other unmeasured quantities (e.g., cafeteria cooking etc.). The relationship indicates that for each degree that the interior temperature is increased, the chilled water load should decrease by 9,210 (±2,000) Btu/hr. Given the measured new chiller efficiency (10,009 Btu/kW), its electrical demand should drop by 0.92 kW per °F. This represents a 3.3% cooling energy reduction per degree on school days where average chiller electrical demand was approximately 28 kW.[3]

Figure 10 shows the average temperatures maintained in the facility over the entire monitoring period. Prior to installation of the EMS interior temperatures were often between 68 and 73°F, against a more reasonable interior temperature target of 75°F. A 7% savings in cooling load is estimated to be available from elevating the average interior temperature by 2°F.

[3] The relationship also shows that each kWh of added lighting energy use shows up as 3281 Btu of added chiller load.

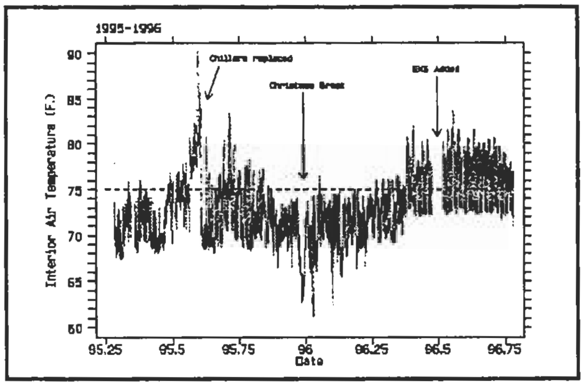

Figure 10. Measured interior air temperature in Fellsmere facility over monitoring period. The line (75°F) represents a reasonable target for efficient cooling operation. Note improvement after EMS install.

Similar analysis for lighting shows that for each kW lighting electrical demand can be reduced, measured chilled water loads will drop by 3,280 (±720) Btu/hr. The coefficient has physical relevance since each kW of electricity consumed inside the school represents an increase of sensible heat load of 3,413 Btu/hr -- very close to the predicted value and well within the standard error. For each kW of lighting energy reduction (now averaging 16 kW), the chiller load would be predicted to decrease by 3,280 Btu/hr or 0.33 kW in its electrical demand.

Insight into chiller demand profiles can be obtained by inspection of the plots in Figures 11 and 12. As expected, there is a strong relationship between both electrical consumption and thermal energy at increasing ambient temperatures. This relationship is particularly noticeable at outside temperatures above 60°F.

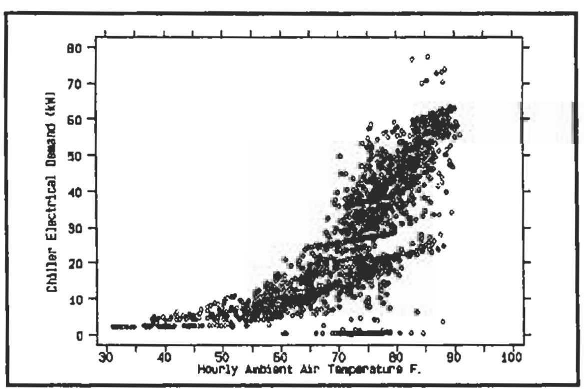

Figure 11. Measured hourly chiller electrical demand vs. Ambient outdoor temperatures.

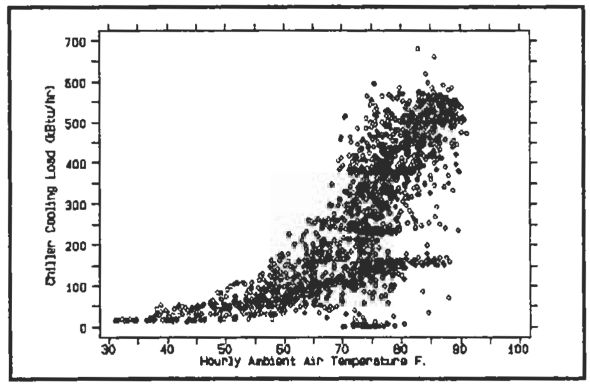

Figure 12. Measured hourly chilled water cooling load against outdoor ambient temperature.

