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Energy Efficiency for Florida Educational Facilities: The 1996 Energy Survey of Florida Schools

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Energy Efficiency for Florida Educational Facilities: The 1996 Energy Survey of Florida Schools

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Executive Summary

A detailed survey of energy use and related physical and operational characteristics of Florida's public schools has been completed. A mailed survey instrument was sent to all 2,512 schools throughout the state in March 1996. A total of 1,298 surveys were returned -- a response rate of approximately 52%. Of these some 680 provided matching utility data. The survey data was analyzed to create a school energy use profile as well as to identify characteristics that may influence efficiency. Based on our findings, the total annual energy cost for the Florida school system totaled $205 million in 1995. As shown in Figure E-1, elementary schools make up almost half of this energy cost since they represent the largest total floor area within the Florida school system. Annual total energy costs averaged $1.24/ft^2.

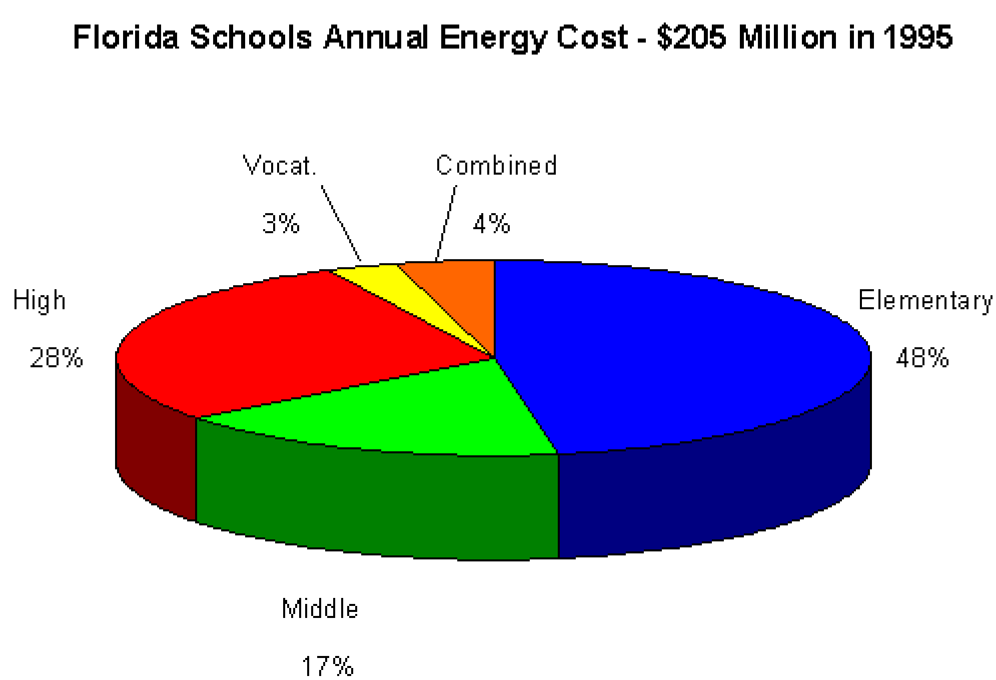

Figure E-1. Annual energy costs by school type.

We ranked schools with complete data (654 facilities) by their energy use per square foot, or Energy Use Index (EUI, $kBtu/ft^2$). The EUI's varied from 2 - 226 $kBtu/ft^2$. The 10% of schools who used the most energy per square foot were identified as potential candidates for future improvement projects.

Finally, an analysis was performed of the statistical influences on energy use in schools based on the responses to the survey questionnaire against the matched utility data. The analysis showed some surprising influences:

- Floor area and number of students and faculty were significant factors increasing annual energy use. High schools, Middle schools and vocational schools used more than elementary schools. Portable classrooms increased annual energy use by approximately 10,800 kWh each.
- Schools conditioned on non-school days and those with central thermostats used more energy. Schools with manual lighting and clock thermostat controls used less. Cooling set points were shown to have a strong influence.
- Classrooms with windows used 18% less energy than those without them. This may be due to reduced need for interior lighting, available ventilation or both.
- Schools with light colored roofs used 7% less annual energy.
- Schools relying predominantly on packaged cooling equipment rather than central chillers used 24% less energy. However, the reason for this finding stems from the fact that chillers in older schools showed evidence of very poor performance; newer chiller installations did not show this tendency. Elevated consumption associated with chillers may also reflect the need to consider zoning by evaluating space loads and schedules. Chiller sub-systems such as pumps, air handlers and cooling towers consume significant amounts of energy and efficient options should be selected.
- Heat pump systems except water loop types were shown to be beneficial.
- Schools with a history of humidity problems tended to use more energy. Complaints of indoor air quality (IAQ) and humidity problems were strongly related.
- Schools using windows for ventilation reported significantly lower IAQ concerns although schools with higher cfm ventilation per student showed lower incidence of IAQ problems. We believe operable windows provide a sense of control to faculty and students on the IAQ issue. Greater cfm/student will tend to increase interior humidity levels which were shown to be strongly linked to IAQ concerns.
- Facilities with ceiling fans in classrooms showed substantially reduced energy needs and higher cooling set point temperatures.
- Schools with operable windows which could be opened for ventilation showed 13% lower energy use.
- Schools or demand controlled ventilation more energy on an annual basis.
- Low temperature air distribution systems showed no significant reduction to annual energy costs or monthly peak demand and were associated with increased complaints of indoor air quality and humidity problems. These systems were also associated with the largest increases to annual normalized energy use of all identified survey characteristics.

I. Introduction

Over the last four years, the Florida Solar Energy Center (FSEC) has been under contract to assist the Florida Department of Education (FDOE) with identifying energy saving strategies. In 1993-1995 FSEC produced a detailed simulation study and three workshops outlining how efficiency could be improved for new construction (McIlvaine et al., 1995).

During the course of the workshop sessions, many participants requested similar information for improving energy performance of existing schools. However, a similar simulation study would lead to concepts that were meaningless for most schools because of Florida's diverse school building stock. A more feasible exercise would be to prioritize energy improvements based on individual or district wide school characteristics. Toward that end, an extensive survey was launched in early 1996 to assess energy use in over 2,500 Florida public schools. The survey, results, and implications are summarized here. The project was funded by the Florida Department of Education (DOE), Office of Technology.

II. Objectives of the Study

In response to FDOE's desire to improve Florida schools' energy performance, our objectives were threefold:

- To develop detailed information on the characteristics of Florida schools which might have energy implications.
- To develop ranking of schools based on relative energy use.
- To analyze the statistical association of school characteristics and energy use.

The principal yardstick used in this analysis is that of energy used per square foot of air conditioned floor area, or Energy Use Index:

EUI = Annual Energy Use (kBtu) / Facility Floor Area (ft^2)

This measure allows comparison of schools to determine those with the largest opportunities for savings.

III. Data Collection

Data collection took place over a nine month period beginning March 1996.

Survey Instrument

FSEC staff designed an extensive, six-part hundred item questionnaire targeting key energy profile information for Florida educational facilities. The DOE reviewed the draft document and FSEC subsequently mailed roughly 2500[(1)] to Florida's public schools (primary, secondary, and specialty) in early March 1996. The survey also called for schools to forward 1995 utility records with the response. A cover letter from the Bureau Chief of Educational Facilities, accompanied each survey. In early September 1996, each non-respondent received a mailed reminder notice. A sample completed survey is presented in Appendix A. A breakdown of the schools within the state are as follows:

Table 1

Breakdown of Florida Schools

Type	Number	Percentage
Elementary	1,510	60.1%
Middle/Jr. High	436	14.4%
High School	294	11.7%
Combination	126	5.0%
Exceptional	79	3.1%
Vocational Ed	35	1.4%
Adult	32	1.3%
Total	2,512	100.0%

Source: Charles Wooten, Florida Department of Education, June 19, 1997

Response Rate

Over 900 schools submitted a response to the questionnaire by late August, 1996. The reminder letter netted about 400 additional submissions before the December 31, 1996 deadline. Many surveys lacked important details and were completed or clarified with telephone follow up.

A total of 1,298 schools comprise the final database, a response rate of approximately 52%. The geographic distribution of the survey responses by Florida county is shown in Figure 1. Of these schools a subset of about 670 submitted the requested utility data. For most mailed surveys a response rate of 10% is typical and 20% is the best that can usually be expected (Steeh, 1979). Thus, the staff of Florida's schools provided an exceptional return rate for such a lengthy and detailed survey.

