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ABSTRACT

A study of the Florida Public Building Loan Concept pilot program determined its effectiveness in helping to upgrade building energy systems. The pilot program, termed FLASTAR (Florida Alliance for Saving Taxes and Resources), involved the comprehensive metering of an elementary school to demonstrate energy savings potential after retrofitting the facility with new chillers and sensor controls for classroom and office lighting. Data show the chiller upgrade had resulted in a 30 percent reduction to cooling energy use. Sensor controls failed to achieve energy savings and actually increased lighting energy usage. An energy management system (EMS) was added that provided direct digital control (DDC) of the school chillers, air handlers, and packaged direct expansion (DX) roof-top systems. The EMS reduced chiller energy use by an additional 16 percent, and air handling and DX system energy consumption by 30 percent. Project retrofits achieved overall energy savings of approximately 15 percent or 120,000 kWh per year resulting in annual energy savings of $4,600. An appendix provides important project dates. (Contains nine references.) (GR)

FLASTAR: Florida Alliance for Saving Taxes and Energy Resources

Final Report

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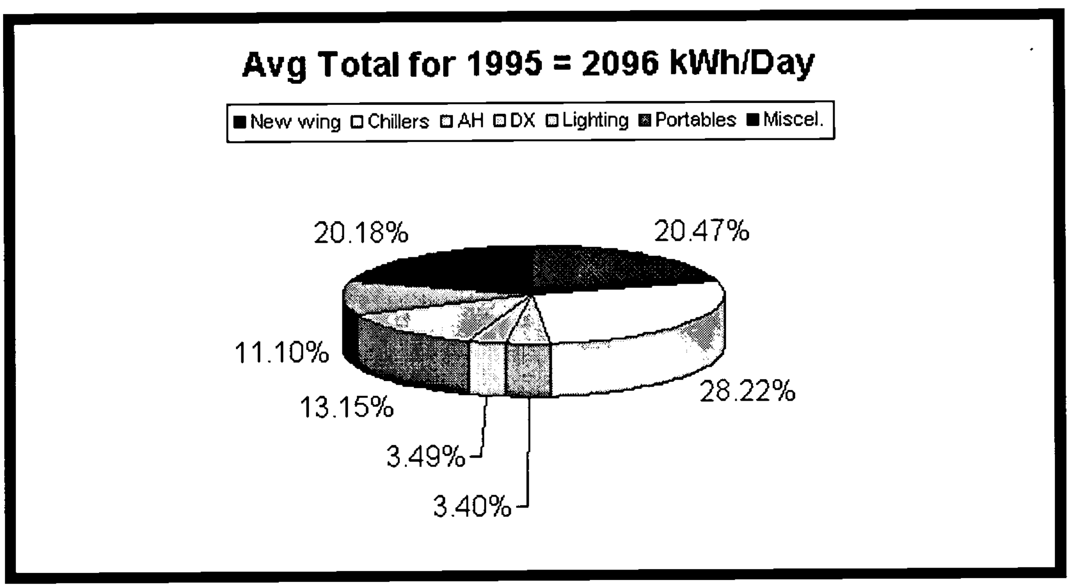
Executive Summary

This report describes the final results for the pilot demonstration of the Florida Public Building Loan Concept. This loan program provides low cost funds to eligible public entities for upgrad 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.

The facility is composed of the main school building, with an attached new wing and various portable classroom areas. All electrical end-uses were individually sub-metered. Figure E-1 details the proportions of the energy end-uses throughout 1995. Cooling represented approximately one third of total consumption; lighting was approximately 13%. Portable classroom electricity use was substantial and grew over the course of the monitoring project as more modular units were added. The large "other" end-use category represents refrigeration, kitchen cooking loads and miscellaneous end-uses such as computers, office equipment, exit lighting and water coolers. Measured electricity consumption totaled 2,700 kWh on school days and 1,540 kWh on non-school days. Annual billed energy consumption for the 41,000 square foot facility was approximately 775,000 kWh or 60 kBtu/ft2 in the base year (1994).



During the summer of 1995, the first retrofit, replacement of aging chillers was completed with a measured 30% reduction to cooling energy use. The second retrofit was occupancy sensor controls for classroom and office lighting which were installed in December 1995. Unfortunately, post retrofit data showed that metered lighting energy use actually increased after the occupancy sensors were installed. An attempt was made to adjust and improve the performance of the lighting controls in February of 1996. This did reduce lighting energy consumption, but not to less than the base level. 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. We speculate that this may have increased lighting "on times" equal to the additional sensor time delay.

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 chillers, 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 loads.

Although the formal contract is complete, FSEC plans to meter the facility for one additional year. This to quantify any savings from the final retrofit to be installed, a new lighting system using thin-line T8 lamps and electronic ballasts.

FLASTAR: FLORIDA ALLIANCE FOR SAVING TAXES AND ENERGY RESOURCES

Final Report

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Introduction

This document comprises the final project report in supporting the demonstration of the pilot Florida Public Building Loan Concept. This loan program provides low cost funds to eligible public entities 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 [1,2]. Within that program, funds provided from oil overcharges are loaned to various facilities for building system retrofits. These loans are repaid (with interest) from energy cost savings. As of the most recent reporting, the LoanSTAR program had saved the State of Texas some $13.7 million in verified project savings at an average payback of 3.3 years.

Central to the FLASTAR program is the demonstration of real energy cost savings associated with each retrofit measure [3]. These savings were documented through a comprehensive metering, monitoring and reporting service provided by either the Florida Solar Energy Center (FSEC) or the University of Florida (UF) depending on geographic area. The monitoring covered a time frame to include both pre-retrofit and post-retrofit periods and include those parameters necessary to quantify resulting energy savings.

Site Description

Fellsmere Elementary School was chosen from a list of several candidate facilities for the demonstration project. The school was chosen 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 learn 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. A view of the main facility is shown as Figure 1. 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. Figure 2 shows the facility site plan. Electricity is the primary source of energy, with liquid propane used for heating and cooking.

Figure 1. Fellsmere Elementary School.

The building has an average occupancy of 550 students and staff. Classes are held from 8:30 AM to 3:05 PM daily. Faculty and staff hours are from 7:30 AM to 4:30 PM. Limited janitorial staff remain until 5 P.M While the facility is largely unoccupied during the nighttime and weekend hours, the school serves occasionally as a meeting place for various events during the course of the year.

The first day of classes for the fall semester 1996 was August 19. A detailed annual school calendar is provided in the Appendix A along with a "typical" daily schedule.

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

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.

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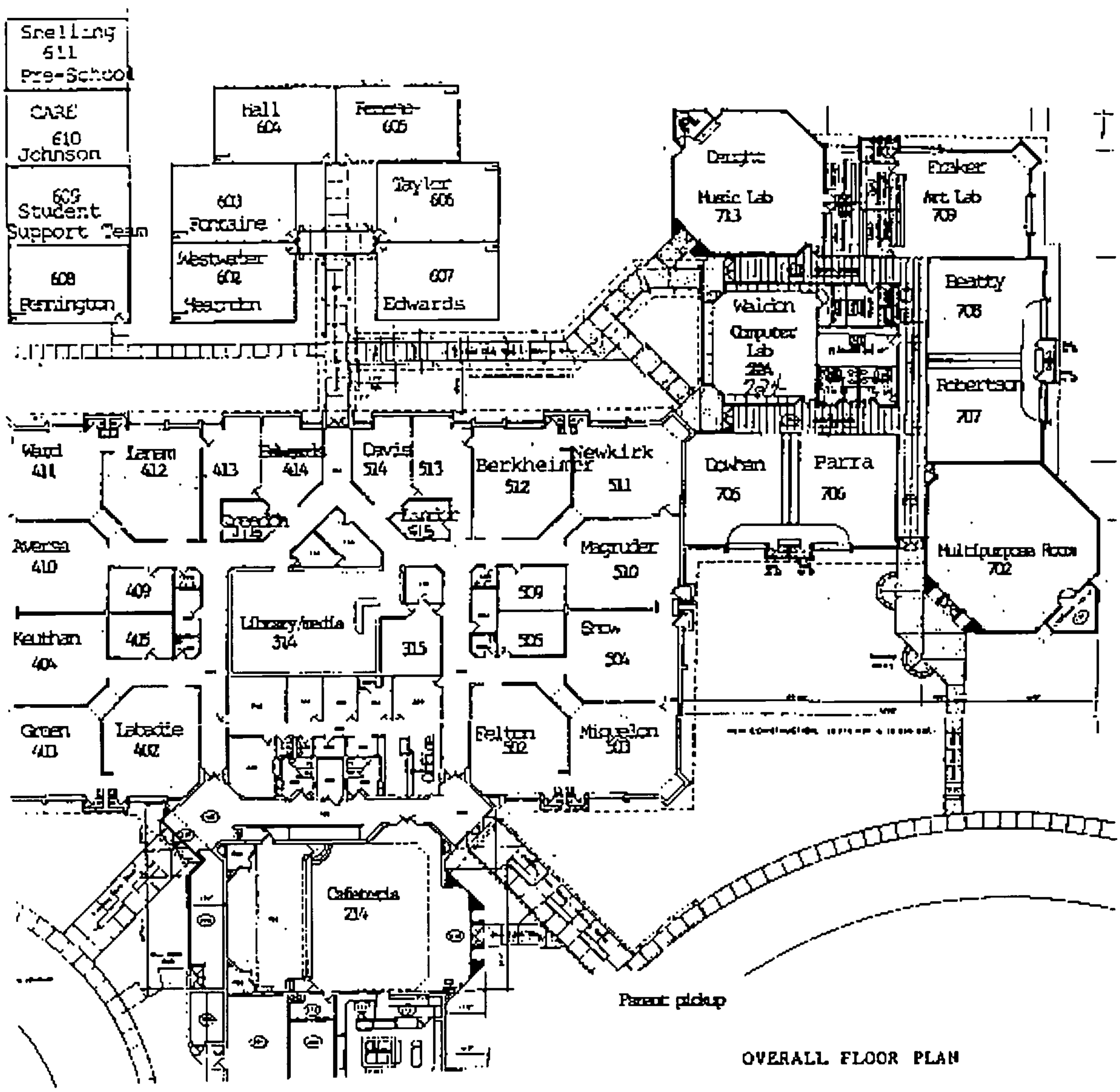

Figure 2

Floorplan for Fellsmere Elementary School.

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HVAC Systems

The original heating, ventilation and air conditioning (HVAC) systems at Fellsmere Elementary are summarized in Table 2. The system consists of both direct-expansion roof-top heat pumps for the administrative and lobby area (Figure 3) and a chilled water system for the rest of the building. At the beginning of the project, most of the equipment was approximately 12 years old and fairly inefficient.

One horsepower (hp) exhaust fans serves the kitchen area exhaust hood with another 1 hp supply fan providing make-up air. A 2 hp exhaust fan serves the cafeteria dining area with a 1.5 hp fan providing make-up air. 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.

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

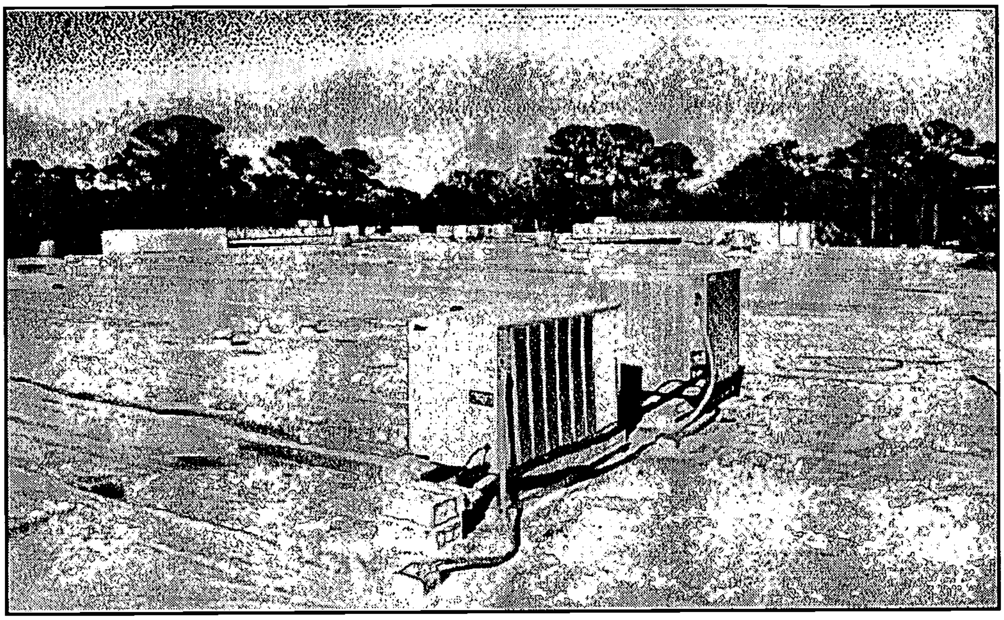

Figure 3. Roof-top heat pumps over administration area.

Air Distribution System

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.

Table 3
Fellsmere Elementary: Air Distribution System Characteristics

Unit Number	Supply Air CFM	Outside Air CFM	Motor Horsepower
1	2250	250	1.50
2	1950	310	1.50
3	1000	150	0.75
4	3000	720	2.00
5	2000	1,300	1.50
DX#1	1950	150	1.50
DX#2	1950	150	1.50
Total	14,100	3,030	9.25

Lighting System

Interior lighting is predominantly from fluorescent fixtures. Two lamp fixtures are the most common type. The primary lamp utilized is the T12 34-W type, but these, along with the aging magnetic ballasts, are inefficient relative to contemporary systems. Table 4 shows the audited lighting systems in the main building:

Table 4
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

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 [4]. As described in the original project Technical Audit Report (TAR), a change out of the facility lighting system has been identified as a potential savings measure for the facility [5].

Historical Site Energy Consumption

The facility historical energy usage is available from utility records. 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. Average monthly peak demand was 248 kW, varying from 149 kW in July during the summer break to 307 kW in September. The key point is that electrical use had increased over the period. Heating consisted of the consumption of 951 gallons of propane in 1995.[1]

In 1994, energy costs totaled $55,162. The facility's annual energy usage index (EUI) is approximately 60 $kBtu/ft^2$ or about $1.25/ft²$ when expressed as a normalized cost.

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.

For the pilot project at Fellsmere Elementary School, FSEC emphasized proven, reliable metering methods that would ensure accurate energy results. This involved a metering plan providing necessary calibration of sensors and data acquisition methods. The fundamental metering plan summary was as follows:

[1] Fuel oil and/or LP gas consumption was not monitored in this study; as such, it is not discussed in this report.

1) Measurement Points: Whole building energy consumption was to be metered in the facility. Sub-metering was be 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.

2) Metering Plan: A metering plan was established. The plan centered on data collection to isolate the electrical end-use performance of the ECMs intended for the Fellsmere facility.

3) Meter Installation: 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.

4) Data Acquisition: A data acquisition plan was established for the project. The plan involved 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 [5]. The schedule of retrofits indicated in the report included replacement of the current HVAC chillers, motion sensor control for lighting and the addition of an energy management system. The scope of these upgrades were to be expanded to include a complete lighting retrofit as part of the FLASTAR loan program.

Energy savings associated with the above described retrofits were directly determined by metering the power consumption of the individual systems themselves, and in the case of the HVAC system, the thermal efficiency of the chillers and the thermal distribution system components. The metering equipment was configured and calibrated in early March, and installed by April 7th. The modem phone line was established on April 11th, 1995. Figures 4 and 5 show some details of the instrumentation installed.