While the chiller upgrade did produce savings, analysis of the data indicate that further reductions in energy consumption could be obtained through more effective energy management. Over the entire period monitored, there were numerous examples of chiller operation during unoccupied time frames, weekends, and holidays. Discussions with on-site personnel indicated that control over these systems was largely manual. According, an energy management system (EMS) was installed as part of the project the following summer.

Energy demand data on the direct expansion (DX) heat pumps that serve the building's administration area are presented in Figure 13. Similar to that for the chiller, the data indicated numerous instances when cooling systems were left in operation during unoccupied periods during evenings or weekends.

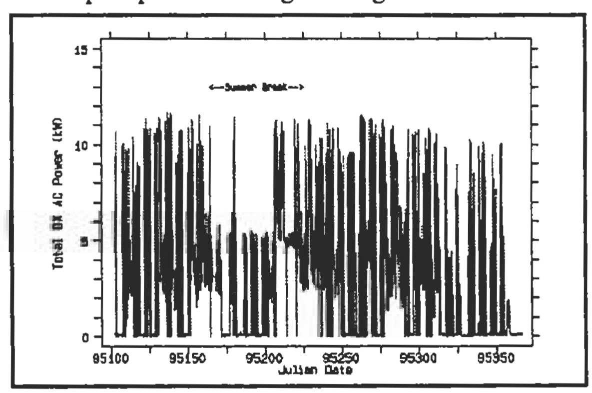

Figure 13. Measured DX air conditioner power throughout 1995.

<u>Lighting Controls: Occupancy Sensors</u>

The second ECM installed in the project were occupancy sensing controls added to the lighting system. The general intent was to reduce wasted lighting energy use in classrooms. Manufacturer's literature often claims a 20-40% reduction in lighting energy when such controls are added to classrooms.

This retrofit was installed during the Christmas break at the end of 1995. A total of 59 controls were installed; 39 ceiling mounted hybrid passive infrared-ultrasonic sensors were placed in the classrooms and 20 wall mounted sensors were located in the office and administration areas.

After the retrofit was completed, analysis of the aggregate lighting energy consumption data showed unexpected results. The installation of the sensors actually resulted in an *27% increase* of lighting electrical consumption. Figure 14 shows the lighting electric demand profile before the retrofit; Figure 15 shows demand after the change. The post retrofit lighting data showed frequent instances where class room lighting was unintentionally activated between midnight and 6 A.M. The data suggested problems with the adjustment and set up of the sensors. Problems with "false triggering" had been observed with ultrasonic sensing types in previous research [6].

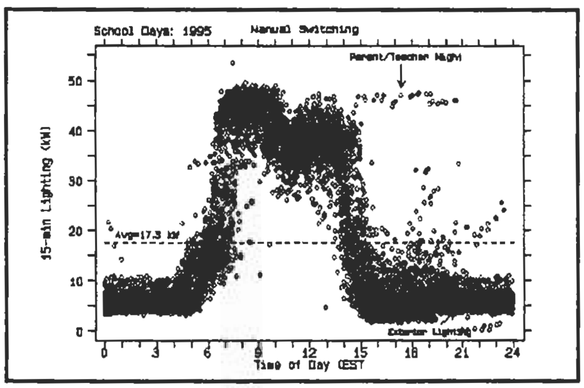

Figure 14. Lighting electrical demand profile for school days in 1995 under manual switching.

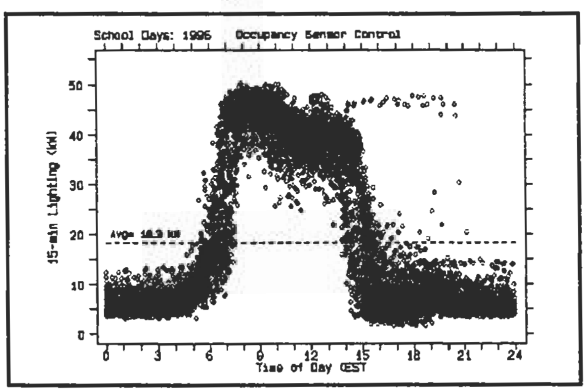

Figure 15. Lighting electrical demand profile for school days after the lighting control retrofit. Consumption increased in the post period.