Statistical Significance

With the population taken as 2,512 schools the total returns of 1,298 are sufficient to meet a 95% confidence level if those returning the surveys were random. However, the questionnaire was administered using a written survey, so the returns are not necessarily a random representation (Overton, 1977). It is difficult to determine whether the respondents are representative of Florida schools as a whole. However, the follow-up mail reminder was used as an effort to obtain data from initial non-respondents. Generally, the fundamental statistics (energy use and costs and floor area) showed no systematic bias ($p < 0.1$) between the initial group and those responding to the reminder. This gives good confidence that the survey respondents are representative of the overall population.

Coding of Surveys

One staff member manually coded in each survey response using a personal computer and standard statistical software, SPSS for Windows Version 7.0. Written responses to multiple choice questions, and other ambiguous entries were classified as accurately as possible. A second staff member checked data for reasonableness with respect to maximum and minimum values for each question. Out-of-range data were corrected manually (i.e., age of space conditioning system listed on form as 1981 was corrected to 15 years) or set to missing. Very few errors were detected, therefore, the data likely vary little from the original submissions. This is not to say, however, that the submitted responses are accurate. In certain cases we were clearly able to determine that incorrect information had been submitted (e.g., conditioned floor area > gross floor area). To the extent possible, these were corrected, or otherwise set to missing. Unfortunately, some questions-- often dealing with technical aspects or equipment -- were difficult for the respondents to gauge accurately, so that responses were of limited utility.

Response by District

Each school district was asked to participate in the study. However, response within districts was not uniform with respect to the survey or, particularly, the utility data. Under-represented districts may have lacked resources or interest in the project. Well-represented districts, such as Okeechobee and Volusia Counties, may reflect existing interest in reducing energy use. In most districts, surveys were completed at the school level and matching utility data was provided by the district. The response for Orange County schools was most complete of those submitted. Three smaller districts -- Gilchrist, Madison and Liberty counties -- provided no responses.

IV. Tabulation of Results

A school's energy use is determined by the construction of the building(s), the mechanical and electrical equipment and its efficiency, and occupant activities ranging from interior temperature settings to daily schedules. In the sections which follow, we briefly summarize some of the highlights from the results in Sections B, C, and D of the survey.

Section B. School Type and Characteristics

Survey questions in Section B. School Type and Characteristics, collect details about the school type, size, number of occupants, grade level of students, and special facilities (i.e., gymnasium, media center) that relate to energy use. Some of the highlights from the responses:

Responding facilities

- Elementary schools: 58%[(2)]
- Middle/Jr. High schools: 18%
- High Schools: 14%
- Vocational: 3%

Floor Area

- Average (Avg.) Gross = 98,900 sq.ft.
- Avg. Conditioned = 87,151 sq.ft.

Portable Classrooms

- Number: Avg. school has 9.9
- Avg. Total Portable floor area = 8,362 sq.ft.

Special Facilities

- 33% have gymnasium
- 29% have auditorium
- 96% have media centers
- 47% have computer labs
- 36% have athletic facilities with showers
- 4% have a pool

Food Preparation: 97% have a cafeteria facility

- Avg of 739 meals prepared daily
- 82% are main cooking facility; 14% are satellite serving facility
- Avg of 5.5 refrigerators or freezers per school

Student/Faculty and Staff

- Students: Avg = 981
- Faculty: Avg = 57
- Administrative: 26

Discussion: The data provide an interesting portrait of a typical Florida school. The survey respondents are weighted towards elementary schools since these comprise the largest overall group within the Florida school system, (see Table 1). Appendix B provides the survey frequency information broken out by school types. Figure 2 shows how middle schools and high schools are both larger and use more energy. Interestingly, high schools and vocational schools use disproportionately more energy than their conditioned floor area would indicate.

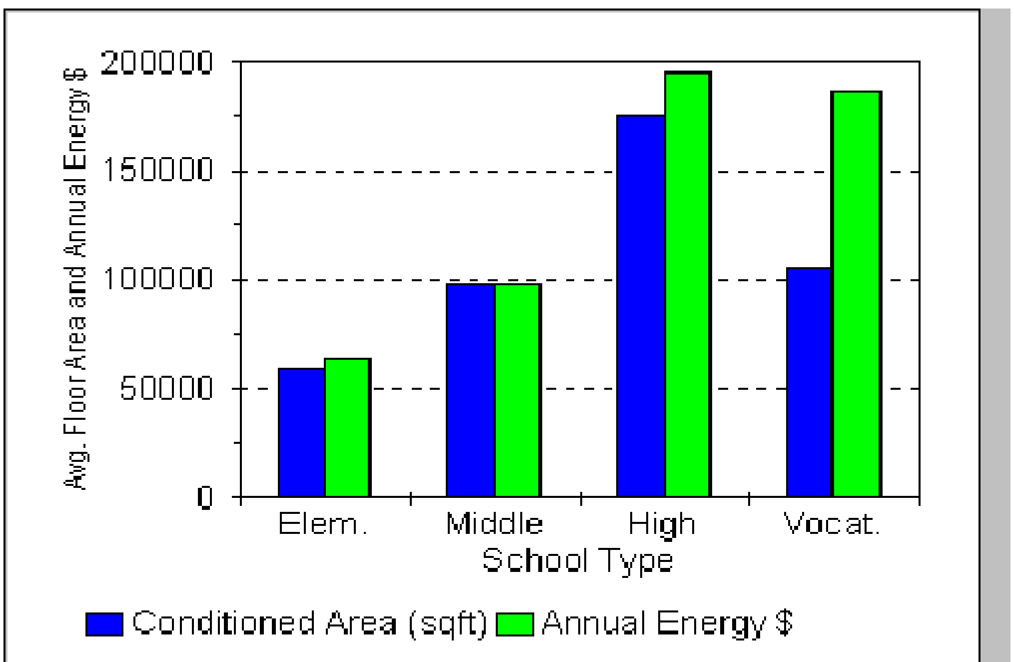

Figure 2. Variation of conditioned floor area and annual energy cost by school type.

Section C. Operation and Schedule

Section C. Operation and Schedule characterizes how the facility is operated including daily and annual schedule, HVAC operational characteristics, including zoning, classroom temperatures, natural and mechanical ventilation, and problem areas.

School Year

- Avg of 186 days per year with students
- Avg of 19 teacher work days
- Only 9 % were year round schools

- Majority (65%) were not closed during summers
- 58% had summer school programs
- 87% had year round administrative operation
- 25% had night school or adult education

Typical Schedule

- Maintenance staff arrives at 6:35 AM
- Faculty arrives at 7:30 AM
- Students arrive at 8:00 AM
- Students depart at 2:45 PM
- Faculty departs at 3:15 PM
- Maintenance staff departs at 8:55 PM
- Night school staff departs at 9:05 PM

Air Conditioning Operation during Non-School Periods

- 45% during non-school hours
- 41% during non-school days
- 41% over summer break and holidays

Areas Air-Conditioned during Non-School Days

- 34% classrooms and main building are conditioned
- 51% library or media center
- 9% gymnasiums
- 53% administrative offices
- 26% cafeterias

Cooling Thermostat Temperatures

- Classroom facilities: 74.8F
- Classrooms non-occupied: 77.8F

Heating Thermostat Temperatures

- Classroom facilities: 71.7F
- Classrooms non-occupied: 69.5F

Interior Temperature Regulation(3)

- Manual thermostats: 67%
- Central thermostats: 40%
- Locked thermostats: 37%
- Clock thermostats: 18%
- Energy management system: 50%

Ventilation

- Windows used sometimes for natural ventilation: 52%
- Average design ventilation rate per student: 7.9 cfm

HVAC System/Problems

- System Age: 10.8 years
- Problems with excessive humidity: 53%
- Complaints of poor indoor air quality: 59%
- Complaints regarding interior temperatures: 69%
- Changed thermostat settings in last year: 63%

Energy Awareness Programs

- 60% have programs at school level
- 67% have programs at district level

Discussion: The information on operation and schedule shows that Florida's schools are operating for much of the year. Sixty-four percent were not closed during summers even though only nine percent of facilities surveyed were "year around schools." Even during non-school days, most schools air condition a good portion of the facilities. Although this is understandable for media centers and libraries, it seems likely that reducing the cooling of classrooms during such periods (34% conditioned) may offer opportunities to energy savings. This was clearly illustrated in a recent project at a Florida school (Sherwin and Parker, 1996). Based on the survey, proper cooling set points appear contentious. Although 75^{o}F was the most common thermostat setting, over two thirds of respondents (69%) experienced complaints associated with thermostat settings and 63% of total respondents had changed thermostat settings in response within the last year. Manual thermostats were the most common control method.