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

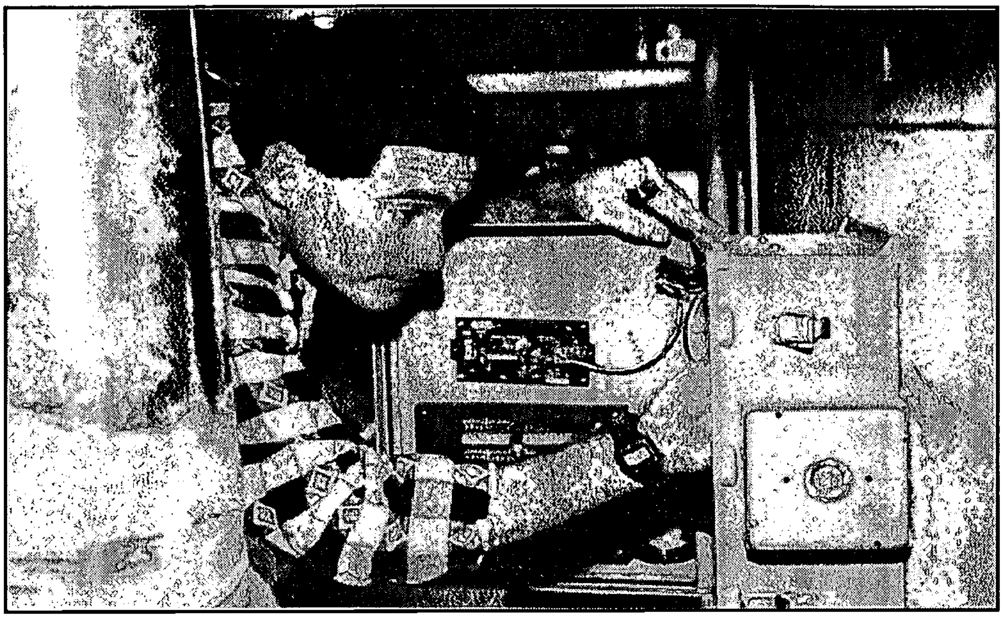

Figure 4. Installed project data logger.

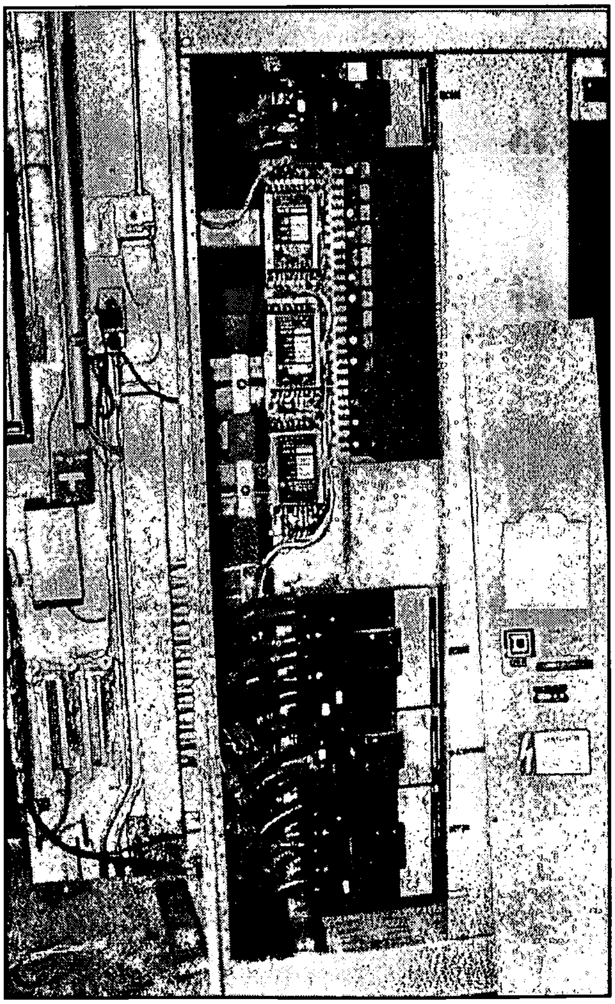

Figure 5. Power transducers installed on load panel to provide energy use data.

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. These packaged units condition offices and spaces which also include a reception area, teacher's lounge and clinic.

<u>HVAC Performance</u>
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.

The differential temperature measurements were recorded by two pairs (a primary pair and redundant back-up) of double ended copper-constantan thermocouples located on the supply and return loops of the chilled water piping system. The first used two in-stream thermo-wells and the back up consisted of two similar sensors mechanically attached to the surface of the pipe. This provided redundancy for these critical measurements.

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.

<u>Instrumentation</u>
The instrumentation for the facility consisted of copper constantan thermocouples for temperature measurements, thin film capacitor hygrometers for humidity measurements, solid state watt-hour transducers for measuring power consumption, and a insertion type paddle wheel flow meter. These instruments were then linked to a multi-channel data logger which recorded all data. All pertinent data channels were scanned every 10 seconds and then averaged or totalized over a fifteen minute interval. Data are retrieved daily from the site via an automated VAX data retrieval system at FSEC.

<u>Data Logger</u>
The data logger used in this study was a *Campbell CR-10* measurement and control module. *Campbell Scientific* data loggers were chosen since the specified equipment met the multiple objectives of low cost, with greatest accuracy and reliability. The logger is capable of handling up to twelve single-ended analog input measurements as well as pulse count inputs (low level AC and switch closure) and a number control functions. These basic capabilities were then further extended with the addition of optional peripherals.

Specifically, these were two *SDM-SW8A* switch closure modules and an *AM416* 4 x 16 relay multiplexer. These devices supplemented the basic logger with sixteen more pulse count channels and up to 32 single-ended or differential voltage sensors.

<u>Temperature</u>
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 20 gauge, shielded type-T copper-constantan thermocouple wire.

<u>Humidity</u>
There were two humidity measurements. One monitored interior space conditions and the other was located in the weather station for ambient conditions. Both are *Vaisala* thin film capacitive type instruments . They provide 0 to 100% RH measurements at ± 3% accuracy with minimal temperature dependence.

<u>Flow</u>
Mass flow monitoring for the HVAC system's chilled water loop is accomplished via a *Data Industrial* insertion type, paddle wheel flow meter. 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. The meter was installed in June of 1995.

<u>Weather Station</u>
The site station is made up of a pyranometer, hygrometer, and thermocouple with gill plate solar radiation shield mounted on the school roof-top (Figure 6). The pyranometer is a *Licor LI-200SA* silicon photo-diode, factory calibrated against an *Eppley Precision Spectral Pyranometer*. The gill plate shield minimizes ambient temperature measurement error due to solar irradiance.

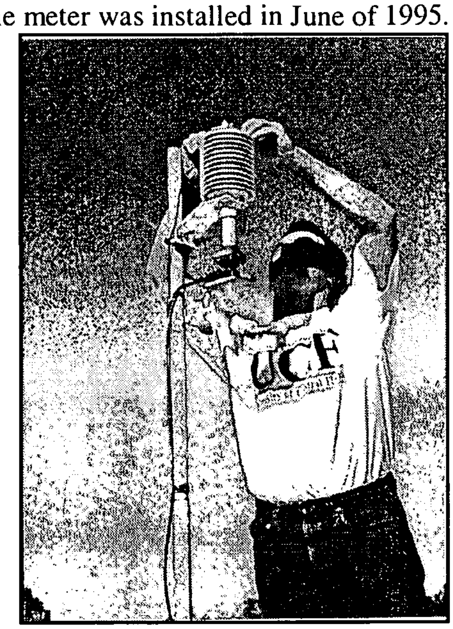

Figure 6. Check out of site roof-top weather station.

<u>Power Measurements</u>
All power measurements were obtained using *Ohio Semitronics* watt-hour transducers. These are solid state instruments connected to split-core current transformers. These true RMS meters provide direct kilowatt-hour outputs as dry switch closures. They are accurate to ±0.5% full scale and ±1% of reading.

A summary of the collected data is given in Table 6.

Table 6
FLASTAR: Fellsmere Site Data Collection Parameters

Parameters	No. of Measurements	Units
<u>Meteorological Conditions</u>		
Ambient Air Temperature	1	°F
Relative Humidity	1	%RH
Solar Insolation	1	Watt/M^2

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Building Conditions		
Interior Core Temperature	1	°F
Interior Core Humidity	1	%RH
Power		
Interior Lighting	5	Watt-hrs
Exterior Lighting	1	Watt-hrs
Adjacent Portable Classrooms	1	Watt-hrs
Added Building Wing	1	Watt-hrs
Air Conditioning		
Chiller Power (2)	2	Watt-hrs
Air Handler Power	2	Watt-hrs
Packaged DX Unit Power	1	Watt-hrs
DX Air Handler/Heat Strip	1	Watt-hrs
Chiller Temperature In/Out (ΔT)	2	°F
Chiller Water Flow	1	lbs

Monitoring

After site selection and review, the Fellsmere facility was surveyed for required instrumentation. The instrumentation was installed between mid-March and early April 1995. On April 10th, the formal monitoring began and has been continuous in the 18 months since. It was desired that the time frame for monitoring would include a pre-retrofit monitoring period of no less than six months. However, this was compromised given the long length of time until a contract was awarded. The pre-retrofit data collection period began four months before the new chiller was installed.

Data retrieval on the pilot project was accomplished daily from the sites to FSEC with archival and back-up of data onto a *VAX/VMS* mainframe computer. Daily performance plots are produced nightly for review by the project engineer. An example of these plots are shown later in the report as Figure 30 and 31.

Project Milestones

The summary below provides a brief chronology of project milestones:

First quarter : Site monitoring plan created. Data acquisition system configured, calibrated and installed at the site. Data collection began on April 10th, 1995.

Second quarter (July 1995): Completion of remaining instrumentation. Mass flow meter was added to chilled water loop.

Third quarter (September 95): First Energy Conservation Measure (ECM) installed during summer break. Existing twin 45-ton chillers were replaced with a single, 100 ton screw chiller.

Fourth quarter (January 96): Operation of the new chiller retrofit under full occupancy. Installation of a second ECM, occupancy sensors on lighting systems during Christmas break.

Fifth quarter (April 96): Review of operation with the occupancy sensors; tuning of controls. O&M recommendations.

Sixth quarter (July 96): Installation of the Energy Management System (EMS). Assessment of the occupancy sensor ECM.

Recent Progress

The objective of the third quarter of 1996 (eighth quarter monitored) was to continue the building monitoring effort in support of project evaluation. Included in this effort was daily data review, verification of system operation, and archiving of the monitored data.

This report also highlights the first quarter where the EMS was operational under full occupancy. Data collection was interrupted on August 15 for a period of about seven days due to a lightning strike on the building's electrical supply. The data logger's analog voltage measurements were interrupted by the event, resulting in a one week data loss until the site could be visited and the data logger reset.

Monitored Energy Consumption

Figure 7 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 15% relative to the base year.

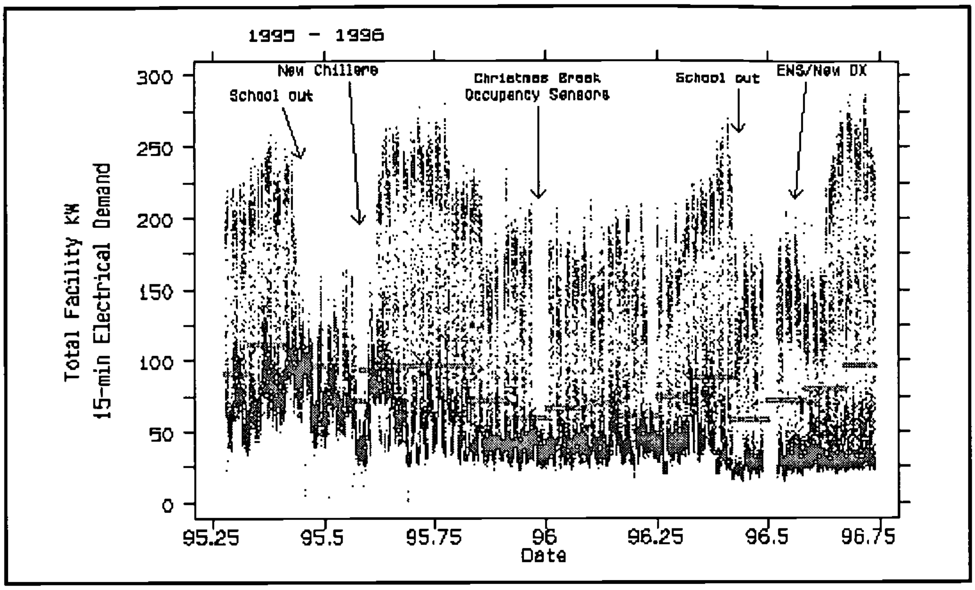

Figure 7. Total facility electrical demand over 18-month study period.

The impact of the recent 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 seems to have produced the greatest impact.

Figure 8 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 (see Figure 9) and portable classroom areas (see Figure 10). 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.

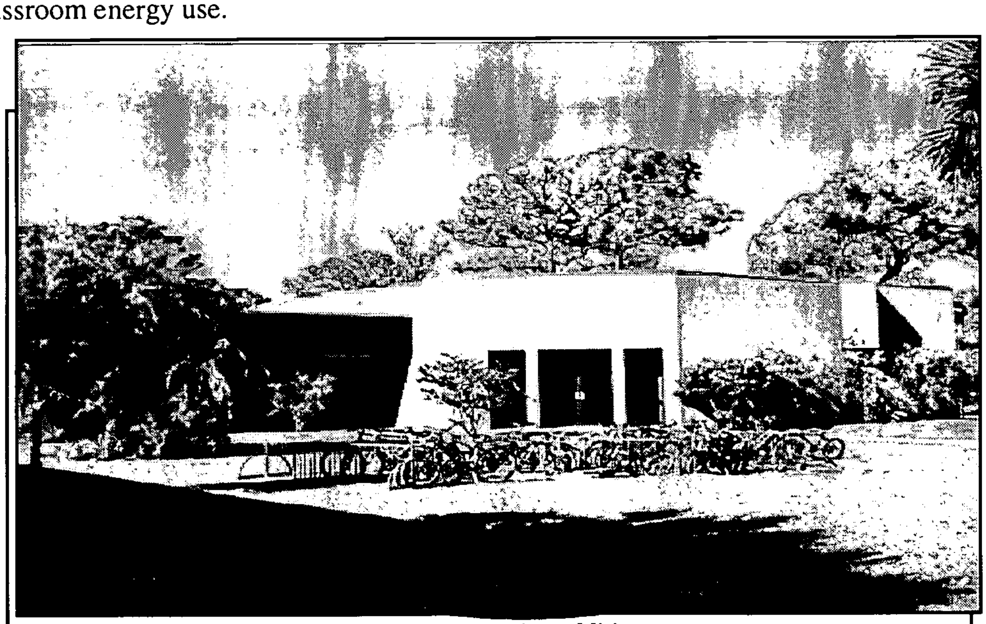

Figure 9. New wing addition.

16%

Figure 8. Summary of quarterly electrical end-use at FLASTAR site.

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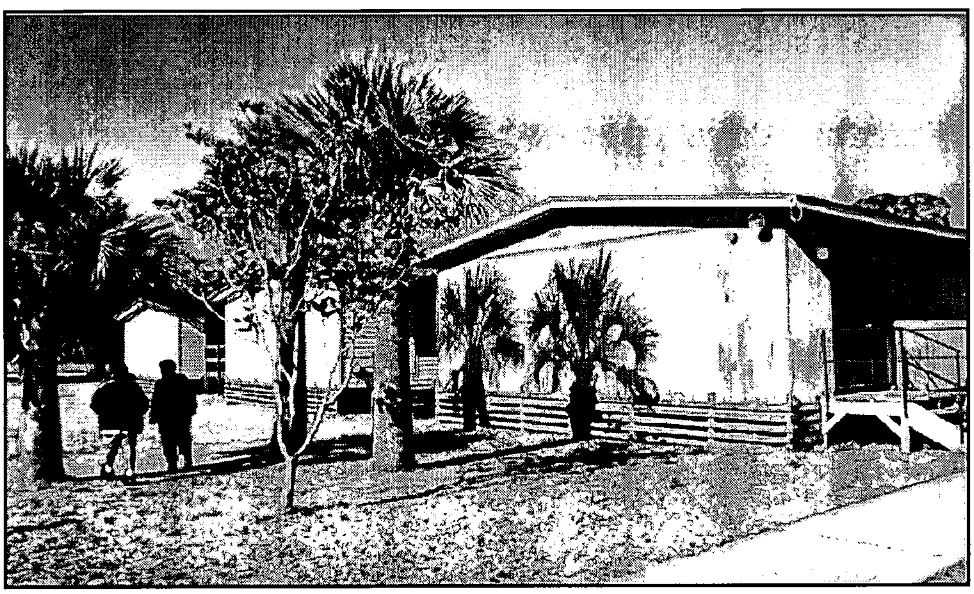
Figure 10. Portable classrooms.