Once this increase was detected, adjustments were made to the sensors in an effort to optimize performance in February of 1996. This included reducing the sensor time delay from fifteen to seven minutes and changing the program logic for the hybrid sensors that would turn lights on. Despite these adjustments, there was still an 8% overall increase in lighting consumption over two similar five month monitoring periods. Figure 16 depicts the average lighting demand profiles during the three periods.

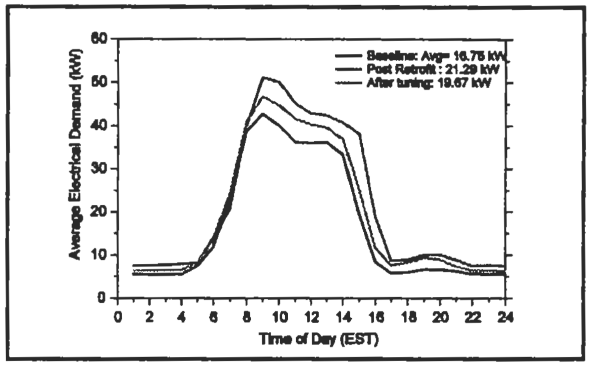

Figure 16. Average daily lighting electric demand profile before and after occupancy sensor retrofit and post occupancy sensor adjustment.

Reasons for this seemingly contrary result are illustrated by a Wisconsin monitoring study which showed that for educational facilities with good existing manual control can find that reliance on automatic switching from occupancy sensors can *increase* daily lighting on-times [6]. The reason is that prior to the installation, classroom lighting is typically turned off immediately upon vacancy. However, under motion sensor control the lights are on for a additional period equal to the time delay. Thus, only on in facilities where lights are frequently left on unintentionally, will savings be realized. However, these results should not be used to uniformly condemn the performance of occupancy sensors in educational facilities. A similar before and after experiment in another Florida school found an 11% reduction in metered lighting energy use from installing similar lighting controls [7]. However, performance may be case specific.

ENERGY MANAGEMENT SYSTEM

A direct digital control (DDC) energy management ECM was installed in May 1996 and was brought into full operation eight weeks later. Prior to the installation, the HVAC systems were manually controlled by a combination of switches, analog thermostats, and time clocks.

For the purposes of control, the school is divided into nine zones, corresponding to each of the air handlers and the administration area. The programming capabilities provide temperature "set-up" during off hours, as well as chiller, AC and air handler shut down during nighttime periods and weekends.

The system responds to analog signals sent by thermistors located in each classroom. Based on this input, the EMS can control the appropriate zone conditions using per-determined temperature parameters contained in memory. The system also controls the quantity of outside air supplied to the zones and/or classrooms. Linked to the occupancy sensors, the outside air is reduced to a minimum level when the conditioned areas are unoccupied. This strategy reduces the cooling ventilation loads by limiting the amount of warm, humid air introduced into the when the building is not heavily occupied.

Since the end-use loads associated with the HVAC system were monitored separately, it is possible to observe operation of each of those components under the energy management system. Part of the savings in cooling performance was directly due to the chiller retrofit. Originally, the cooling system was comprised of two 45-ton air cooled, reciprocating chillers. These units were original installed equipment that averaged 895 kWh per day for April - May of 1995. These chillers were changed out with a single, 100-ton chiller. The new system averaged 542 kWh/day over the same period in April - May of 1996. This represents nearly a 40% reduction in energy use. Figures 17 and 18 shows this comparison. Only part of this reduction is due to improved cooling system efficiency, however. Improved controls, even without an EMS, made up a portion of the energy use reduction.[4]

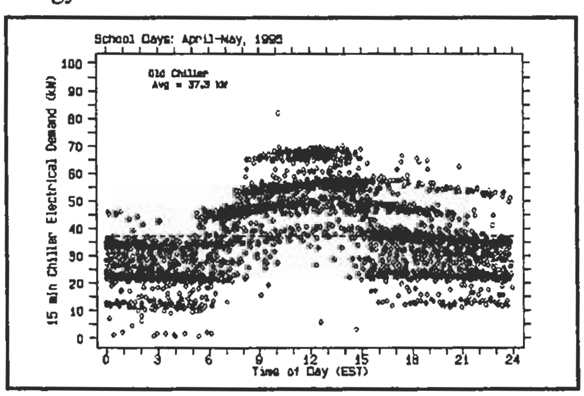

Figure 17. Old chiller electrical demand profile.