The average design ventilation rate was 7.9 cfm per student although a fairly bi-modal distribution; many schools had 5 cfm/student while others had 15 cfm in correspondence to the new ASHRAE Standard 62-1989. We were surprised to find, however, that 52% of respondents reported using operable windows for ventilation rather than air conditioning at some time during the year. This goes against the prevailing wisdom within Florida design circles that natural ventilation cannot produce adequate comfort. Interestingly, a very detailed study in Hawaii schools has recently concluded that good thermal comfort can often be achieved within a tropical setting without air conditioning (Kwok, 1997) As will be shown later, we also found schools who claimed to natural ventilate rather than air condition at some point in the school year to be a statistically significant indicator of lower facility energy use.

Over half of the surveyed schools reported problems with indoor humidity and 59% indicated complaints regarding indoor air quality (IAQ). There was strong correlation between IAQ concerns, and complaints of humidity and the design ventilation rate and the use of natural ventilation within the school. Schools reporting the use of windows for ventilation reported a much lower incidence of complaints associated with IAQ. Demand controlled ventilation (CO_2 sensors) were not associated with improved perception of IAQ. Interestingly, older schools appeared to have the fewest problems in this regard. About 60% of schools reported having an energy awareness program in place.

Section D. Energy Systems

Requested in Section D., Energy Systems, were the building construction characteristics including mechanical systems, building envelope, lighting, and controls. All the inquiries were posed as a simple yes/no check-off for each characteristic. Different portions of the facility may have differing construction so that the characteristics for a single component count will often be greater than 100%.

Building/Roof

- 34% have uninsulated roofs or ceilings
- 50% have gravel over a built up-roof
- 23% have a single ply membrane roof
- 20% have a modified bitumen roof
- 20% have asphalt shingles
- 35% have a light colored roof

Walls/Windows

- 66% of walls are uninsulated
- 22% of classrooms have no windows
- 27% of glass has tint or other solar control
- 16% have skylights

HVAC System Characteristics

- Central Chiller: 57% of schools; 31% have cooling tower
- Packaged or split system AC units: 45%
- Roof-top HVAC units: 38% - Window or wall AC units: 52%
- Heating: Elec. resistance (42%); heat pump (22%); furnace (9%), boiler (42%)
- Variable frequency drives: 7%
- Gas absorption cooling: 1%

HVAC Air Distribution/Ventilation

- Constant volume air distribution: 24%
- Variable air volume system: 19%
- Fan coil system: 32%
- Ceiling return plenum: 32%
- Heat pipe dehumidification: 4%
- Enthalpy wheel dehumidification: 1%
- CO_2 demand controlled ventilation: 5%
- Low temperature air system: 3%

Lighting Systems

- Standard flourescent fixtures (T12, 40W lamps, w/magnetic ballasts): 82%
- Electronic ballasts: 44%
- Automatic scheduling: 47%
- Incandescent exit lighting: 52%
- Occupancy sensor controls: 21%
- Outdoor security lighting: 85%
- Parking lot lighting: 74%
- Athletic field lighting: 19%

Controls and Other

- Fully manual control of energy systems: 38%
- Clock controls: 43%; 37% operating
- Energy Management System: 42%; 38% operating
- Ceiling fans in classrooms: 13%

Discussion: Although we expected walls to be uninsulated in existing Florida school (66%); we were surprised to find that 34% had an uninsulated roof or ceiling. Some 22% of classrooms had no windows, which could both increase interior lighting needs, as well as make it impossible to ventilate if the cooling system was not operating. Just over half of the schools had a central chiller for the cooling system; packaged direct expansion cooling equipment was the common alternative. Heating was most often electric with 42% using electric resistance and 22% with heat pumps. Gas furnaces and boilers comprised 51%. Constant volume air distribution was typical with a few systems using advanced technologies (heat pipe dehumidification, demand ventilation control etc.) to improve performance. Most schools had standard flourescent fixtures, although about 44% had some fixtures with electronic ballasts. Some 21% had occupancy sensor controls of lighting and over two thirds had parking lot and/or security lighting. About 38% of schools had fully manual energy controls; 43% had clock or energy management system controls although fewer indicated these were functioning properly. Thirteen percent of classrooms had ceiling fans.

Section E. Energy Data

Requested in Section E. Energy Data were the primary heating fuels and also the matching utility data from the facility for the last 12 months. Information was not requested on cooling fuels since virtually all of the facilities use electricity for cooling in one fashion or another. Specific questions asked if natural gas cooling systems were in use.

Approximately 677 facilities provided matching electric utility data. Even fewer schools provided natural gas consumption information (approximately 90 facilities) although many do not use this fuel.

Primary Heating Fuel

- Electricity: 53%
- Natural gas: 13%
- Oil: 7%
- Propane: 5%
- Combination: 13%

Primary Water Heating Fuel

- Electricity: 39%
- Natural gas: 24%
- Oil: 5%
- Propane: 12%

- Combination/other: 13%
- No hot water: 1%

Cooling Fuel

- Electric: 99%
- Natural gas: 1%

Total Annual Energy Costs

- Avg was $93,823 per year
- Range varied from $1,282 to $428,288!

Graphical Summary: Figure 3 shows a histogram and detailed statistics of the recorded electricity use in the 677 schools with valid utility data. The data are log-normal, reflecting many facilities with low to moderate energy use, but with a long tail of facilities with considerably greater consumption. Figure 4 provides a similar presentation for natural gas consumption (therms = 100 cubic feet of gas = 10^5 Btu).

Figures 5a and 5b show a bar chart presenting the monthly average electricity use and demand in the surveyed schools. The influence of time of year, including summer break, is obvious in the data. September typically has the largest monthly electricity consumption, followed by May. Electricity use is lowest in January, suggesting that outdoor air temperature has a strong influence on facility space conditioning energy consumption.

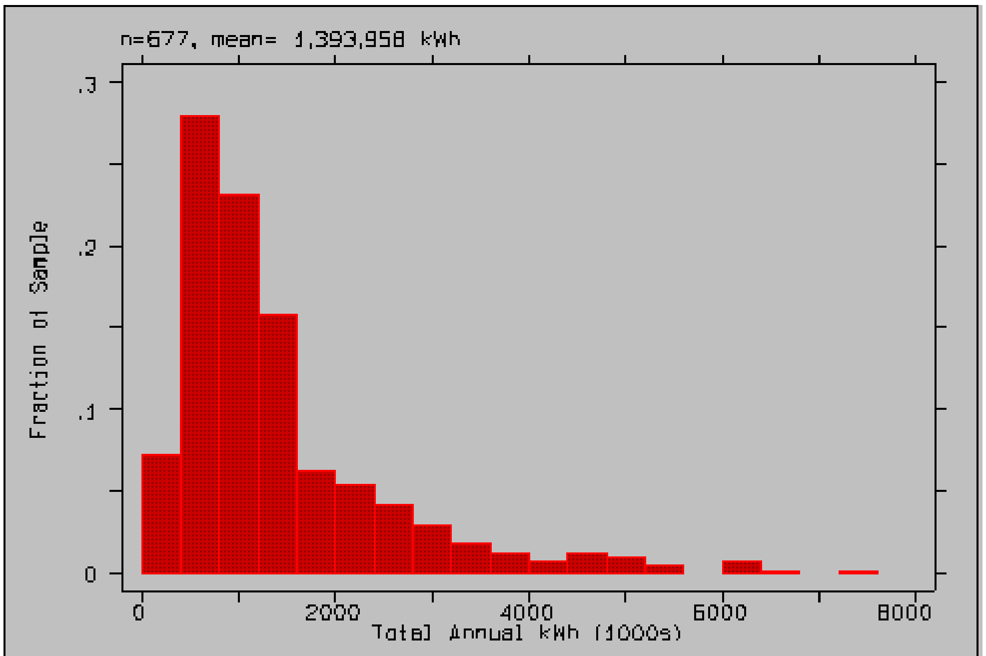

Figure 3. Histogram of total annual kWh of all schools.