The energy demand of the 12 portables (shown in Figure 10) is particularly interesting since this represents the fastest growth of educational floor space in Florida.[2] Figures 11 and 12 detail these loads. The portable classrooms demand an average of 14.9 kW over the monitored period (360 kwh/day). Figure 12 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. Although not explicitly part of our study, these data suggest that portable energy use might be an important area where some form of energy management could be employed.

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

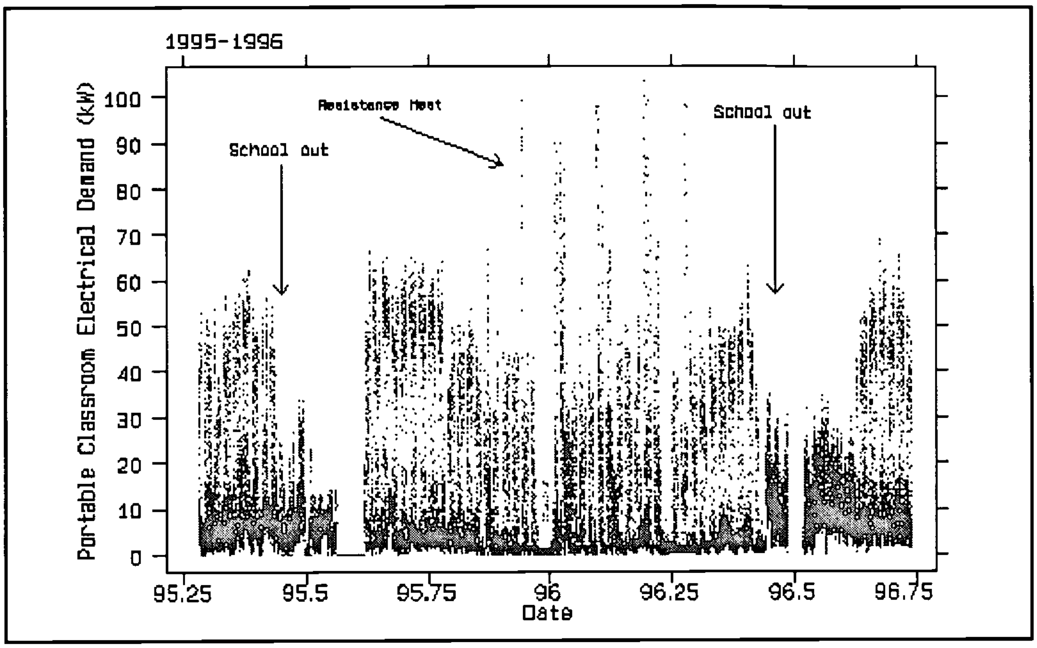

Figure 11. **Time series plot of portable classroom electrical demand over entire monitoring period.**

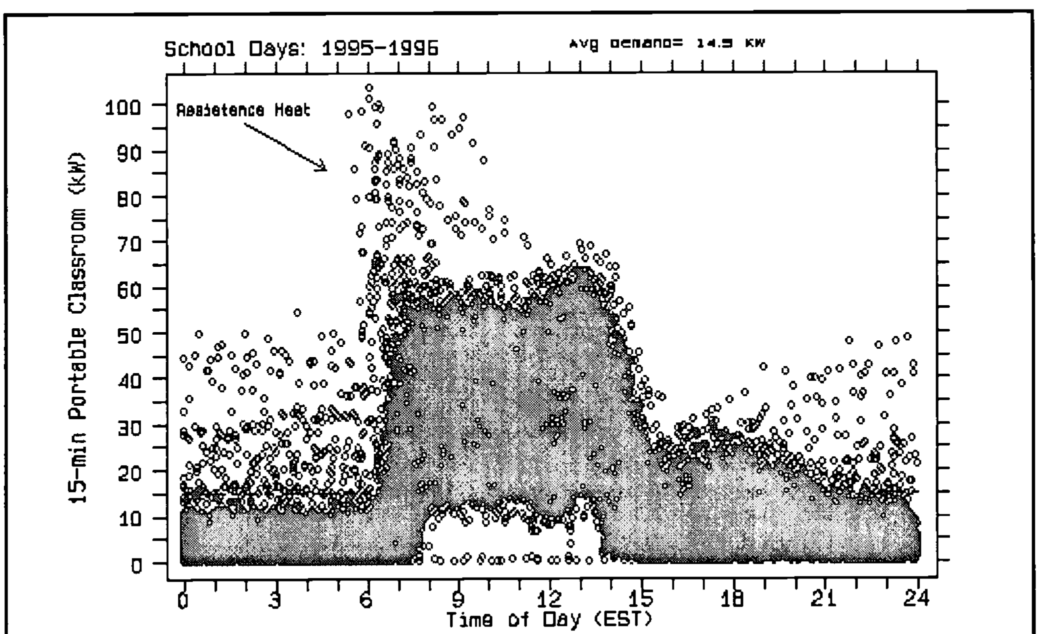

Figure 12. Portable electric demand profile over period.

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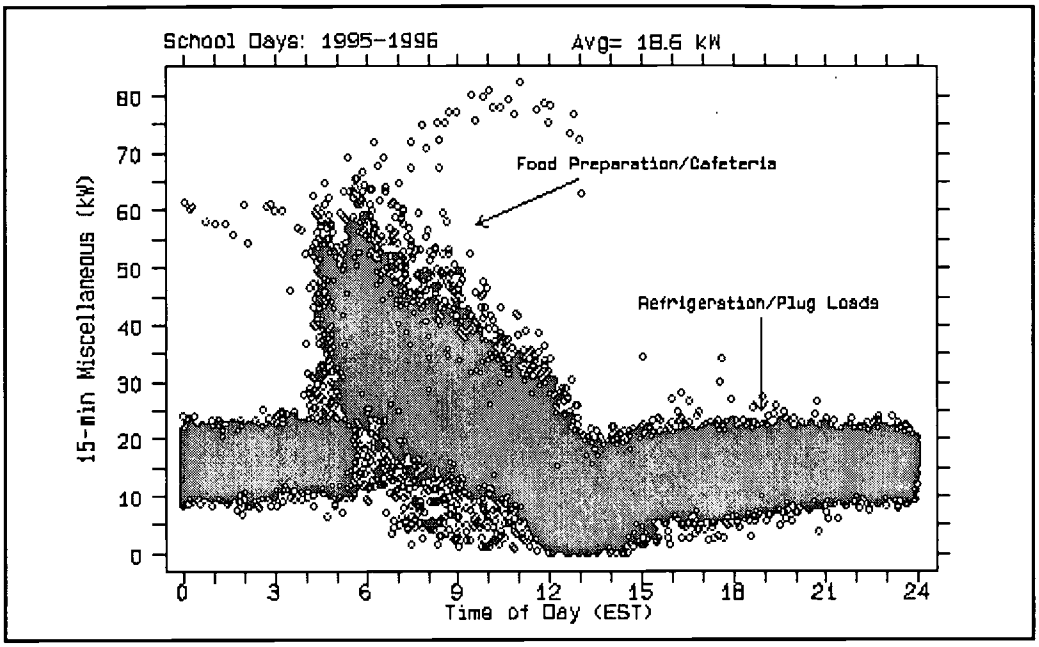


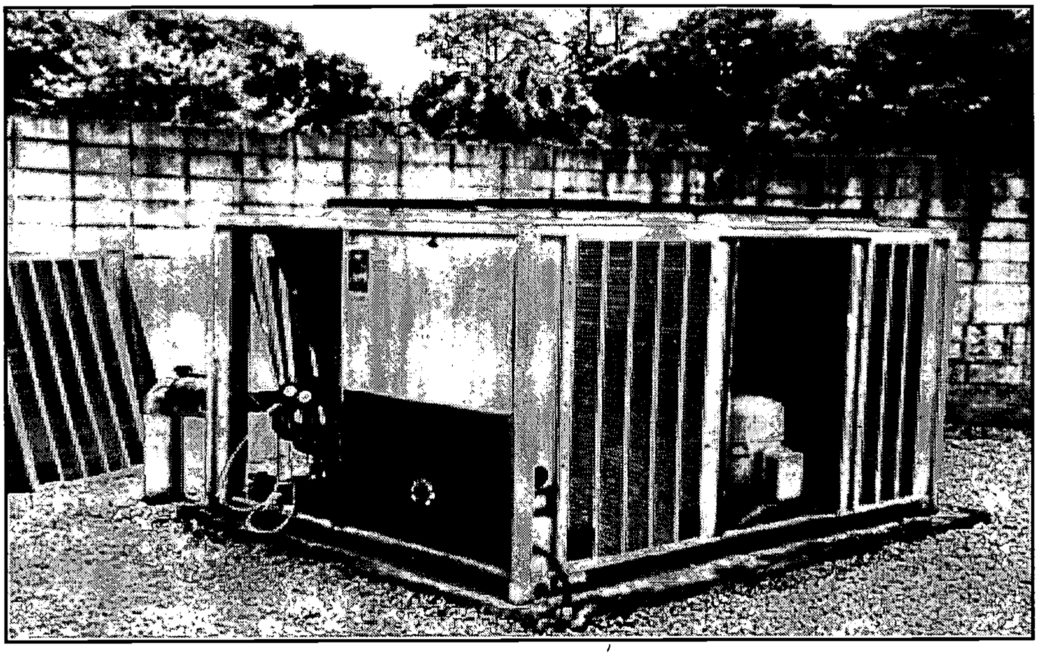
Figure 13. Miscellaneous electrical demand profiles over period.

Chiller Retrofit

As seen from Figure 8, the HVAC systems account for about 16% of the facility electrical energy consumption. In late July 1995 the facility chillers were changed out as shown in Figure 14. This improvement replaced two reciprocating type condensing units with a single high efficiency screw type counterpart (see Appendix B). 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 15 and 16, these savings were 19% and 45% for school and non-school days, respectively. Regression analysis of the new system (Figure 17) resulted in an installed performance of 1.21 (±0.001) kW/ton as installed, which is within the range of factory data. Similar analysis (Figure 18) 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.[3] 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.

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 19 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

[2] Note that only a short period of thermal load data was available for evaluation of the existing chiller since the flow meter only became available on June 14, 1995.



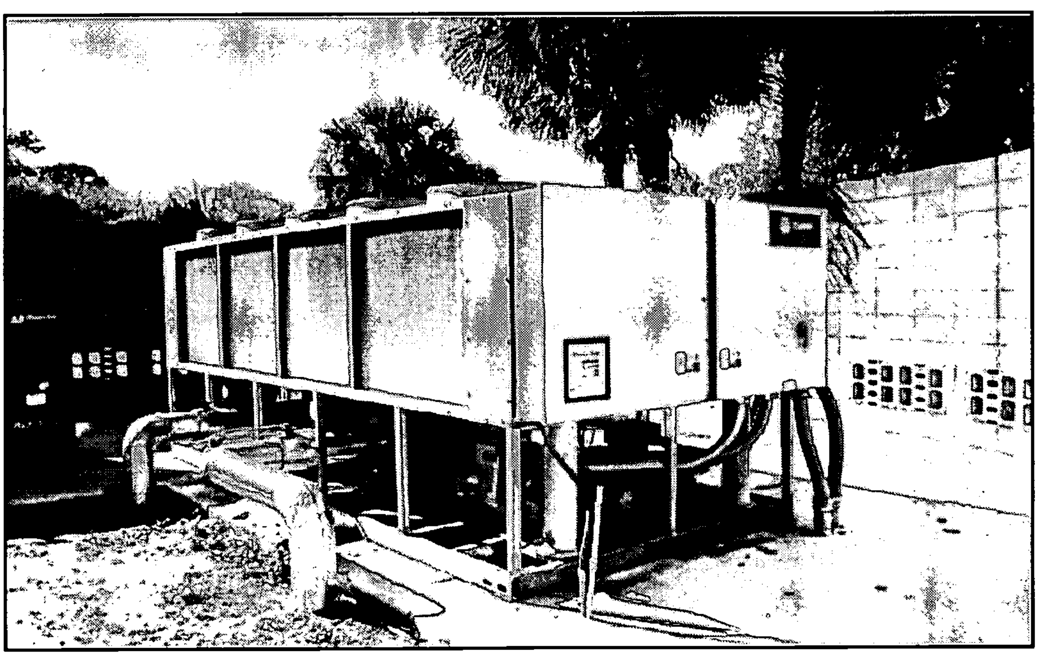


Figure 14. New chiller (bottom) replaced existing unit (above).

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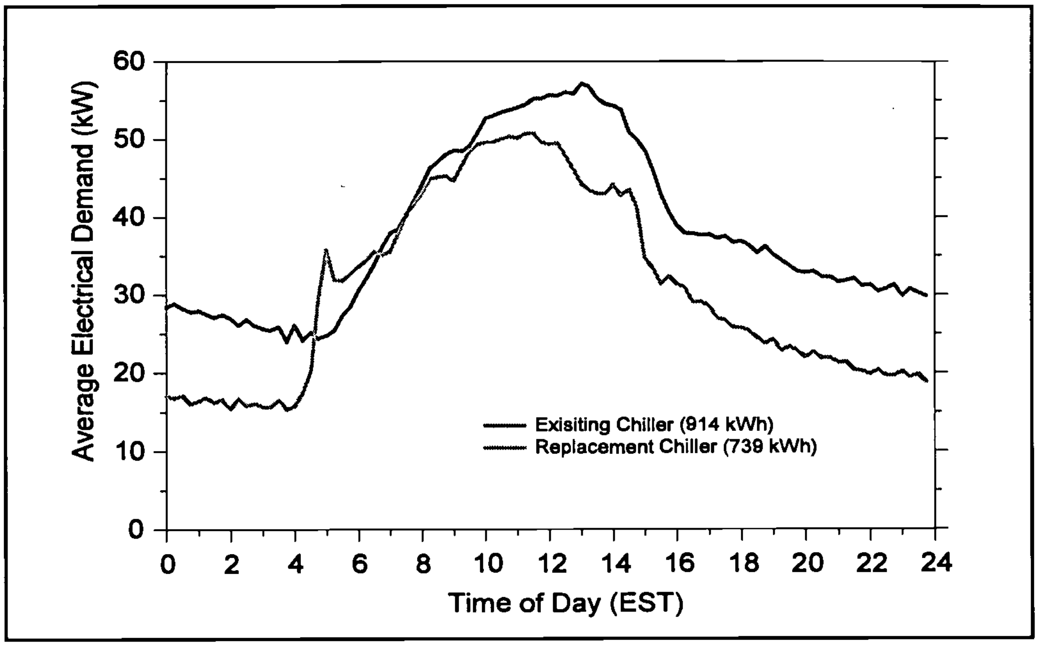

Figure 15. Comparative chiller demand profiles for all school days, April 12 - November 15, 1995.