[4] In each of the succeeding plots the symbols indicate the actual 15-minute data points over the monitoring period. The bold line is the 15-minute average over the 24-hour cycle. The black dotted line is the daily average.

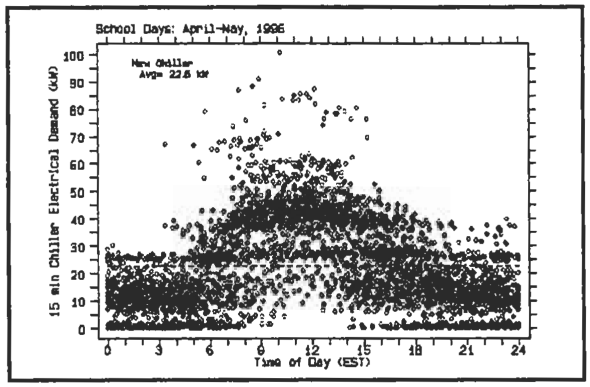

Figure 18. New chiller electrical profile.

With the energy management system installed, the new chiller data exhibits nearly the same demand during mid-day, although the real impact is seen during school hours where it is frequently cycled off and operating hours are reduced. The EMS control results in a net reduction in cooling power of 17% (355 kWh/day) in a six week period from August - September of 1995 and 1996 (see Figures 19 and 20). The peak load during the school operating hours remained unchanged though, during the unoccupied hours, the load is virtually eliminated because of system control.

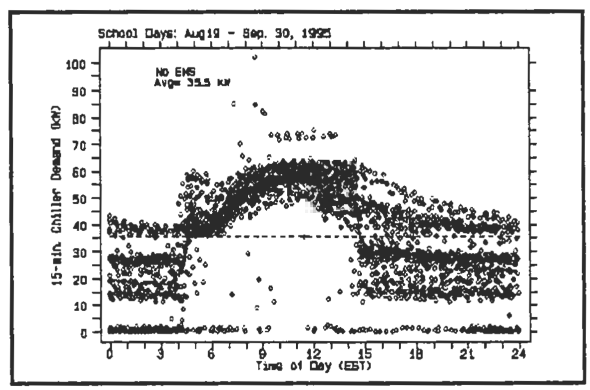

Figure 19. New chiller demand profile without EMS (Aug. - Sept., 1995).

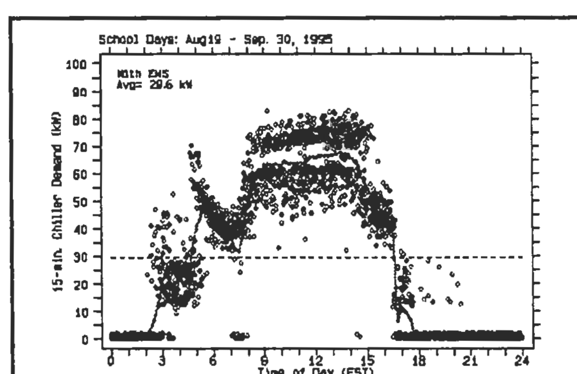

Figure 20. New chiller demand profile with EMS (Aug. - Sept., 1996).

Measured savings from EMS control of the air handlers mirrored the impact on chiller demand, but were even greater. At the start of the project and up until the EMS was installed, the air handlers were manually operated from the equipment room. Data analysis indicated there was considerable use after hours, where some the buildings air handlers were left running continuously. More consistent scheduling of air handling equipment by the EMS produced a 30% energy savings (26 kWh/day).

Most of the changes in system cooling load come from the much tighter temperature control provided by the EMS. Figures 21 and 22 show the differences in interior temperature set points. Prior to EMS use, the typical temperature inside the building was 73°F, was fairly unpredictable and on many occasions, would go below 70°F during the night. After the EMS was installed, the level was set to 76°F during school hours and 78°F at other times. There is also much more consistent control of these settings during the course of the day. Shut down of the cooling systems along with an increase in the interior temperature set points and reduced outside air, lowered the overall cooling loads by 16%.