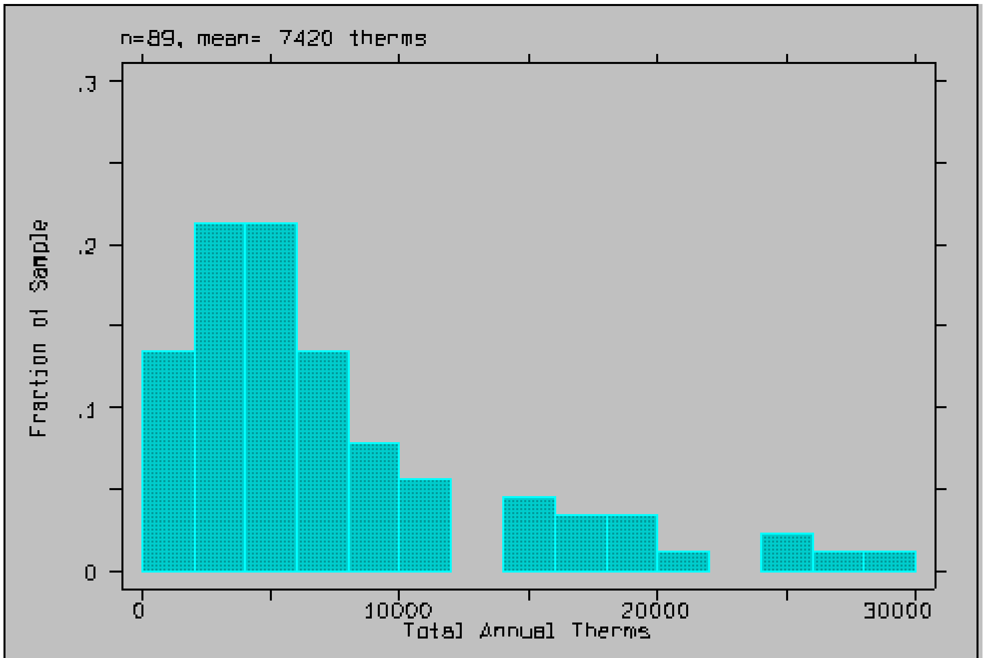

Figure 4. Histogram of total annual therms of natural gas.

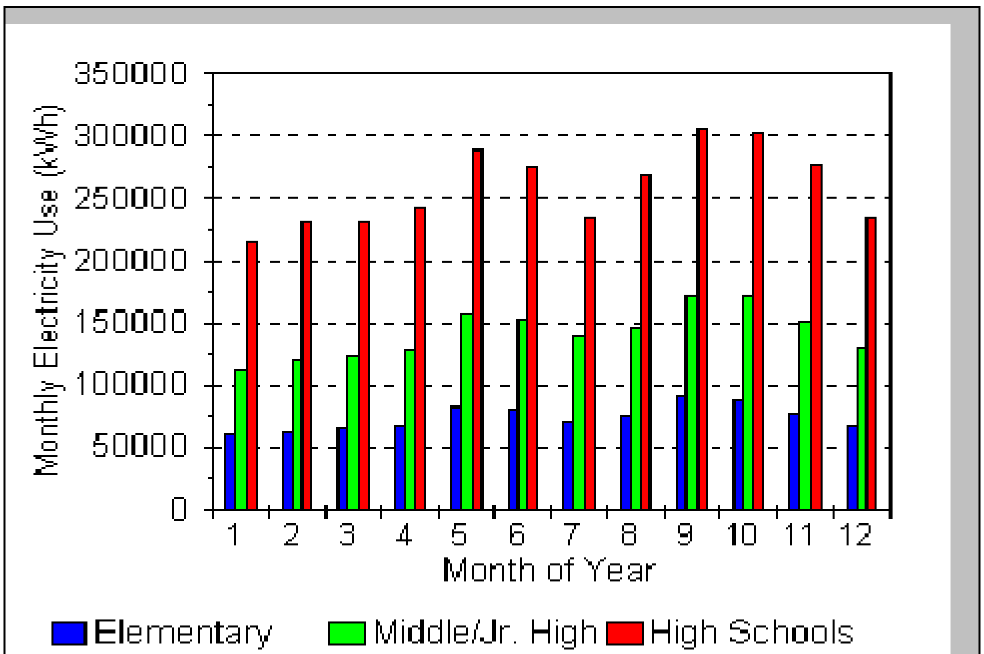

Figure 5a. Average monthly electricity use by school type.

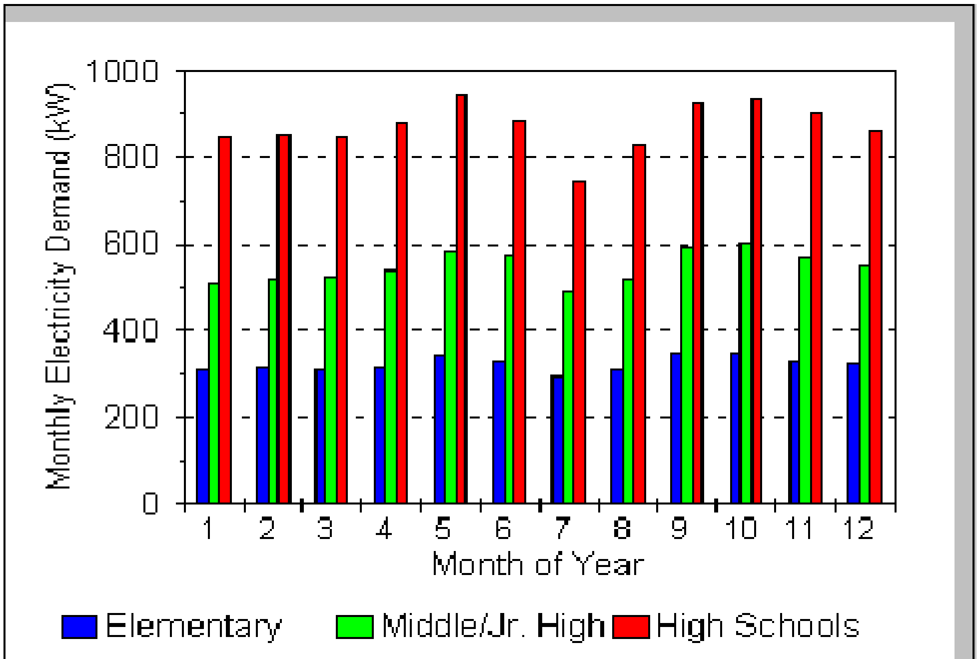

Figure 5b. Average monthly kW electrical demand by school type.

Figure 6 shows a histogram for annual energy related costs for all fuels in the surveyed schools. The average school's energy costs were $94,000 in 1994-1995. This amounts to approximately $1.24 per square foot per year in average annual energy related operating expenses for Florida's education facilities. Based on submitted records, the typical school pays approximately $0.047/kWh with monthly demand charges of $5.90/kW.[(4)]

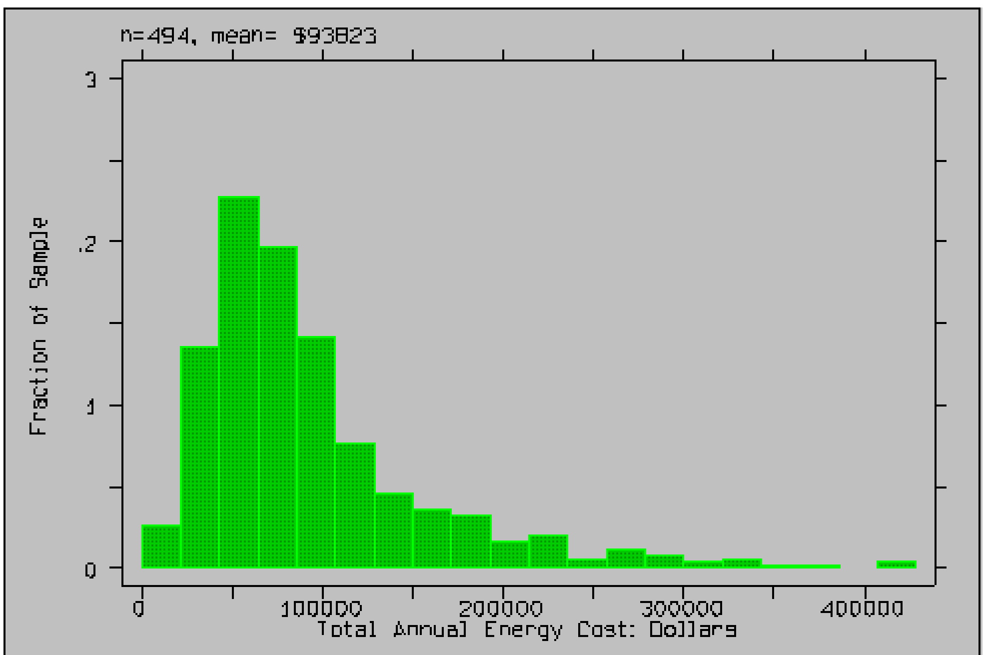

Figure 6. Histogram of energy costs in all schools.