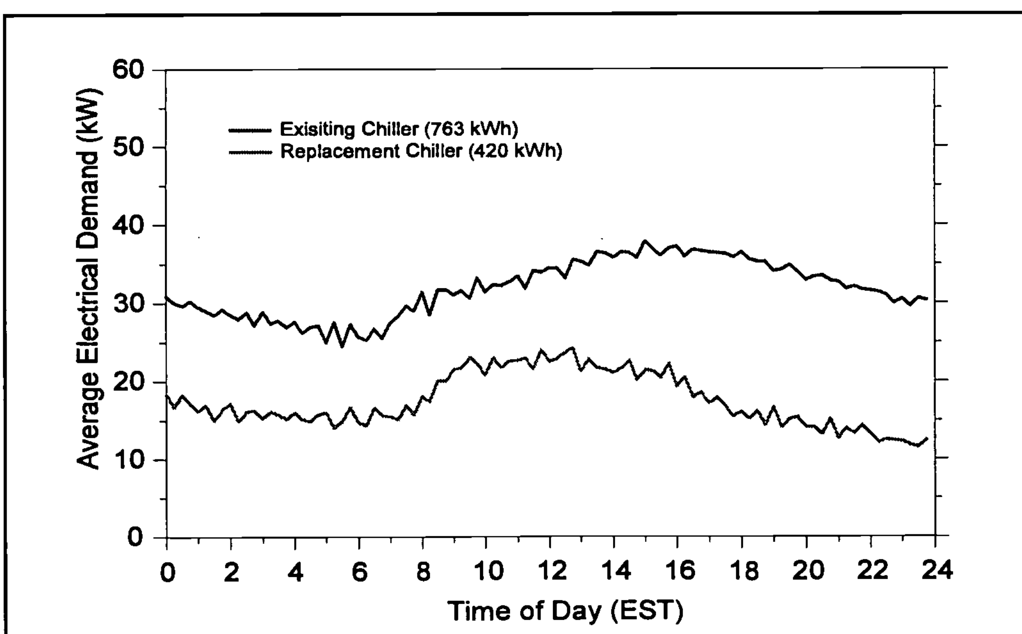

Figure 16. Comparative chiller demand profiles for all non-school days, April 12 - November 15, 1996.

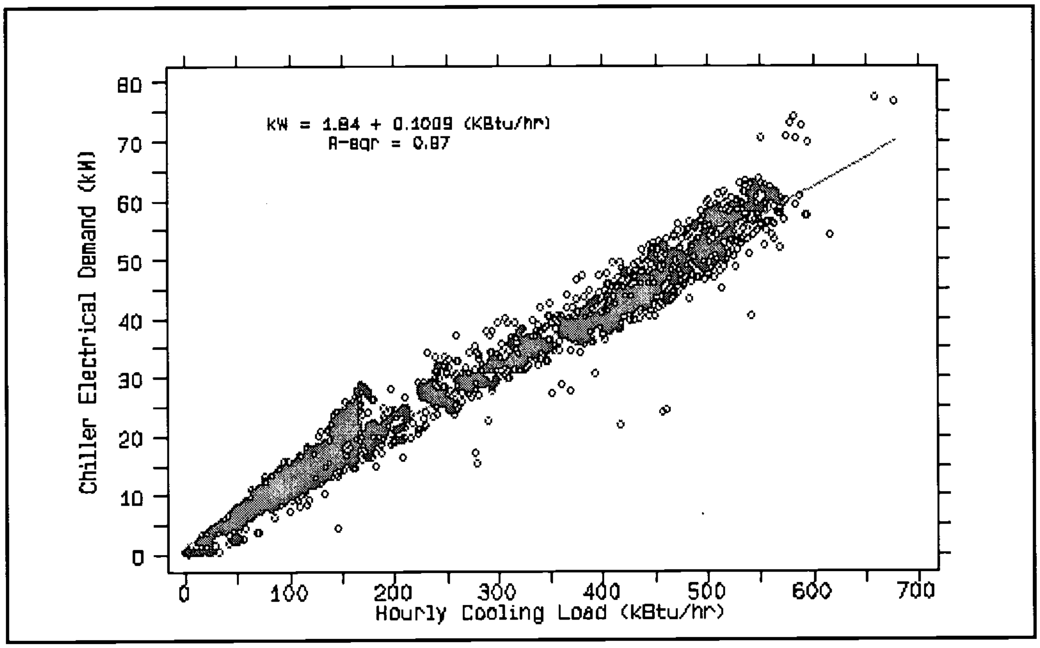

Figure 17. Regression of new chiller electric demand against chilled water cooling load.

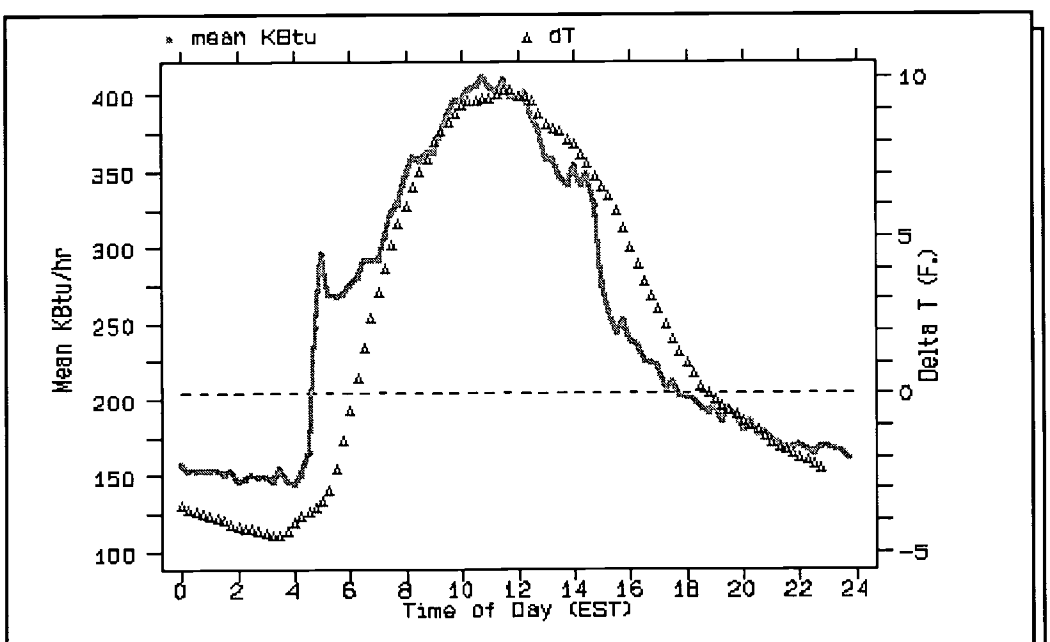

Figure 19. Comparison of average measured chilled water load and temperature difference between interior and outdoor temperatures.

Figure 18. Regression of existing chiller electric demand against chilled water cooling load.

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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:

$$\text{kBtu} = \underset{[34.3]}{181.2} + \underset{[9.16]}{9.21}\,(\Delta T) + \underset{[9.03]}{3.281}\,(\text{Lighting kW})$$

$$R^2 = 0.919$$
$$F(2,96) = 519.92$$

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)

The t-statistics for the coefficients are given in brackets; much of the remaining variance is likely due to occupancy and other unmeasured quantities (eg. 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/W), 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. Figure 20 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. At least a 7% reduction in cooling load was estimated by simply elevating the average interior temperature by 2°F.

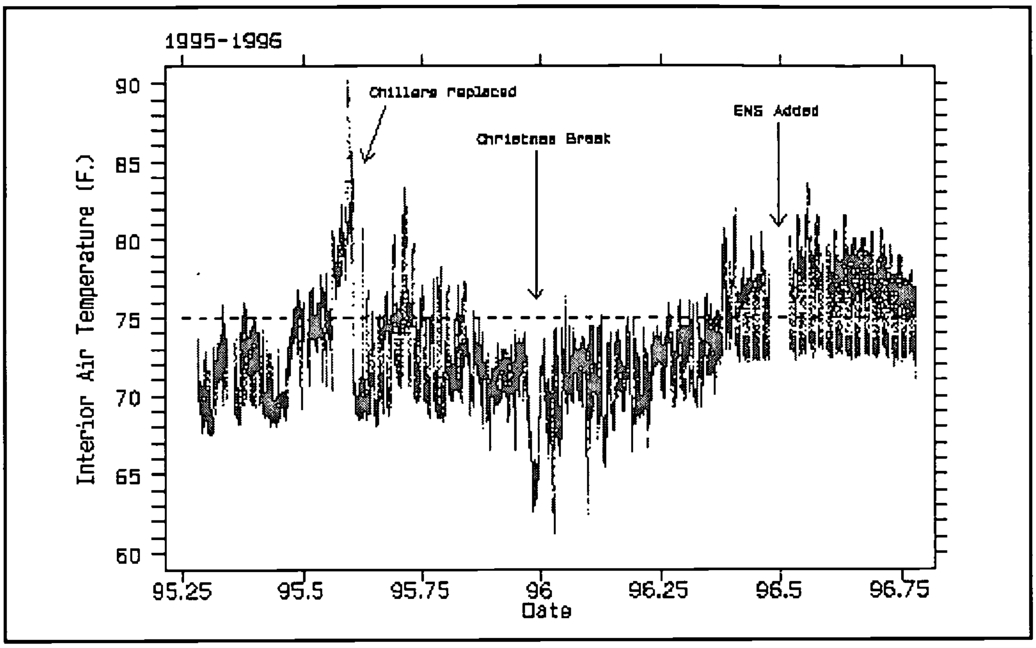

Figure 20. Measured interior air temperature in Fellsmere facility over monitoring period. The line (75°F) represents a reasonable target for efficient cooling operation. Note improvement after EMS install.

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 21 and 22. As expected, there is a strong relationship between both electrical consumption and thermal energy at increasing ambient temperatures. This relation is particularly noticeable at outside temperatures above 60°F.

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 (Figure 23). 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 24. 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.

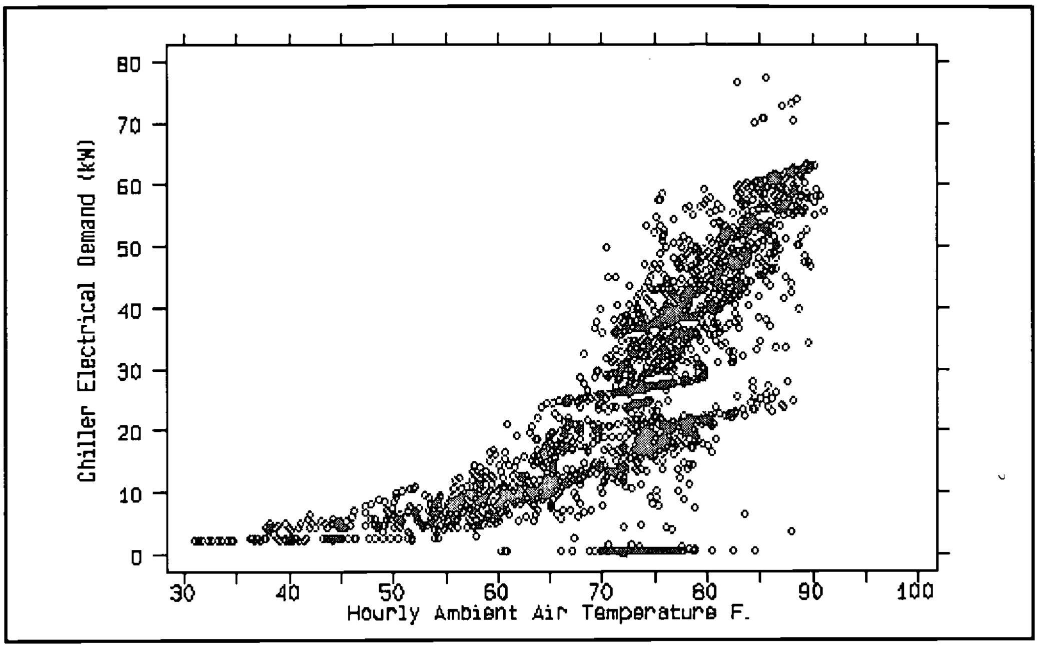

Figure 21. Measured hourly chiller electrical demand vs. Ambient outdoor temperatures.

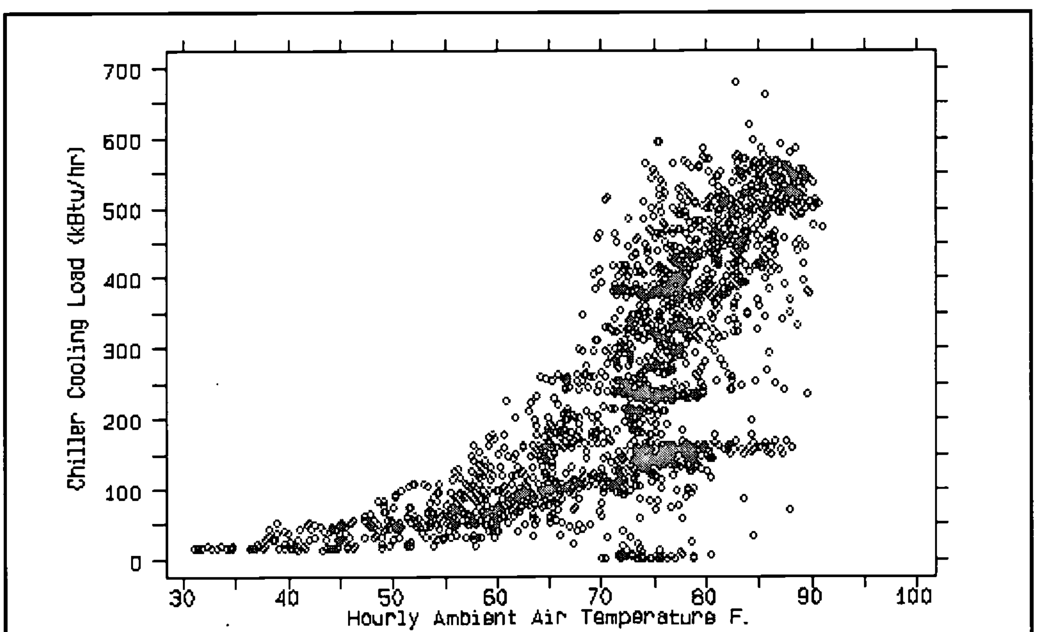

Figure 22. Measured hourly chilled water cooling load against outdoor ambient temperature.

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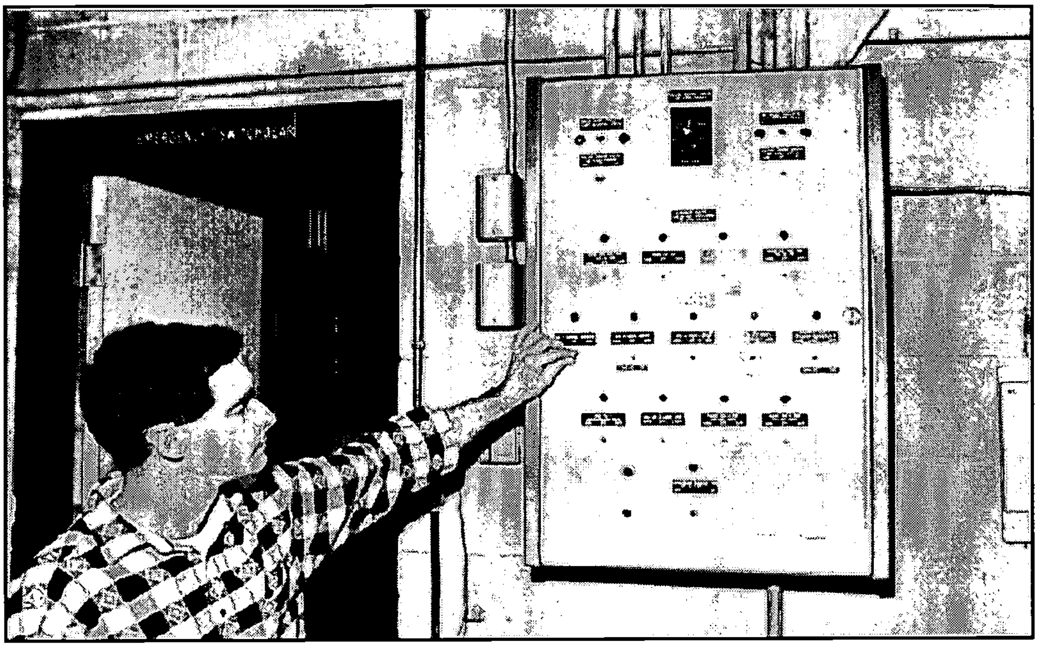

Figure 23. Air handler control panel operated manually by on site staff prior to EMS install. Note blue tags requesting air handlers 2 and 5 to be left on continually.