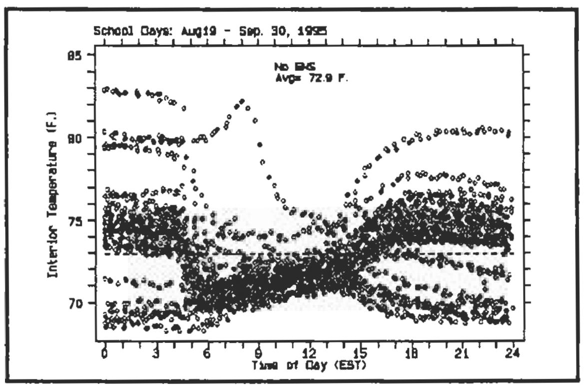

Figure 21. Interior temperature before EMS control (Aug. - Sep., 1995).

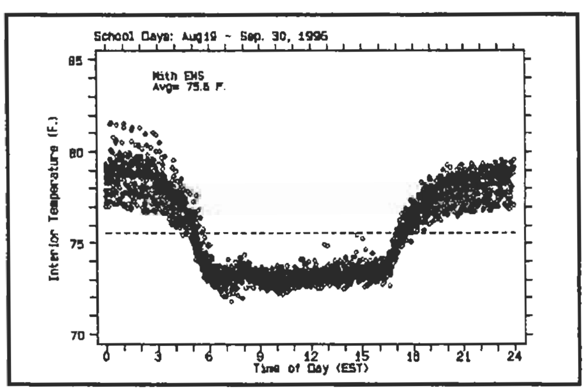

Figure 22. Interior temperature after EMS control (Aug. - Sep., 1996).

The EMS has also reduced energy use of the heat pumps which condition the lobby and administration areas. Two DX heat pumps, represent 10 tons of cooling load. In the summer of 1996 remaining old unit was changed out to a new 5-ton Trane *TWA060C300A* heat pump. As seen in comparing Figures 23 and 24 show the peak demand loads for the DX system show approximately a 12% reduction associated with the newer more efficient equipment (11.5 kW vs 10 kW). Before the energy management system was installed, the heat pumps were cycled on their thermostat settings with the systems available 24 hours a day (see Figure 21). After management, the units are only allowed to operate during occupied time periods (see Figure 22). The combined measures of heat pump replacement and EMS controls, this reduced daily energy use in these areas by over 31%, with the lion's share coming from the EMS system.

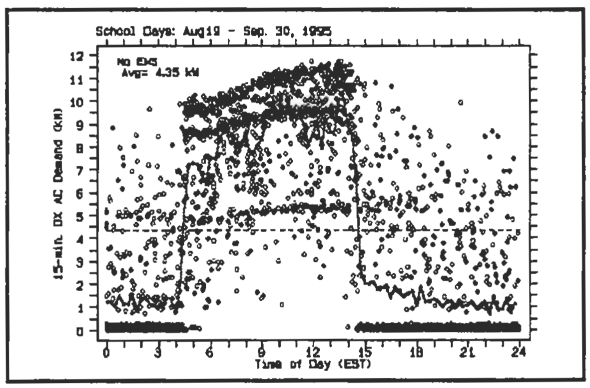

Figure 23. DX AC demand prior to installation of EMS.

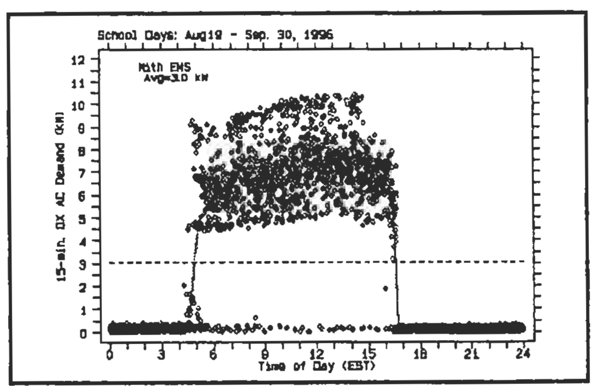

Figure 24. DX AC demand after installation of EMS.