V. Analysis

Ranking of Facility Energy Use

As expected, we found that facility energy use generally tracks floor area. Figure 7 presents a scatter plot of the relationship between school floor area and electricity consumption by school type. There is a strong association between floor area and annual energy use. The correlation coefficient (R) between the two is 80% with a t-statistic of 31.0. Regression analysis showed that floor area of buildings explained 64% of the variation in annual school energy use (12.0 kWh/ft^2). High schools and middle schools tend to be larger and use considerably more energy than elementary schools. However, as evident in the scatter in graph, there is still a considerable amount of school-to-school variation in energy use that is not accounted for by differences in floor area.

A central objective of the energy survey was to obtain the necessary information to classify schools by their normalized energy use (kBtu/ft^2) or EUI. The EUI provides a ready method of identifying those facilities using the greatest amount of energy per square foot. The lower the number the better (analogous to cost per square foot).

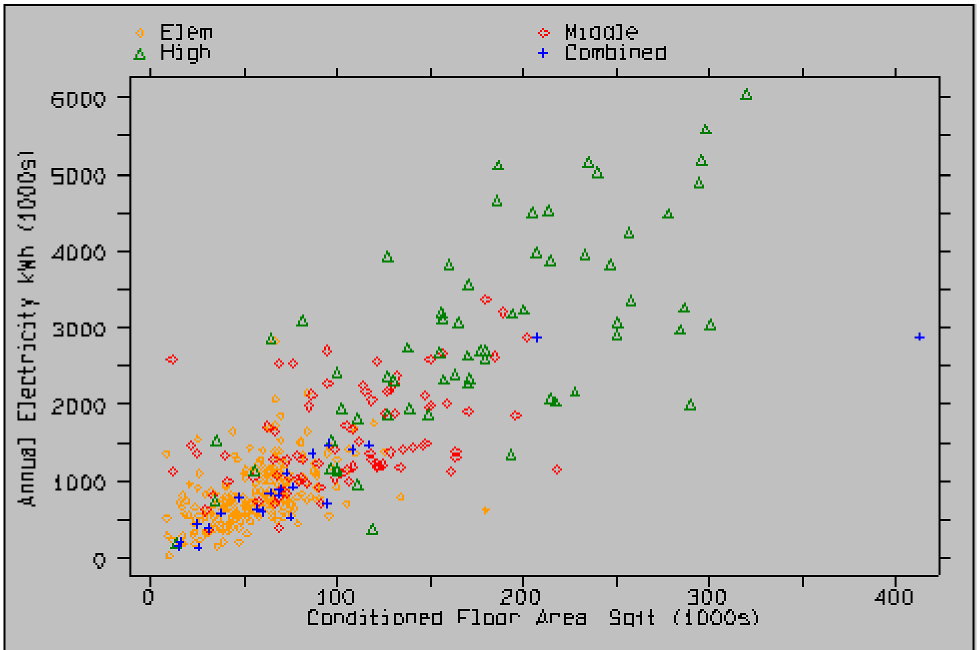

Figure 7. Relationship of annual electricity use to floor area by school type.

We computed EUI for the 654 schools which had valid floor area and energy consumption data (utility data for all fuels). Figure 8 shows the summary statistics for EUI and a histogram of the distribution of EUI values for the facilities with data. Most schools have EUIs of 25 - 100 Btu/ft^2 although there is a significant number with greater energy use. Those with very low EUIs are often associated with closed facilities.

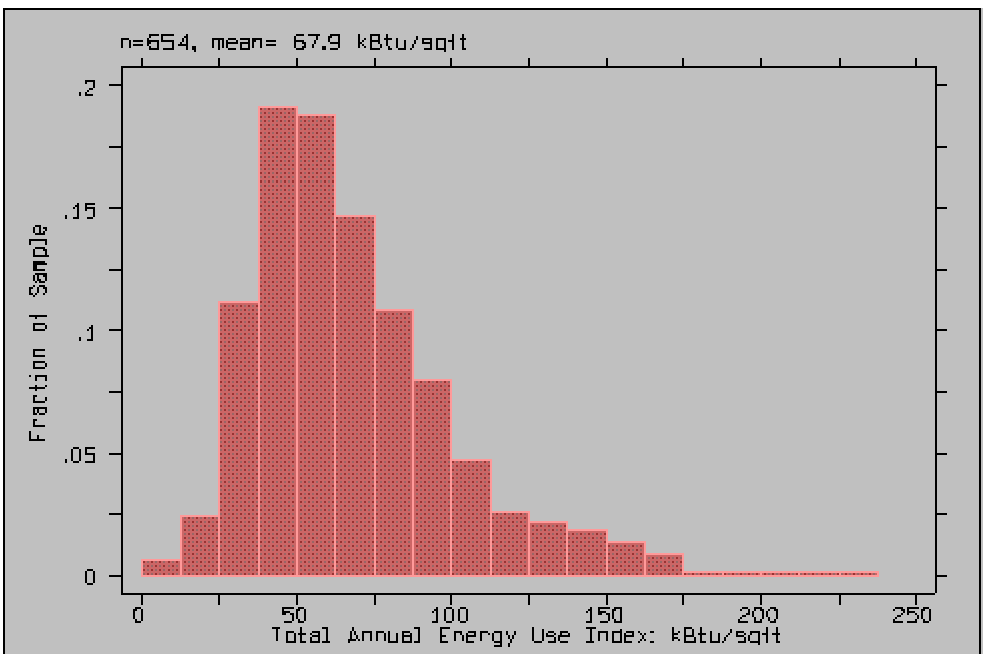

Figure 8. Histogram of energy use index (EUI) for all schools.

Table 2 shows the top 10% of the ranked facilities (65 schools) with the highest EUIs. This listing is potentially useful, since these facilities likely represent good opportunities for further energy audits, renovation and retrofit. Generally, in commercial building retrofit projects, those facilities can save most whose energy costs are currently elevated (Piette et al., 1994). The ranking for all 654 schools is reproduced in Appendix C.

One potential use for this information is to segment the population of surveyed schools into groups with higher and lesser energy use for the purposes of retrofit projects. A relevant example of the benefits of such retrofits was recently shown in a Florida elementary school which found a 15% overall energy savings from a series of installed retrofit measures (Sherwin and Parker, 1996).

Statistical Analysis

School characteristics, schedules and equipment efficiency all play an active role in how much energy is used in educational facilities. However, sorting out the individual impacts on energy use is difficult due to complex interactions. Consequently, we used a two step approach to determine which factors were most strongly associated with recorded energy use. The objective of this exercise to create a list of significant factors and to examine these with respect to how they might provide information that could be used to reduce energy use in Florida educational facilities.

In the first step, each potential variable in the data base was compared to the electricity, or total energy use (EUI) using a standard unpaired t-test of means assuming unequal variances. This was used to screen potential variables so that the largest possible data set could be used for the final analysis.[(5)]

After potentially important variables were identified using the t-test, stepwise multiple regression was used in which the dependent variable was recorded energy use and the potential independent explanatory variables comprised all of the responses to the survey questions.[(6)] Yes/no answers were transformed in to "dummy variables" (0=no; 1= yes) to facilitate this process.

In the stepwise scheme, all of the potential survey variables are regressed against the total energy use (annual kWh) with the variable with the lowest F-ratio being dropped from the equation. The scheme then moves on to consider the next group of variables. This process continues until no more variables remain which cannot satisfy the critical F-ratio (2.0).

In our analysis, a series of 24 interactive "models" were created, before the regression halted with the final set of 23 independent variables which were found to be statistically associated with total recorded energy use in the 460 schools composing the data set. We summarize the highlights from the statistical analysis in Tables 3 and 4.