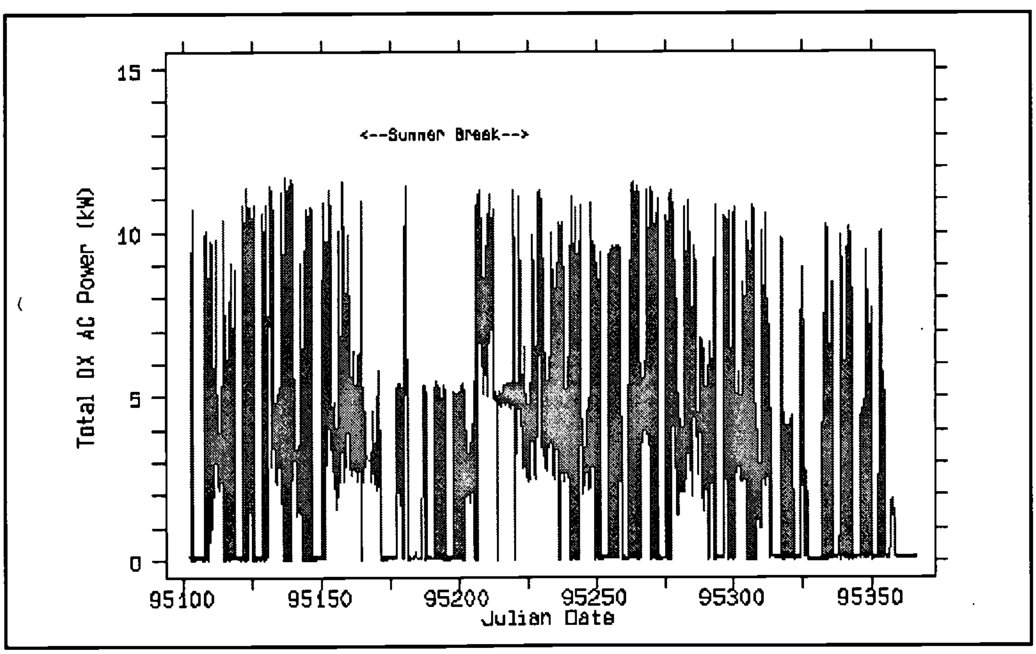

Figure 24. Measured DX air conditioner power throughout 1995.

Lighting Controls: Occupancy Sensors

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The second ECM installed in the project were occupancy sensing controls added to the lighting system (see Figure 25). The general intent was to reduce wasted lighting energy use in classrooms. This retrofit was installed during the Christmas break at the end of 1995.

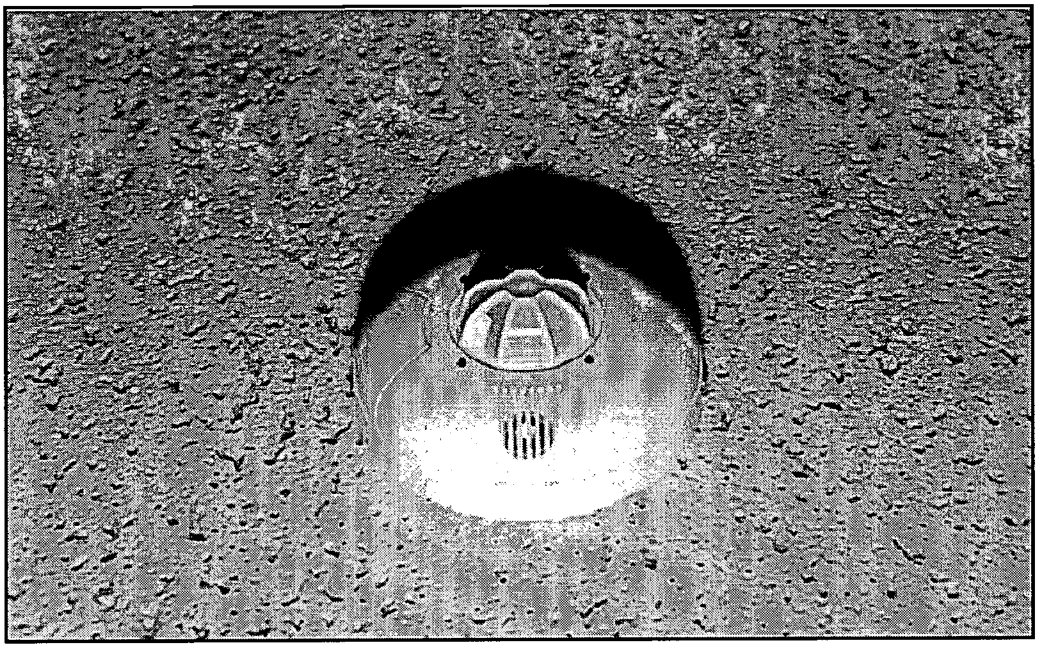

Figure 25. Installed ceiling-mount occupancy sensor from retrofit in December 1995.

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. Figure 26 shows typical classroom lighting with the installed sensors. The equipment is described in Appendix C.

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 [6]. Figure 27 shows the lighting electric demand profile before the retrofit; Figure 28 shows demand after the change. The post retrofit lighting data showed frequent instances where classroom lighting was unintentionally activated between midnight and 6 A.M. The data suggested problems with the adjustment and commissioning of the sensors. These problems with "false triggering" had already been observed with ultrasonic sensing types with research conducted at the Florida Solar Energy Center [6].

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 29 depicts the average lighting demand profiles during the three periods.

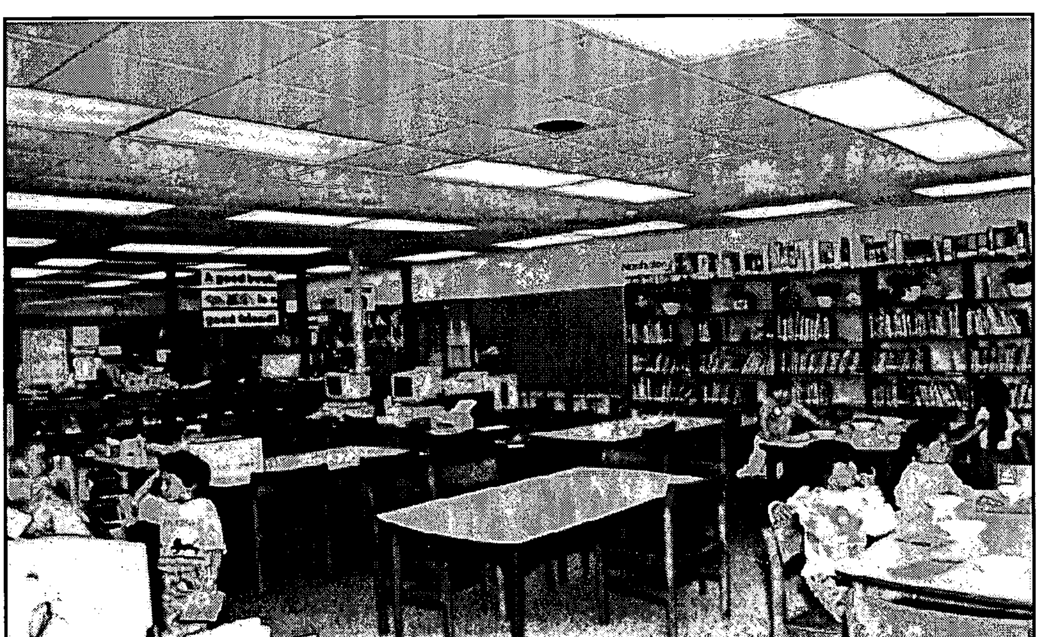

Figure 26. Typical classroom (top) and library (bottom). Note ceiling mounted occupancy sensor retrofit (upper center of photographs).

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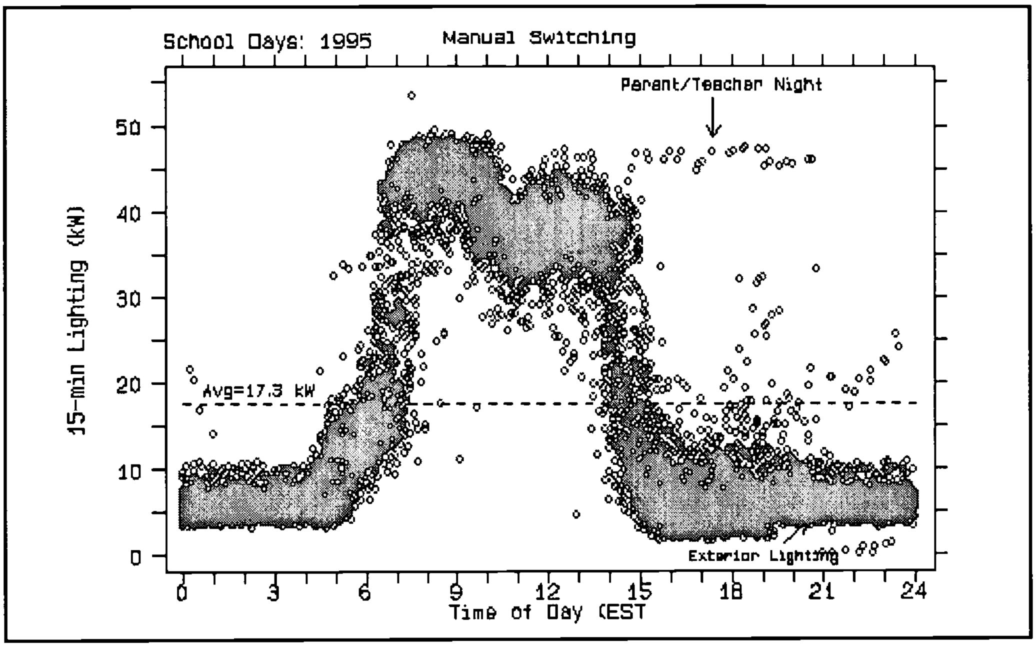


Figure 27. Lighting electrical demand profile for school days in 1995 under manual switching.

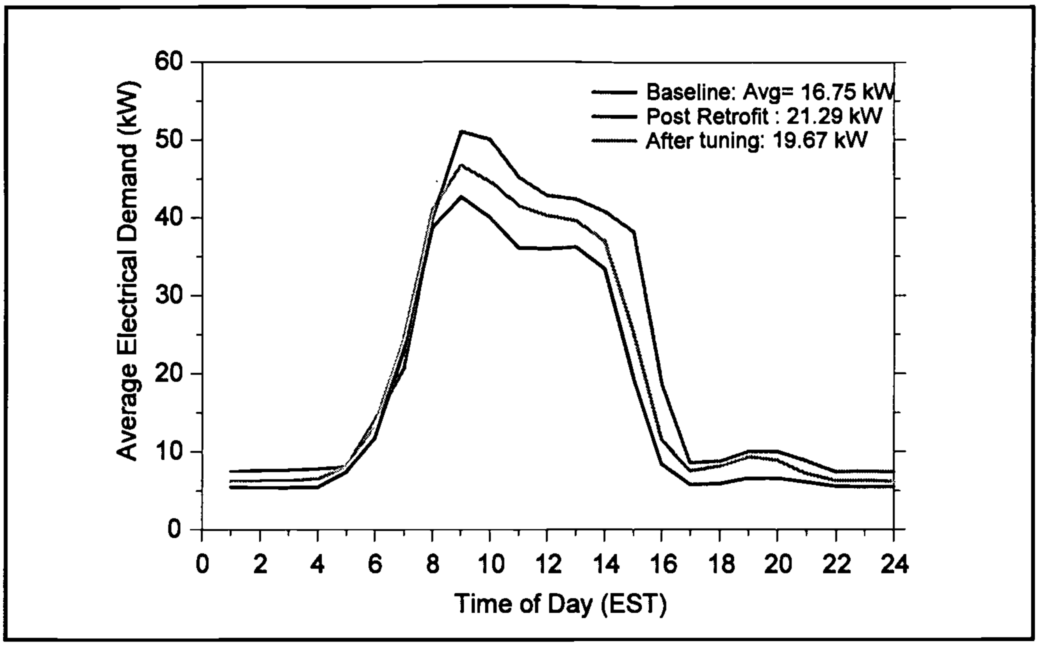


Figure 28. Average daily lighting electric demand profile before and after lighting occupancy sensor retrofit. Consumption increased in the post period.

Reasons for this seemingly contrary result are illustrated by a recent Wisconsin 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 [7]. 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 [8].

Energy Management System

The 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 (see Figure 22). The energy management system is an *Infinity CX 9500* unit manufactured by *Andover Controls* (see Appendix D). It provides direct digital control (DDC) of the HVAC equipment.

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.

Figures 30 and 31 are examples of daily data plots generated for the FLASTAR project. These plots are produced and reviewed on a daily basis to ensure data completeness and accuracy. Figures 30A and 30B show a typical "school" day before the EMS was installed, where the system chillers were left operating unintentionally after school day hours. Figures 31A and 31B show a similar plot one year later under similar weather conditions, after the EMS had been implemented. These figures represent a 26% reduction in chiller power and a 23% reduction in air handler usage on these particular days. Similar comparisons for weekends and holidays (not shown) showed even larger reductions.

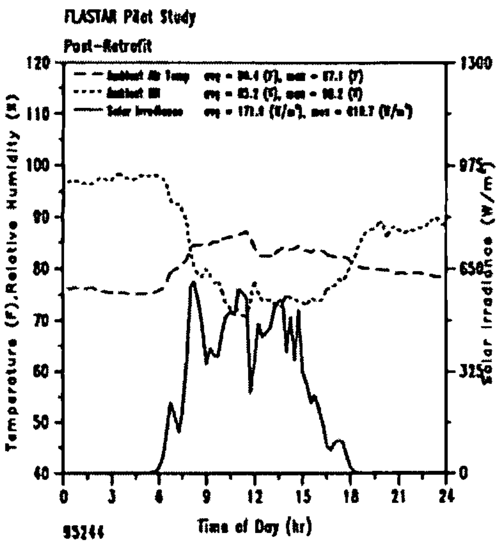
Since the end-use loads associated with the HVAC system were monitored separately, it is possible to observe operation of each of those components under the energy management system. Part of the savings in cooling performance was directly due to the chiller retrofit. Originally, the cooling system was 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 Trane 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 32 and 33 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]

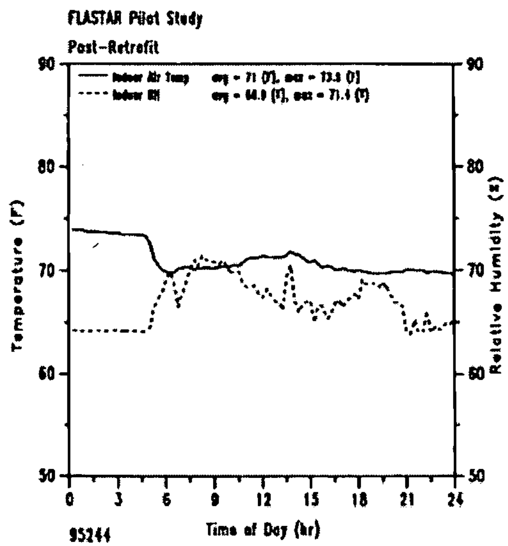
With the energy management system installed, the new chiller data exhibits nearly the same demand during mid-day, although the real impact is seen during school hours where it is frequently cycled off. The EMS control results in a net reduction in cooling power of 17% (355 kWh/day) in a six week period from August - September of 1995 and 1996 (see Figures 34 and 35).