Lighting Retrofit

The original lighting system consisted of F34 T12 lamps and magnetic ballasts. The fixtures were changed in July - August 1997 to a new thin-line T8 system with electronic ballasts. Based on previous evaluation at FSEC's lighting flexible test facility

(LFTF), the proposed combination of lamps can reduce typical fixture lighting consumption by approximately 23% [9].

The measured savings from the lighting retrofit, summarized over the daily cycle, are shown in Figure 25. The plot shows the measured average lighting demand from August 15th, 1996 - January 15th, 1997 as compared with that after the lighting change out during the same period a year later. Measured daily lighting energy use dropped from 13.83 kWh to 11.33 kWh – a 18% reduction. This compares reasonably with the 23% savings estimate based on the technical potential from comparative fixture performance. The likely difference between the two may be due to the fact that some of the lighting panel loads – such as miscellaneous incandescent bulbs – were not altered. The annual electricity reduction based on the five month monitoring period was estimated at 21,860 kWh. The average monthly reduction in demand was estimated from the measured data at 4.9 kW. Annual energy cost savings are estimated at approximately $1,300 at current energy prices.

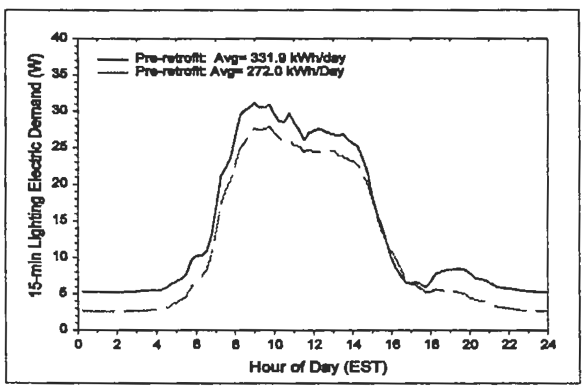

Figure 25.

CONCLUSIONS

Collective performance of the retrofits in reducing site energy use was obtained by comparing the most recent 12 month period with the baseline year in 1994 showed that overall electricity consumption had dropped from an average of 64,480 kWh per month to 57,180 kWh -- an 11% reduction. I should be noted that the recent 12 month period includes only the chiller retrofit and lighting control retrofits. Since the later measure was shown to provide no energy reduction, the savings must all be attributed to the change out of the chiller. It is noteworthy, however, that the peak demand in the more recent period was up by approximately 16 kW per month. This is likely attributable to the larger capacity of the replacement chiller (ten tons) and suggests that the impact of the EMS system on monthly peak demand be carefully monitored to prevent loss of the energy cost savings due to increased monthly demand charges.

The EMS system installation dropped central cooling energy consumption by a further 17% when evaluated with the new chiller. Savings for the air handlers and heat pumps was roughly 30% for each end-use. The string of installed retrofits (chiller, lighting controls and EMS) thus far will reduce site energy consumption by roughly 140,000 kWh/yr. Assuming no change in peak demand, the likely energy reduction will yield a $5920 annual savings. Against this savings must be balanced the expense of the retrofits. Project costs are summarized in Table 5.

Table 5
Preliminary Cost Effectiveness of Retrofit Measures

Measure Description	Installed Cost	Annual Saved kWh	Annual $ Savings	Simple Payback (Years)
Chiller Replacement	$47,985	65,000	$2,500	19.2
Lighting Controls	$15,446	None	None	None
EMS System	$26,173	50,200	$1,950	13.4
DX AC Replacement	$ 5,033	2,700	$ 170	29.6
Lighting System Retrofit	$48,000	22,000	$1,300	36.9
Project Total	$142,637	139,900	$5,920	24.1

The actual costs born by the school district are approximately half of the values shown in the table, due to grants from the Institutional Conservation Program (ICP). Thus, their incremental costs are low enough that the economics are much more attractive than the values shown above. However, without these subsidies the payback on the project is long, particularly given the poor results from the lighting control retrofit. It should also be noted, however, that some measures, such as the DX air conditioner replacement may not be entirely discretionary since worn out equipment must be replaced regardless of energy savings.

The reduction of energy-related costs of 11% is due to the negligible impact of some of the installed measures on the peak facility electrical demand.

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