Table 2
Top Ten Percent of Florida School's with Highest Energy Use

DISTRICT	SCHOOL	CITY	TOTAL EUI
Dade	Fairchild Elementary	Miami	226.82
Pinellas	Oldsmar Community Elementary	Oldsmar	214.72
Escambia	C A Weis Elementary	Pensacola	209.83
Dade	North Miami Senior	North Miami	191.6
Pinellas	Dixie Hollins Senior	Saint Petersburg	180.24
Broward	South Plantation	Plantation	174.51
Palm Beach	West Technical Ed. Center	Belle Glade	166.17
Brevard	Gemini Elementary	Melbourne	166.12
Brevard	Enterprise Elementary	Cocoa	166.07
Pinellas	Oldsmar Elementary	Oldsmar	165.94
Orange	Windy Ridge Elementary	Orlando	165.31
Dade	Ponce De Leon Middle	Coral Gables	160.35
Broward	Palmview Elementary	Pompano Beach	159.74
Dade	Greenglade Elementary	Miami	157.09
Dade	W. R. Thomas Middle	Miami	155.65

Dade	Florida City Elementary	Florida City	153.15
Martin	South Fork	Stuart	151.47
Volusia	Read-Pattillo	New Smyrna Beach	151.22
Broward	Piper Senior High	Sunrise	150.66
Lee	Buckingham Exceptional St. Center	Fort Myers	150.58
Dade	Miami Killian Senior	Miami	149.84
Clay	Clay Junior Senior High	Green Cove	148.82
Lee	Lehigh Senior	Lehigh Acres	148.6
Dade	Robert Morgan Voc. Tech. Institute	Miami	147.31
Charlotte	Vineland Elementary	Rotunda	145.09
Broward	Tropical Elementary	Plantation	144.22
Dade	Hammocks Middle	Miami	143.34
Lee	Suncoast Middle	N Fort Myers	142.68
Broward	Dillard Elementary	Fort Lauderdale	141.95
Dade	Marine & Science Tech. Academy	Miami	140.38
Palm Beach	Boca Raton Senior	Boca Raton	139.24
Orange	Arbor Ridge Elementary	Orlando	138.22
Broward	Sheridan Vocational Center	Hollywood	137.12
Orange	Winter Park Senior	Winter Park	136.67
Escambia	Brentwood Middle	Pensacola	134.11
Orange	Baymeadows Elementary	Orlando	133.15
Palm Beach	Jupiter Elementary	Jupiter	132.1
Broward	Stranahan Senior High	Fort Lauderdale	132.09
Dade	Hialeah Gardens Elementary	Hialeah Gardens	130.59
Dade	Lindsey Hopkins Tech. Ed. Center	Miami	130.06
Lafayette	Lafayette Elementary	Mayo	128.63
Broward	Driftwood Middle	Hollywood	128.2
Okaloosa	Clifford Meigs Middle	Shalimar	127.56
Lee	Cypress Lake Middle	Fort Myers	126.48
Palm Beach	Adult Education center	West Palm Beach	125.28
Palm Beach	Palm Beach Public	Palm Beach	125.12
Palm Beach	Boca Raton Community Middle	Boca Raton	124.88

Pinellas	Lealman Avenue elementary	Saint Petersburg	123.57
Dade	Golden Glades Elementary	Opa Locka	123.33
Palm Beach	W Riviera Elementary	Riviera Beach	120.48
Dade	Kinloch Park Middle	Miami	120.07
Dade	Brownsville Middle	Miami	119.21
Dade	Allapattah Middle	Miami	118.49
Broward	Atlantic West Elementary	Margate	117.54
Dade	Thomas Jefferson Middle	Miami	116.78
Dade	Jose Marti Middle	Hialeah	116.67
Palm Beach	Olympic Heights Senior	Boca Raton	115.98
Broward	Plantation Senior High	Plantation	115.56
Dade	Redland Middle	Homestead	115.31
Okaloosa	Laurel Hill	Laurel Hill	113.42
Brevard	Endeavor Elementary	Cocoa	113.30
Charlotte	L A Ainger Middle	Rotunda	113.12
Palm Beach	Suncoast Senior	Riviera Beach	112.05
Dade	Miami Coral Park Sr	Miami	111.85

The following factors showed a tendency to increase annual school energy consumption:

Table 3
Factors Identified as Increasing Annual Energy Consumption

School Type

- Middle Schools and High Schools
- Vocational Schools

Building

- Building floor area
- Presence of an auditorium
- Additional portable classrooms

Operation

- Average number of students, faculty and staff
- Administrative offices open year round and after hours
- Higher winter heating set points
- School conditioned on non-school days and after hours
- Night schools
- Number of meals served

Equipment and Energy Systems

- Central chillers/cooling towers

- Constant volume air distribution systems
- Water loop heat pumps
- Fan coil systems
- Outdoor and parking lighting
- Low temperature air distribution system

Swimming pools

- Having pools
- Heated swimming pools

Controls

- Clock based lighting controls
- Occupancy sensor lighting control
- Previous problems with excessive humidity
- Demand controlled ventilation
- Past problems with thermostat setting

The following factors were found to lower annual energy consumption.

Table 4
Factors Identified as Reducing **Annual Energy Consumption**

Building

- Classrooms with windows
- Classrooms with operable windows
- Ceiling fans in classrooms
- Light colored roof

Equipment and Energy Systems

- Heat pump heating
- Natural gas furnace

Operation

- Closed summers
- School energy awareness program

Controls

- Higher cooling set point temperatures
- Fully manual HVAC controls
- Clock thermostat

Although statistically significant coefficients are provided in Figure 9, indicating magnitude of the effect, we do not emphasize these results since we believe that the direction of the influence of the variables are much more robust than the numbers attached to them.

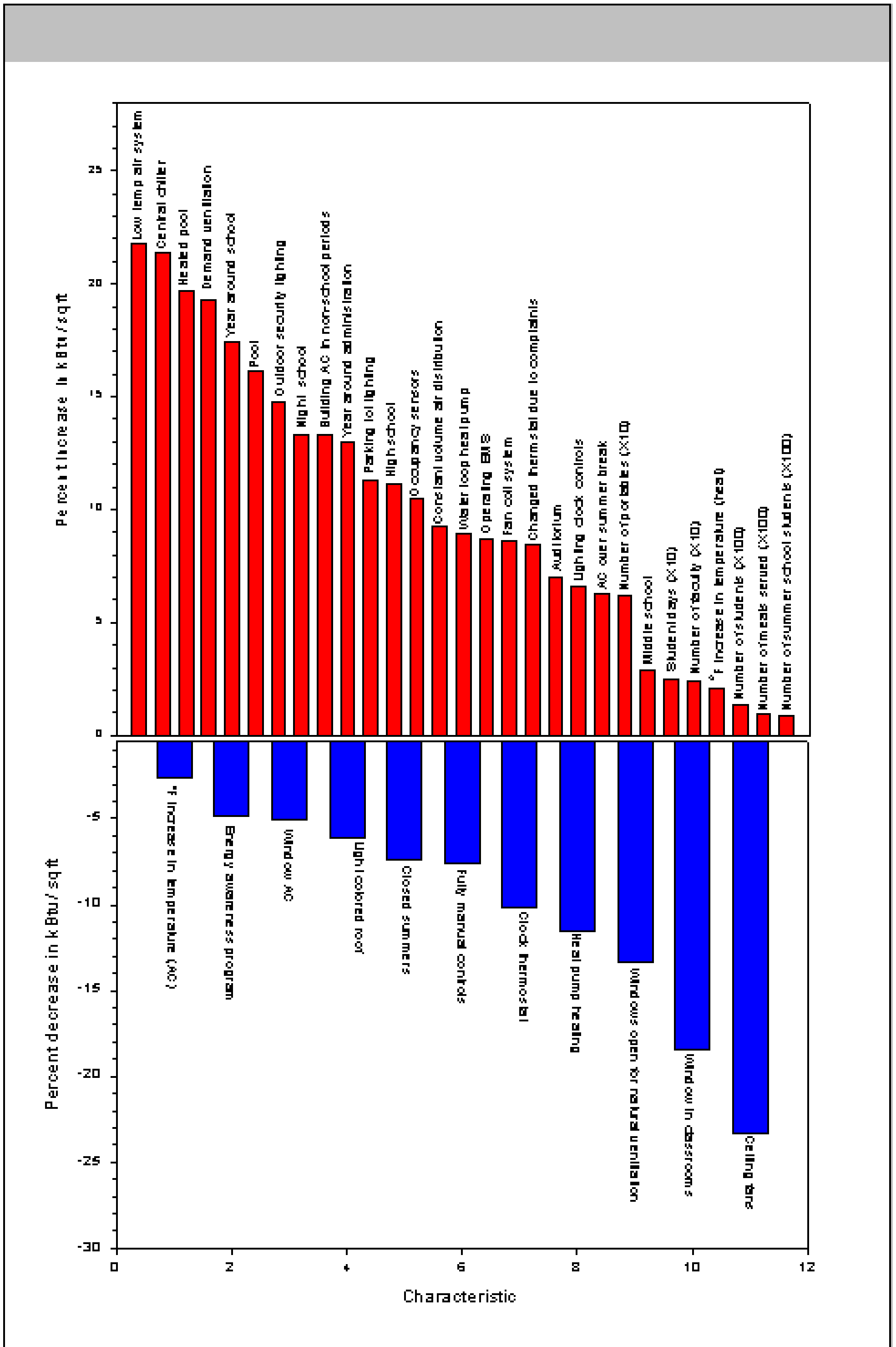

Figure 9. Statistically significant influences on annual energy consumption.