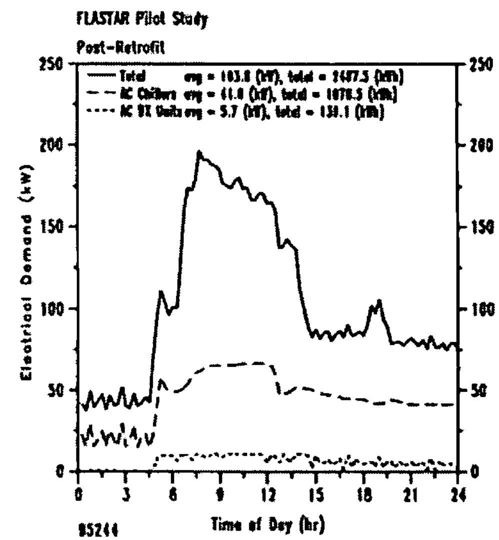
One area where the EMS retrofit has made a significant impact has been on the chiller cooling load. This parameter is a product of the mass flow rate in the building chilled water loop and the temperature differential as measured in the return and supply lines. Factors which influence load are outdoor weather, internal gains, and interior temperature set points. Figures 36 and 37 show the load profiles for the building before and after the installation of the EMS for two similar time frames while the building was in use on school days. The peak load during the school operating hours remained unchanged though, during the unoccupied hours, the load is virtually eliminated because of system control.

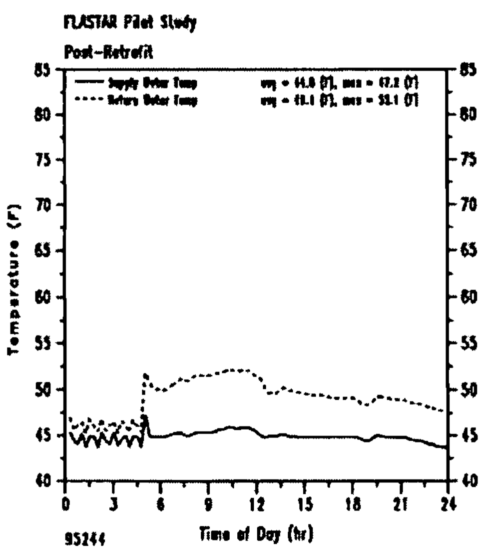
Most of the changes in system cooling load come from the much tighter temperature control provided by the EMS. Figures 38 and 39 show the differences in interior temperature set points. Prior to EMS use, the typical temperature inside the building was 73°F, was fairly unpredictable and on many occasions, would go below 70°F during the night. After the EMS

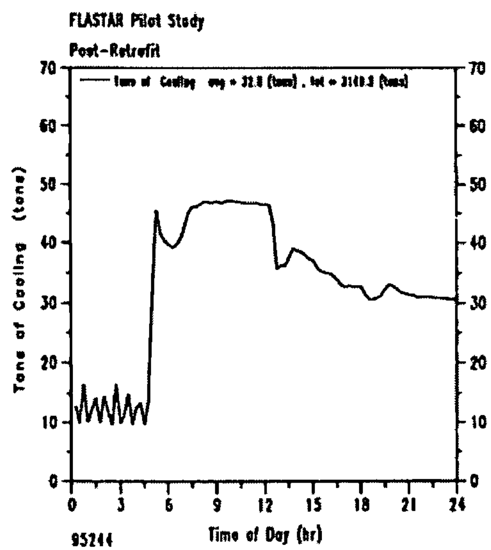
[4] In each of the succeeding plots the red symbols indicate the actual 15-minute data points over the monitoring period. The bold green line is the 15-minute average over the 24-hour cycle. The black dotted line is the daily average.











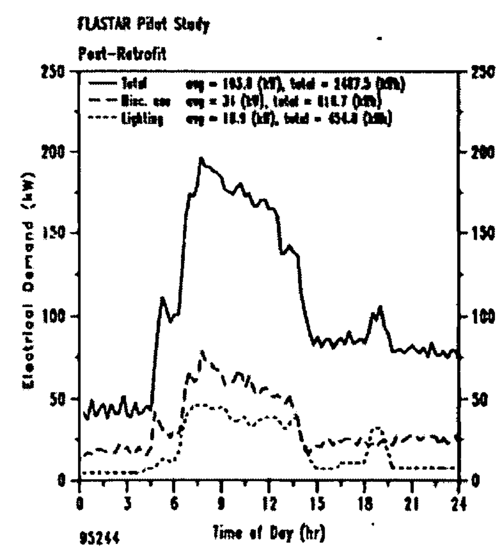


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Figure 30A. Fellsmere facility performance *before* EMS install (Friday, Sep.1, 1995)

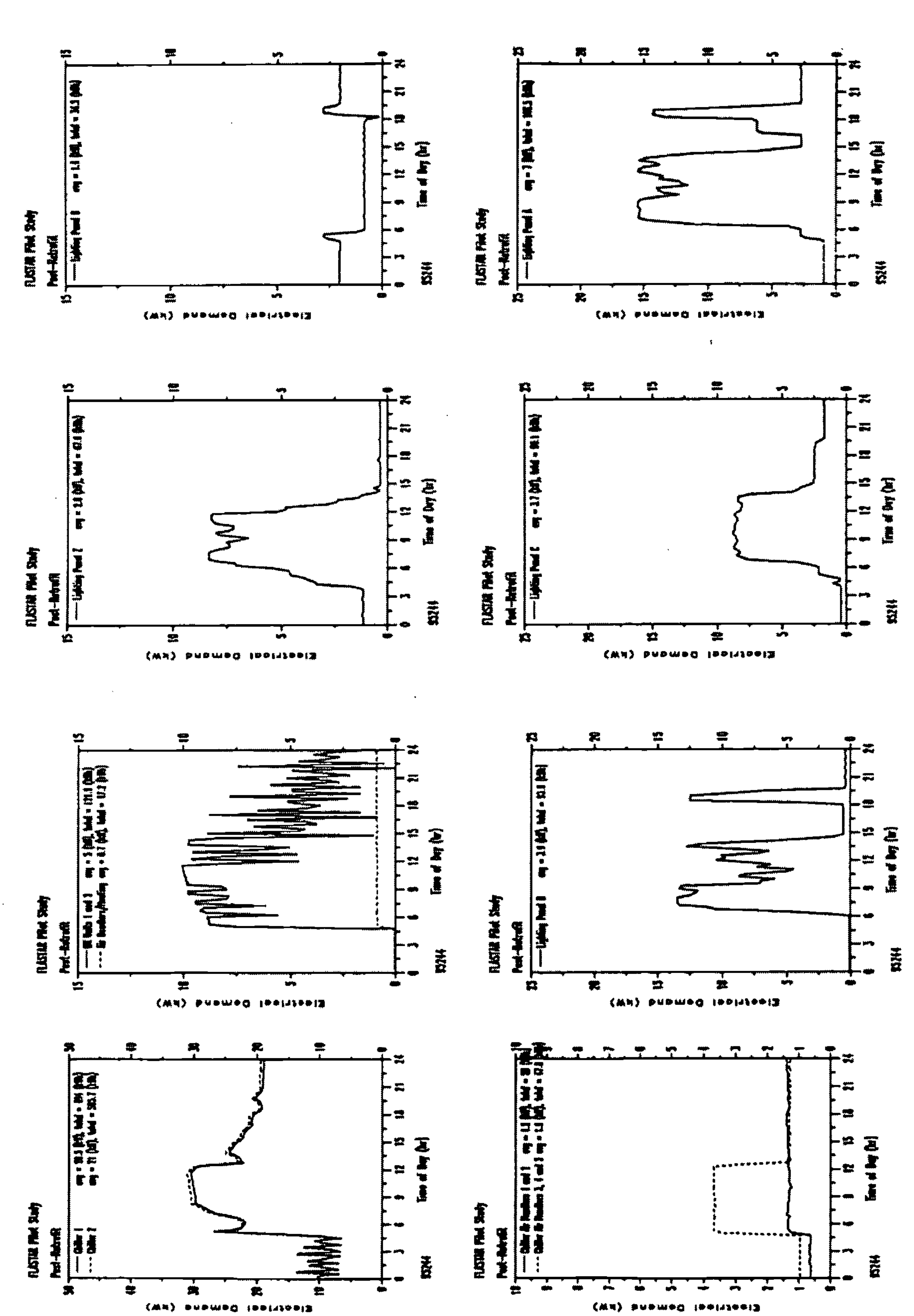

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Figure 30B. Fellsmere facility performance *before* EMS install (Friday, Sep.1, 1995).

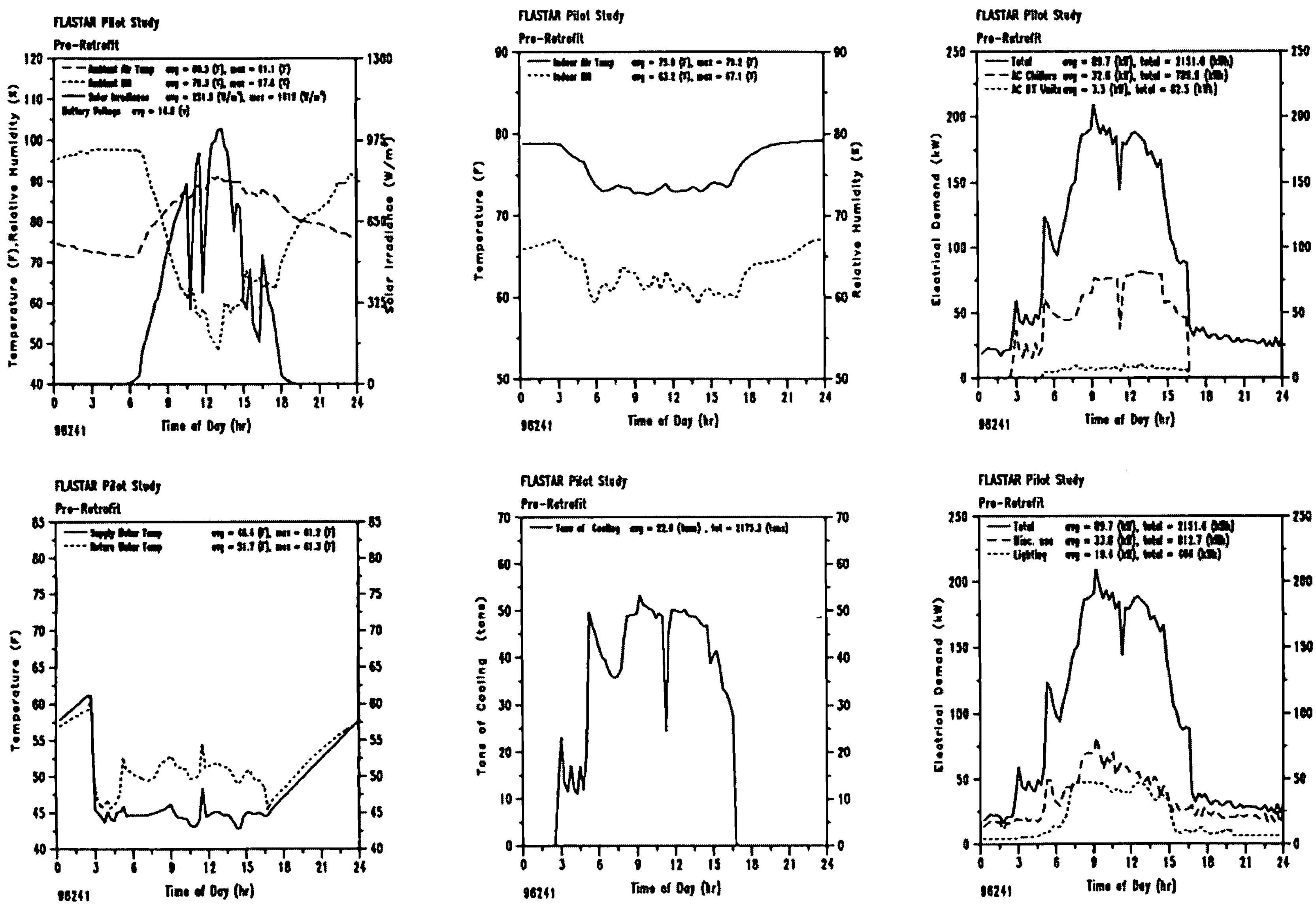

Figure 31A. Fellsmere facility performance *after* EMS install (Wed., Aug.28, 1996).

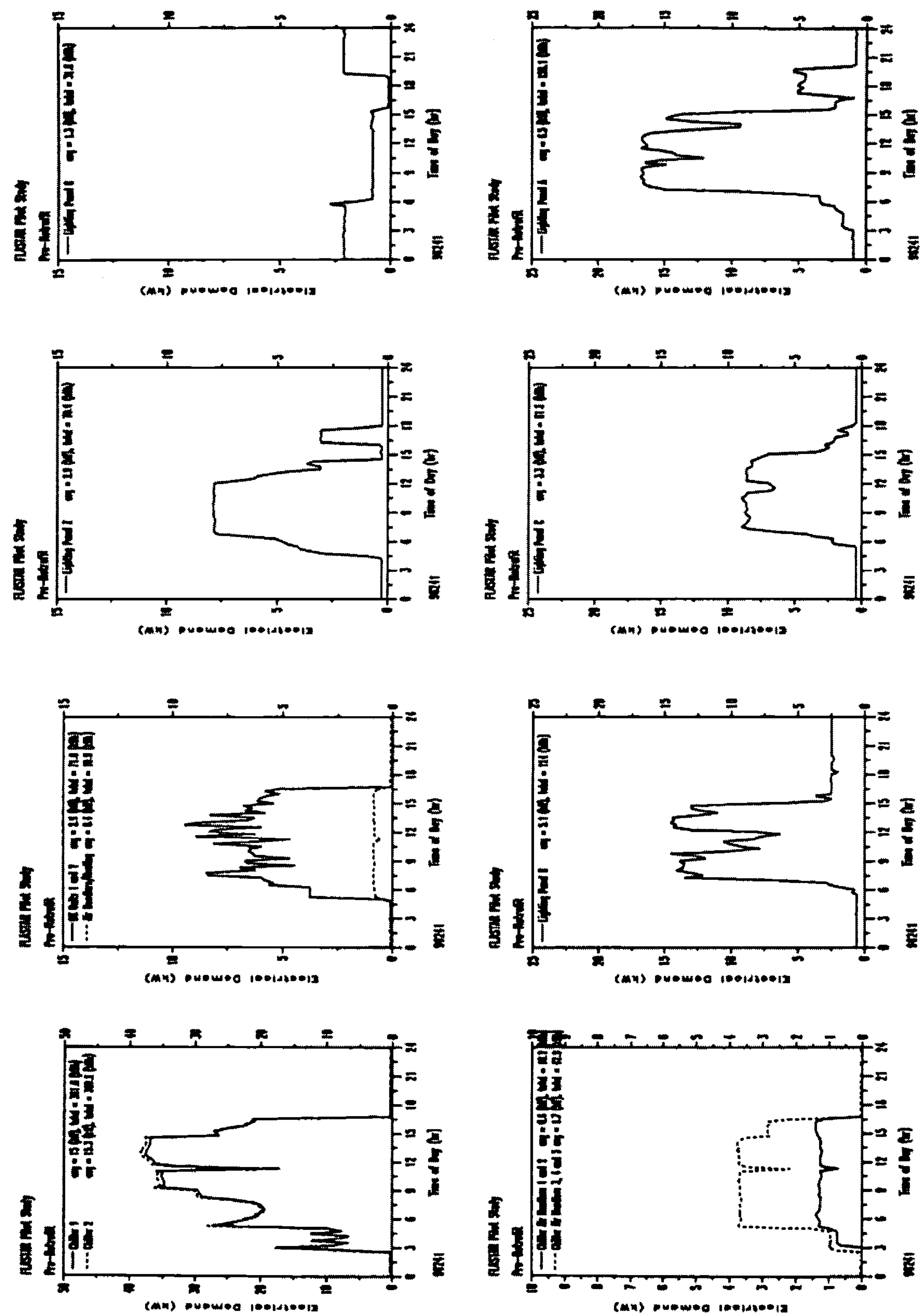

Figure 31B. Fellsmere facility performance *after* EMS install (Wed., Aug.28, 1996).