General

As indicated in the initial analysis, we found that high schools, middle schools and vocational schools used more energy on a per square foot (normalized) basis than did elementary schools. Auditoriums appeared to lead to added energy use, but analysis of covariance indicated that this was mainly due to the variable's function as an indicator for middle schools or high school. Due to their numbers, however, elementary schools represent a larger fraction of the overall conditioned floor area within the Florida educational system. They also had a greater variance in their relative energy use. While high schools uniformly used more energy than did elementary schools, the use in the elementary schools varied greatly for a given school size. This indicates that other factors are at work that account for the differences. There is a sizeable portion of the stock of elementary schools which have poor energy utilization efficiencies that can possibly be rectified.

Many of the identified statistically significant influences were expected. These include the influence of building floor area, number of portables and the numbers of students and teachers. Each square foot of conditioned floor area was found to increase annual electricity consumption by 11.3 (±0.8) kWh.

A statistical analysis found that on average each portable classroom increased facility energy use by about 10,840 (±5141) kWh per year. The average school had about ten portables with an area of about 856 (±18) square feet each. We did not find, however, that portable classrooms used appreciably more energy per square foot than did permanent facilities. On a annual basis, portable classrooms used about 12 kWh/square foot. A t-test of means revealed that the difference between energy use for permanent building floor area and that of portables was not statistically significant. Based on monitoring of twelve portable classrooms at Fellsmere Elementary in Indian River County Florida a full year, we know that portable classrooms average about 30 kWh per day (Sherwin et al., 1996). This equates to about 10,950 kWh/year-- very close to the statistical estimate. Thus energy use in portable classrooms in the state is very large: 250 million kWh and costing about $18 million dollars in their operation. FSEC currently has a research project underway to evaluate how efficiency in Florida portable classrooms might be improved (Callahan et al., 1997). Simulation analysis of portable energy savings potential, suggests that energy use in such portables may be reduced by up to 23% with a payback of less than three years (Brown et al., 1997).

As expected, we found with all other things equal, each additional hundred students added to a facility's enrollment could be expected to increase annual energy use by about 1.3%. This partly reflects physical realities. The human body produces heat at a rate of about 250 Btu/hr sensible and 200 Btu/hr latent. A facility faculty and student body of 500 would need 19 tons of air conditioning to remove body heat alone. Further, each student adds to the facility design ventilation rate, which considerably adds to the cooling system latent and sensible cooling requirements. Finally, a larger body of students and faculty tend to turn on more lights, eat more meals in the cafeteria and use more computers, etc.

Facility Age

In general, we found that newer Florida educational facilities are more efficient. Schools aged 5 years or less used 1.6 kBtu/ft^2 per year less than did older facilities, although the difference between groups was not statistically significant.[(7)] Since these facilities are typically better insulated with more modern equipment, this finding meets expectations. However, there are other factors at play, such as per student ventilation rate, and cooling equipment choices that may be responsible for the variation unexplained by facility age. Multi-variate analysis indicated that these factors (ventilation rates/humidity concerns) and cooling equipment choices (chiller vs. packaged equipment) were ultimately responsible for the observed differences rather than facility vintage itself.

Operation

Not surprisingly, our analysis verified several common assumptions relative to school operations. Year round schools used more energy -- particularly during June and July -- than did those closed during the summer. Similarly, schools reporting keeping administrative offices open year round or those operating night schools or adult education sessions were also associated with elevated consumption. Finally, those schools reporting that most of the facility was air conditioned during non-school days and after hours showed an increase of 13% in annual normalized energy relative to those that did not. This may indicate a savings opportunity in such facilities based on improved zoning for cooling or through the use of clock or automated thermostats to allow temperatures to be elevated during non-school periods.

Building Characteristics

One of the most common building improvements associated with energy efficiency, added insulation, did not show up as being a statistically significant factor for differences in school energy consumption. This finding was true both for ceilings/roof and wall insulation. The finding that wall insulation was not important was expected based on previous simulation analysis (McIlvaine et al., 1995). However that schools reporting no ceiling insulation did not show elevated energy use was unexpected. A t-test of means showed energy use in schools with insulated roofs consumed 0.17 kBtu/ft^2 less than in non-insulated schools, but with an uncertainty of ± 4.54 kBtu/ft^2 -- without statistical significance. Thirty five percent of schools reported the absence of ceiling or roof insulation.

In general, these schools tended to be older than those with insulation. One hypothesis for our finding was that older schools had other characteristics that reduced energy use, masking the fact that ceiling insulation was really a benefit. Accordingly, we segmented the data into two groups of schools with similar ages. However, our results still showed no differences to the conclusions above -- no statistical significance could be attached to energy savings from ceiling insulation within our sample. It should be pointed out, however, that the fact that ceiling insulation does not appear significant does not mean it is ineffective. Instead it may indicate that other factors are at work which obscure the benefits involved.[(8)]

One envelope related factor did appear to be influential: schools reporting a predominantly light colored roof showed lower energy use per square foot. This was expected, given a previous evaluation conducted in 1996 for the Department of Education which showed that white roofs can significantly reduce sensible cooling requirements in Florida schools (Parker et al., 1996). That study showed that a white roof reduced an elementary school's measured annual chiller energy use by 10%.

One of the big surprises was that schools which reported windows in classrooms showed an 18% lower normalized annual energy use. The observed difference, 12.28 $\pm$5.38 kBtu/ft^2, was highly significant. Mirroring these results, those schools possessing windowless classrooms showed increased annual energy consumption. Since building energy simulations indicate that added window areas in school facilities increase cooling loads, we hypothesize that the effect of windows in classrooms observed in our data was to reduce the need for electrical lighting through daylighting. Windows may also provide an opportunity for ventilation as an alternative to space cooling during the appropriate seasons. Analysis of covariance indicated that the physical presence of windows in classrooms was the primary driver for the observed differences. (see the section below on ventilation and indoor air quality). A project already performed for the Department of Education has shown that daylight dimming lighting systems have the potential to automatically reduce classroom lighting needs by 27% in spaces with appropriate daylight (Floyd and Parker, 1994).

Schools with swimming pools showed a 16% greater relative energy use than those without them; schools with heated pools showed a 20% increase. Both findings argue for careful consideration of pool pumping in the design of new facilities and for the consideration of solar heating in facilities which consider providing heated pools. A study of swimming pools showed that reduction in piping and filter friction losses with oversized piping could significantly reduce pumping energy (Messenger and Hayes, 1984).

Cooling

Simulation analysis of energy use in a Florida school has estimated that consumption associated with space cooling and ventilation is responsible for about 43% of total consumption (McIlvaine et al., 1995). Reinforcing the validity of this estimate was a detailed monitoring project of a Florida elementary school which showed that the space cooling end-use comprised 40% of measured annual energy use (Sherwin et al., 1996).

Chillers

A somewhat surprising finding was that schools with central chillers used considerably more energy than those relying on packaged systems. The reason may have to do with both efficiency and zoning.[(9)] It must be emphasized that the COP of a chiller cannot be directly compared with the EER of a packaged unit. A chiller's efficiency may reach a COP of 6 (EER=20). However, other components must be used with this equipment which ultimately bring down the efficiency substantially. This includes cooling towers or air-cooled condensers, as well as air handling and pumping equipment.[(10)] Large chillers can also suffer degraded performance when used under part load conditions.

Schools reporting a central chiller used 14.24 $\pm$4.26 kBtu/ft^2 (24.5%) more than those who relied on packaged equipment. This translates to an added annual increase in energy costs of \$0.11/ft^2 per year. However, in further examining the data, we were able to discover that the elevation of energy use by chillers in educational facilities was strongly tied to the facility age. For instance, the presence of a chiller had no statistically significant impact on normalized utility costs if the building was less than 15 years old. However, where chillers were used in older buildings, the impact of chillers to increase energy use was large and very pronounced.[(11)] We believe this reflects the fact that newer chiller installations are much more efficient than older systems. Also, older chillers may be in poor operating condition. This likely indicates a large opportunity to reduce school facility energy use by replacing aging chillers or proper recommissioning of systems.