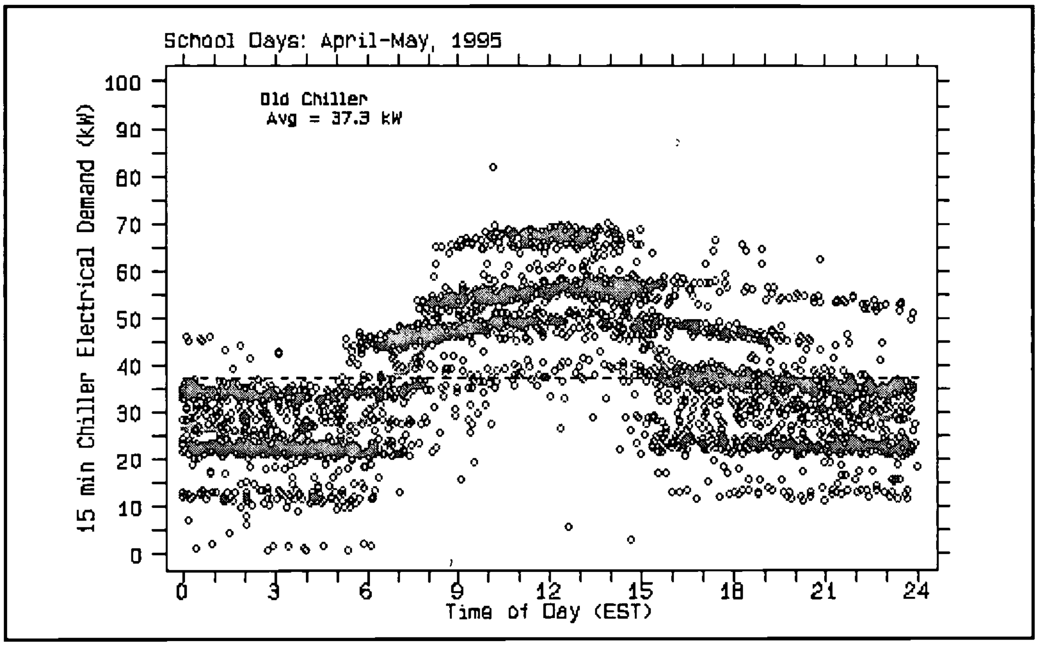

Figure 32. Old chiller electrical demand profile.

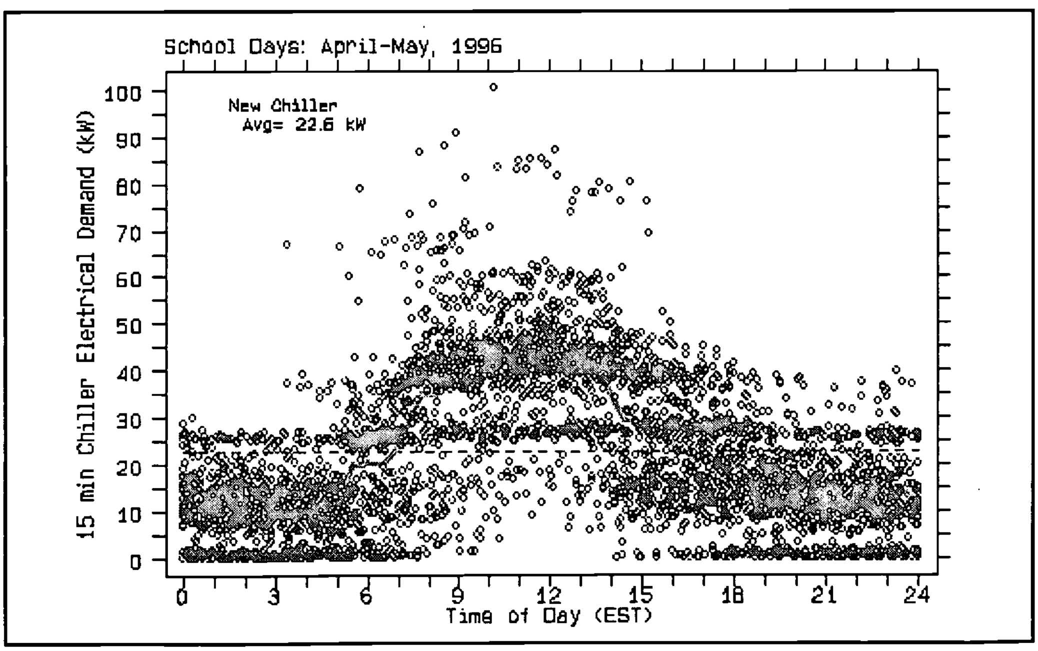

Figure 33. New chiller electrical profile.

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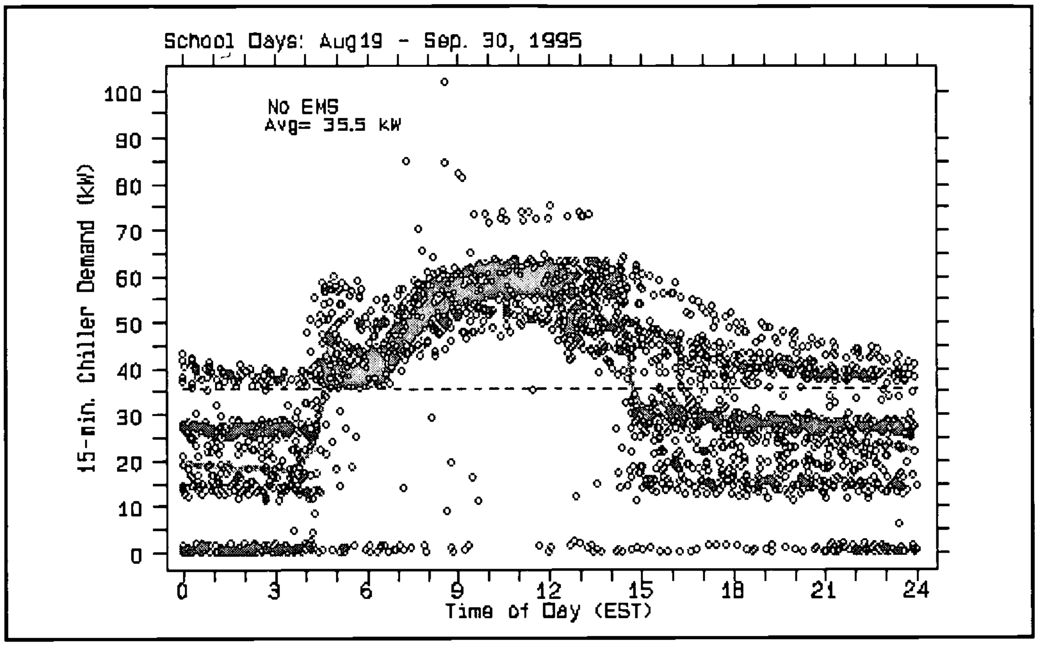

Figure 34. New chiller demand profile without EMS (Aug. - Sept., 1995).

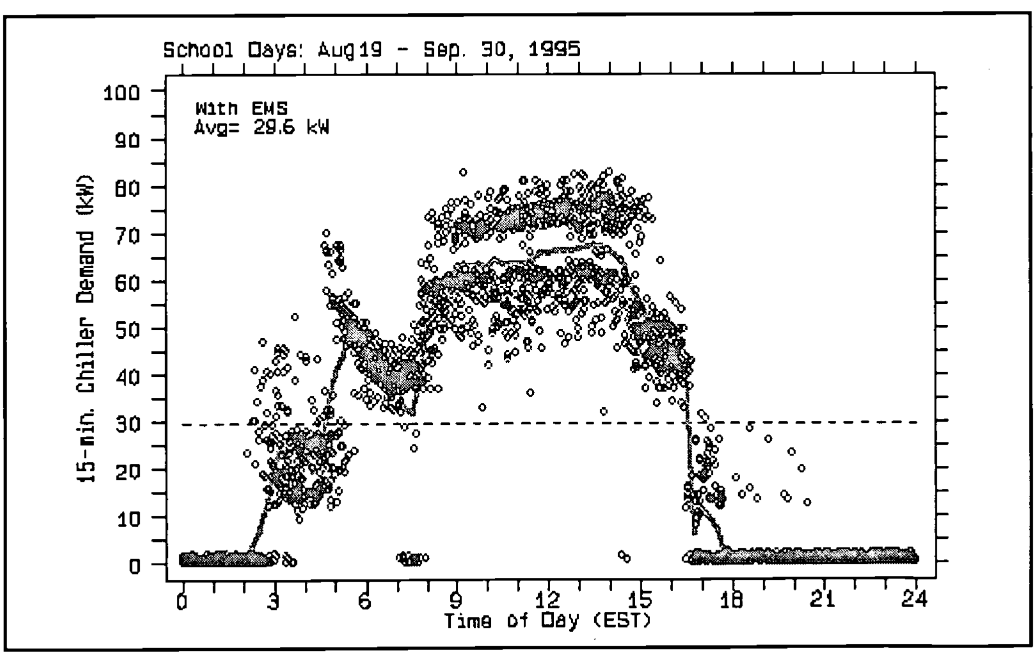

Figure 35. New chiller demand profile with EMS (Aug. - Sept., 1996).

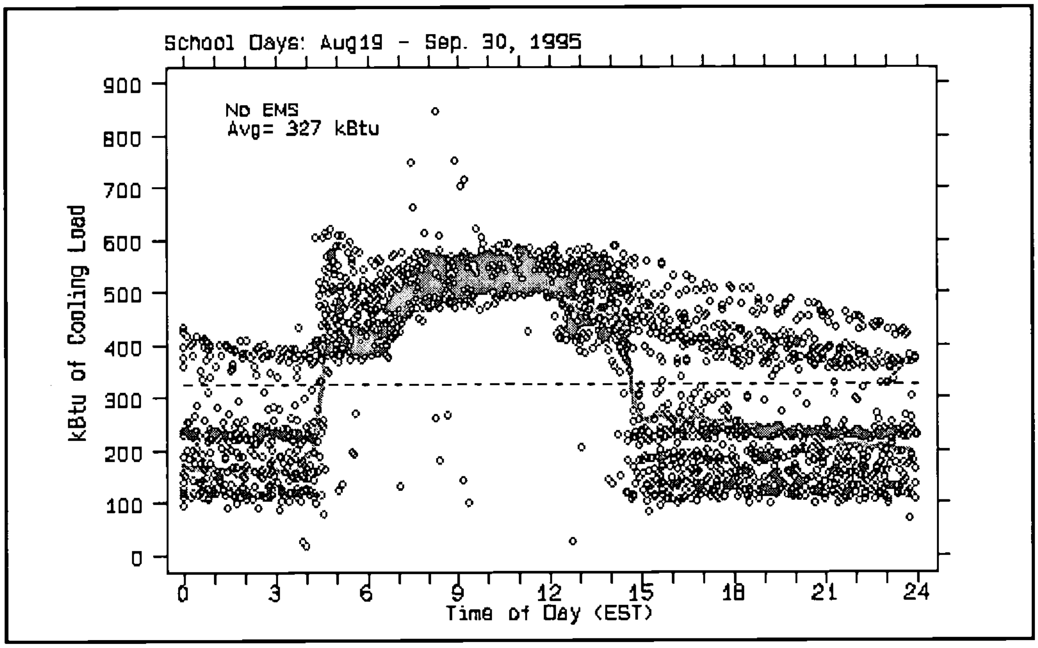

Figure 36

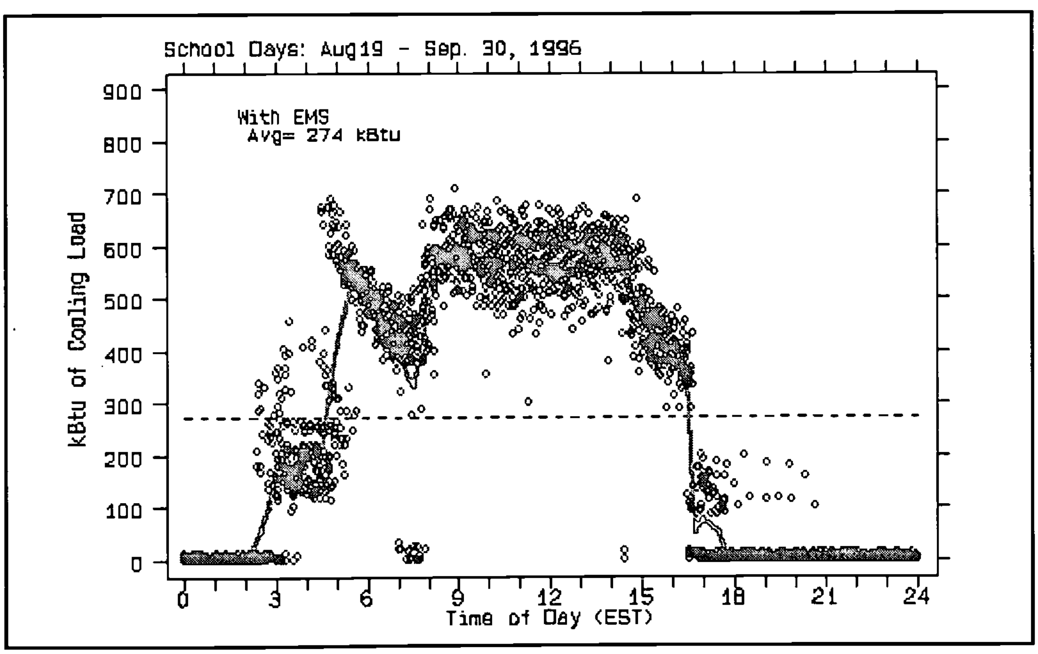

Figure 37

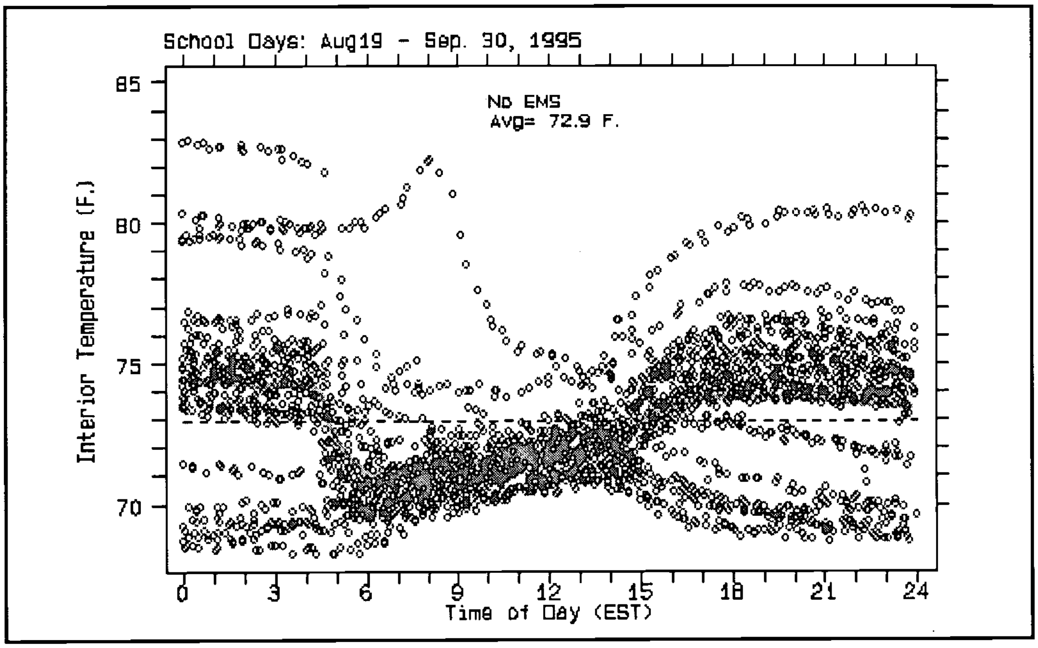

Figure 38. Interior temperature before EMS control (Aug. - Sep., 1995).

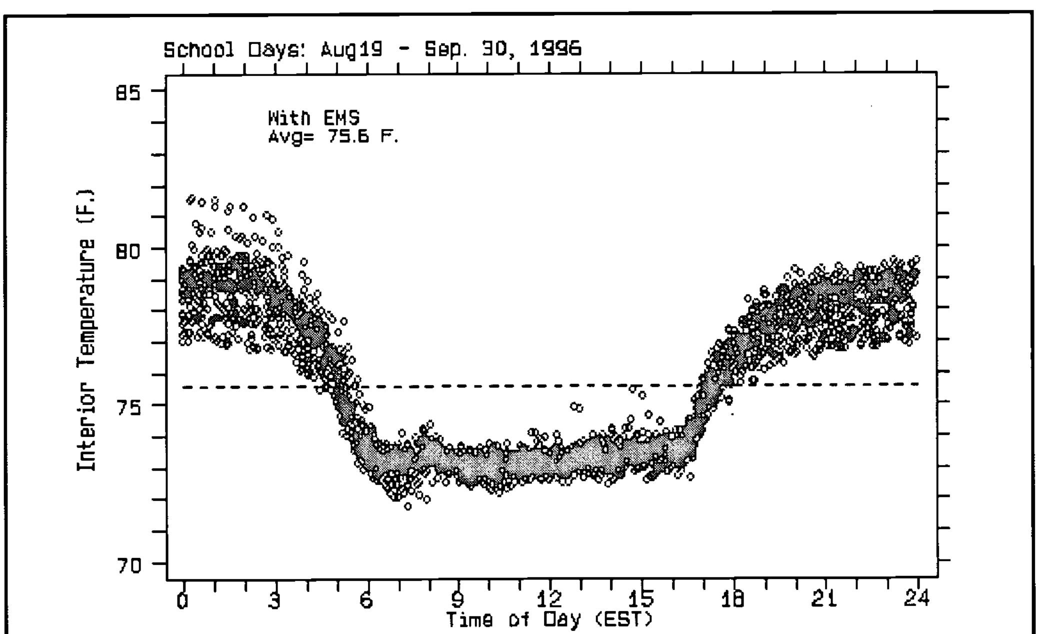

Figure 39. Interior temperature after EMS control (Aug. - Sep., 1996).

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%.

Figures 40 and 41 show the pre and post data from the building's air handler systems. At the start of the project and up until the EMS was installed, the air handlers were manually operated from the equipment room. As the plots indicate, there was considerable use after hours, where some the buildings air handlers were left running continuously. More consistent scheduling of this equipment by the EMS has produced a 30% energy savings (26 kWh/day).

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 42 and 43 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 39). After management, the units are only allowed to operate during occupied time periods (see Figure 40). 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.

Overall Performance of Installed Retrofits

The savings of the individual retrofits have been individually covered in the appropriate sections of the report. Collective performance of the retrofits in reducing site energy use is more difficult to evaluate since some of the best performing measures have just been installed. However, using 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 may be 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.

As described in this report, the EMS system installation dropped central cooling energy consumption by a further 17% when comparing September, 1996 and September, 1995, both with the new chiller. Savings for the air handlers and heat pumps was roughly 30% for each end-use. Although, a longer period of monitoring will be required to verify this estimate, it seems likely that the string of installed retrofits (chiller/lighting controls and EMS) thus far will reduce site energy consumption by roughly 120,000 kWh/yr. Assuming no change in peak

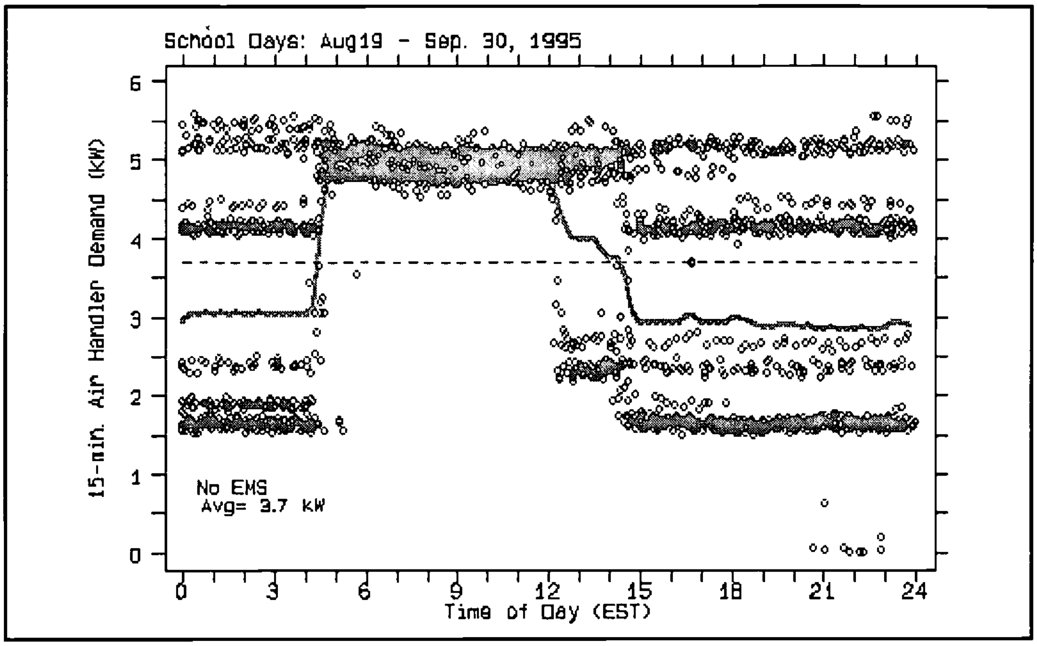

Figure 40. Air handler demand before EMS install.

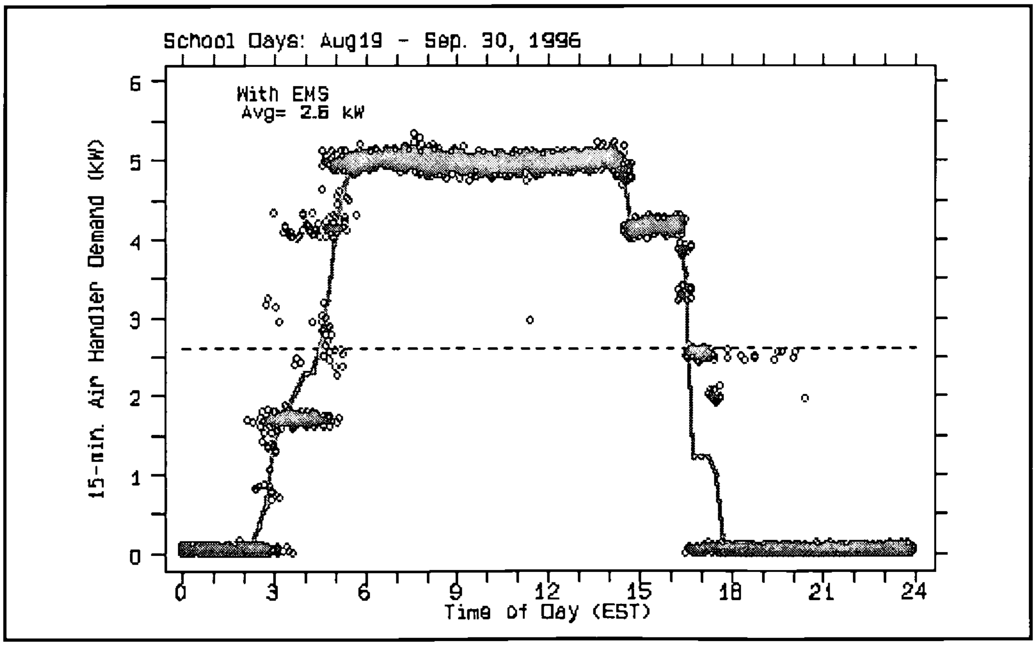

Figure 41. Air handler demand after EMS install.

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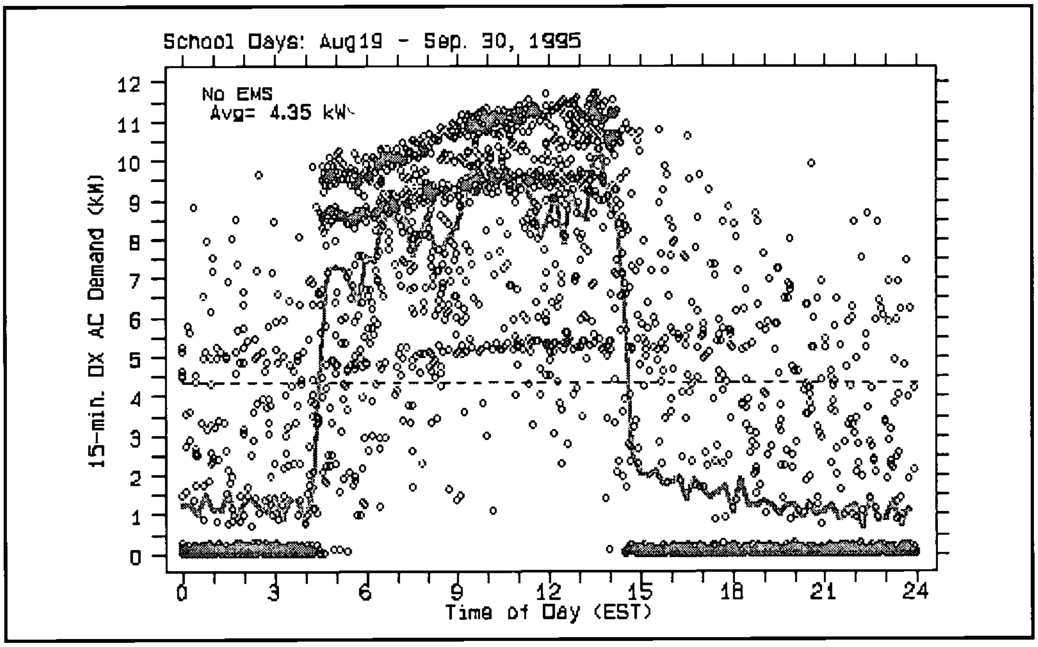

Figure 42. DX AC demand prior to installation of EMS.

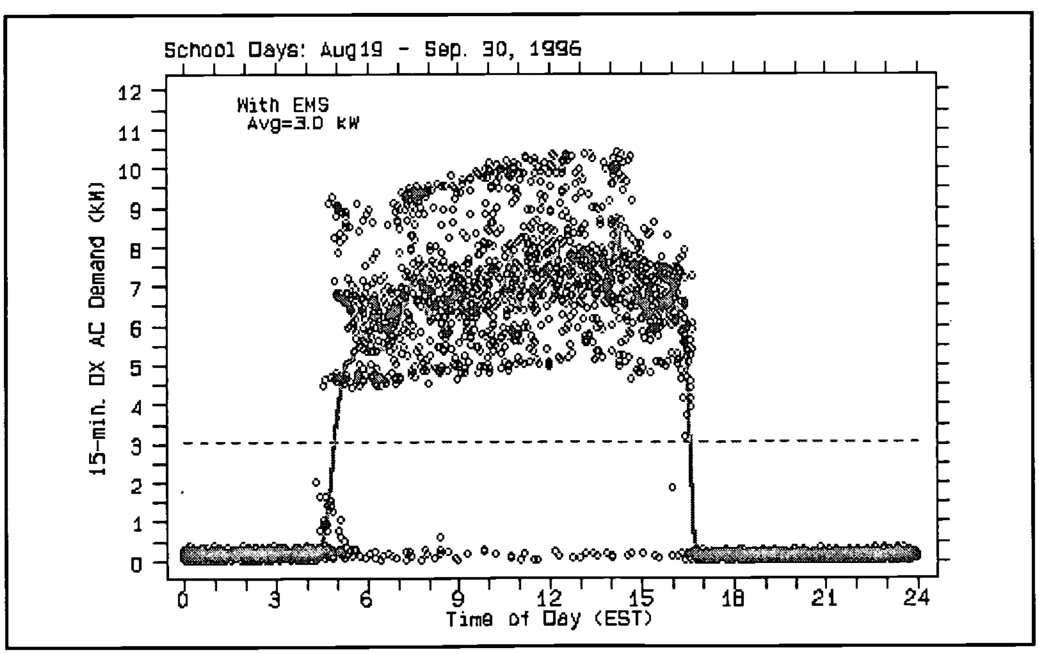

Figure 42. DX AC demand after installation of EMS.

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demand, the likely energy reduction will yield a $4600 annual savings. Against this savings must be balanced the expense of the retrofits. Project costs are summarized in Table 7. The savings values are calculated from measured data thus far, and should be considered preliminary:

Table 7
Preliminary Cost Effectiveness of Retrofit Measures

Measure Description	Installed Cost[5]	Annual Saved kWh	Annual $ Savings[6]	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
Interim Project Total	$94,637	117,900	$4,650	20.4

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 at 8.4%, mainly due to the negligible impact of the installed measures on the peak facility electrical demand. However, these preliminary figures will have to be re-evaluated after the project has been monitored for a longer period to time.

The Future

Although the pilot project for the FLASTAR Project is formally at an end, we plan to continue monitoring the facility for one additional year. This is being done since the school is planning to install a new lighting system in the facility in December of 1996. Also, by extending the monitoring period we will obtain a five month period under the EMS controls to estimate their long-term effectiveness.

The current lighting system typically consists of F34 T12 lamps and magnetic ballasts. The fixtures are to be changed to a new thin-line T8 system with electronic ballasts and potentially with reflectors and de-lamping. Based on previous evaluation at FSEC's lighting flexible test facility (LFTF), the proposed combination of lamps should be able to reduce typical fixture lighting consumption by approximately 23% [9]. Tandem wiring of the many two lamp fixtures in the Fellsmere facility should be able to both reduce per fixture energy consumption by a further 6% while significantly reducing the number of electronic ballasts to be purchased. This practice is therefore recommended for the retrofit.

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5 Project costs were supplied by John Aiken with the School District of Indian River County, memorandum to John Sherwin, October 17, 1996.

6 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).

In our continued monitoring, FSEC plans to document the lighting energy savings achieved from the final retrofit and to examine any interactions with the chiller cooling loads.

Acknowledgments

Special thanks are due to our project sponsors, the Florida Energy Office, for supporting this important research. The Florida pilot project represents the first attempt of its kind in our state and has provided a wealth of information which is valuable, not only for improving the energy efficiency of our public buildings, but also provides important experience and information to the Florida school system. We would also like to express appreciation to Dan Turner and Jeff Haberl at the Energy Systems Laboratory at Texas A&M University, who freely shared their wisdom from LoanSTAR. We would also like to thank John Aiken, the energy coordinator for the Indian River County School District, as well the school principal, Howard LaPointe and his cooperative staff at Fellsmere Elementary. The Vero Beach office of the Florida Power and Light Company assisted with overall facility service metering. At FSEC, Stephen Barkaszi, Jr. assisted with instrumentation installation and setup. David Floyd assisted with commissioning of the lighting controls, Steven Spencer provided photographic documentation, Kashif Hannani assisted with data reduction and analysis and Wanda Dutton ably prepared project reports. Thanks to all involved.

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Appendix A

Annual Schedules: Fellsmere Facility

Important Dates in Fellsmere Project

95102	Good data start up
95157	School out (Summer 95)
95165-95167	Flow meter in
95203	Old chillers out
95226	New chillers up
95223	School back
95327-95330	Thanksgiving Holidays
95349	Last day before Christmas Break
95352-95356	Faculty and staff only
95357-95365	Christmas Break
96053	Occupancy sensor adjustment
96085-96089	Spring Break

Typical School Day
Daily Schedule

6:00 AM	1st custodian arrives
6:45 - 7:00 AM	Remaining custodians/kitchen staff arrives
7:45 AM	Breakfast served
8:00 AM	Faculty arrives
8:25 AM	Classes begin
10:40 AM - 1:00 PM	Lunch served
3:00 PM	Classes end
3:15 PM	Faculty dismissed
3:30 PM	Custodians dismissed
4:30 - 5:30 PM	Remaining staff/custodians leave

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