This potential was recently demonstrated in a monitored elementary school which found replacement of an aging chiller with a new, more efficient model to reduce cooling energy use by 15% (Sherwin et al., 1996).However, further complicating this issue is cost. While it is known to facilities planners that the cost of central chiller systems remains one of the greatest sources of expense in new educational facility construction, the differences in differential maintenance costs against packaged systems are unknown or undocumented.

There are obviously other issues-- arguably more important than energy. Central chiller systems can potentially provide better humidity control -- a fact made important by the new ventilation requirements with ASHRAE Standard 62-89. The increased ventilation rates for Florida schools established by this standard will typically increase space conditioning energy by 15-20% (Davanagere et al., 1996). The best solution may be to use dehumidification technologies and demand controlled ventilation to hold costs down.

Other Heating, Ventilation and Air Conditioning (HVAC) Equipment

HVAC equipment other than chillers showed significant influences within the data on annual energy use. Cooling towers evidenced elevated energy use relative to schools without them, although the analysis of covariance revealed that the seeming influence of cooling towers was masking heightened consumption associated with central chillers.[(12)] Fan coil systems also showed a similar indication of higher use; fan coil systems are almost always associated with chiller systems. Constant air volume systems also showed higher use, although here the impact appeared genuine. This is not surprising, since constant volume air distribution systems may be less efficient at meeting cooling loads without reheat for humidity control than variable air volume systems.

Analysis also indicated that schools who relied primarily on window air conditioning systems used less annual energy than those with other systems. This seemingly contrary finding may indicate two potential benefits from window air conditioners: 1) Ability to easily zone each space so that cooling systems are only used where needed, and 2) the improved performance from a cooling system which does not result in commonly observed problems in commercial buildings with uncontrolled air flow (Cummings et al., 1996) and unintended heat gain to duct systems located in roof/ceiling plenums. Maintenance, however, may be more expensive.

Heat pump systems showed 18% lower annual energy use than those systems without them -- likely due to the increased effectiveness relative to electric resistance. A more detailed examination of the data revealed, however, that water loop heat pump systems were considerably less effective than other heat pump systems. One explanation is the additional energy required for the operation of the pumps, drives and cooling tower associated with such systems. As expected, schools using natural gas for heating showed lower usage in annual electrical. However, when examining total energy consumption, including the use of natural gas, systems with gas furnaces appeared comparable to heat pump systems. Natural gas boilers showed a tendency to use more fuel for heating than did furnace systems.

Another finding of interest was that low temperature distribution systems, often associated with thermal storage cooling systems, were associated with the largest elevation in normalized energy use of any characteristic identified in our analysis.[(13)] Often these systems are operated with a time of use (TOU) rate to take advantage of their ability to reduce facility monthly demand charges. Even so, we found no evidence that energy costs per square foot were lower for facilities with low temperature systems than those without them. An unpaired t-test of means revealed that annual energy costs per square foot were not significantly different for those systems with low temperature distribution systems than those without them. In addition, a similar test of the average monthly kW demand per square foot revealed no statistically significant reduction. Such systems are often advocated for their superior humidity control. Again, our analysis found no evidence to support such a contention. Within facilities which were newer than ten years, complaints of humidity problems were actually 13.9% higher for facilities with low temperature distribution systems than for those without them, although the differences were not statistically significant.

HVAC Controls

One of the most important opportunities with energy using equipment is examination of the ways in which the equipment is switched. The reported preference for an annual cooling temperature for educational facilities had a mean value of 74.8^{o}F, but varied from 65 - 82^{o}F. Individually, many schools reported recent disagreement among faculty and staff regarding preferred interior temperatures. This same group was also shown to have higher annual energy consumption than the group of schools without such problems. Of those reporting changes to the thermostat in response to complaints, analysis revealed that this group had a 0.3 F^{o} lower reported thermostat setting than those who did not report complaints. A statistical evaluation showed that for each degree (F) which the reported facility cooling thermostat was raised, the annual normalized electricity use fell by 2.6%. Since cooling energy use is about 40% of facility energy use, each degree decrease in cooling thermostat setting will increase annual space cooling energy use by an average of 7%. Obviously, methods of reliably setting the thermostat upwards during non-occupied periods can show benefits.

Opposite to the effect of cooling thermostat, we found that each degree higher which the classrooms and facilities were reportedly heated to during Florida's short winters increased normalized annual energy use by about 2%. As expected, this influence was found to be relatively lower for the group of schools using heat pumps for heating than those using resistance electric heat. The sample of schools with natural gas data (89) was too small to support a similar analysis for gas heating.

Schools with clock thermostats or fully manual controls showed lower energy use than the group relying on an energy management system (EMS). Of the 311 schools reporting ownership of an EMS, some 68% reported them as operational. However, the group showing operational EMS systems evidenced 9.1 ±6.7% greater annual energy use than those facilities relying on other control systems. We speculated that part of this influence arose from the association of EMS with chillers and higher ventilation rates which were found to be primary drivers of increased HVAC energy use.(14) Constraining our analysis only to facilities less than ten years old, we found that an EMS reduced mean normalized energy use by 7% although the difference was not statistically significant. This is not surprising since proper setup and commissioning of EMS is vital to good performance.

Ventilation and Indoor Air Quality

Indoor Air Quality (IAQ) and ventilation rates have become a major concern in Florida educational facilities, both from a standpoint of energy use as well as for the well-being of students and staff. Our survey revealed some interesting patterns relative to these issues.

Some 252 schools responded to the question concerning the design ventilation rate. The mean value of 7.9 cfm/student is potentially misleading as the distribution was strongly bi-modal. There was a significant group of 185 schools reporting a ventilation rate 5 cfm/student and another large group of 52 schools at 15 cfm/student.(15) The better ventilated schools tended to be newer (24 years for 15 cfm/student against 32 years for those with 5 cfm/student). The group with the higher ventilation rate had a 17% higher electricity use per unit floor area (67.4 $kBtu/ft^2$ against 57.4 $kBtu/ft^2$), although the difference was not statistically significant. It should be noted, that other differences between schools may be associated with the higher ventilation rate. One is the likelihood that a school has a central chiller: 65% of schools with 15 cfm/student had chillers against 43% in the group at 5 cfm per student.

Table 5 shows various influences of variables of interest on frequency of complaints on IAQ. Interestingly, cfm per student showed up as a significant factor increasing the frequency of complaints. However, schools who reported opening windows rather than air conditioning had significantly lower complaints regarding IAQ. We think this finding is due to the perceived control over the indoor air quality issue which operable windows provide to faculty and students.

Table 5
Influences of Statistically Significant Variables on Frequency of Perceived Problems with Indoor Air Quality

Case (n)	Problems with IAQ	Difference (Statistical significance)
No humidity problems (606) Humidity problems (692)	27.3% 86.2%	+59.6%****
No demand vent (1255) Demand controlled vent (65)	57.9% 78.4%	+20.5%****
cfm/student <6 (186) cfm/student >14 (58)	28.6% 65.5%	+36.9%****
Non-low temp. system (1256) Low temperature air system (42)	58.5% 71.4%	+12.9%*
No windows opened (616)	63.7%	-9.2%***

Windows opened for cooling (670)	54.4%	
Older facility (>5 years) New facility (<5 years old)	49.1% 60.1%	+11.0%**

Statistical significance:

90.0% level: *
95.0% level: **
99.0% level: ***
99.9% level: ****

Schools which reported having problems with interior humidity were much more likely to report problems with IAQ. The strong association of IAQ with reported problems with humidity may indicate that schools with larger ventilation rates are more commonly experiencing greater moisture related problems which are perceived as leading to poor indoor air quality. Interestingly, schools that claimed to ventilate with operable windows rather than use air conditioning for cooling, also reported a lower frequency of problems with humidity.

Two additional findings were of surprise. Facilities which claimed to open windows rather than use air conditioning during portions of the year were quite numerous -- 51.6% of the population of schools responding. Further, we discovered that those schools making this claim had significantly lower annual energy use; a reduction of 8.83 $\pm$4.24 kBtu/ft^2 (12.5%). An obvious explanation is that mechanical cooling is avoided through natural ventilation that is not possible in facilities without operable windows.

We also found that the 116 schools who claimed to use ceiling fans in classrooms also had a significantly lower level of space conditioning energy use (15.54 $\pm$6.56 kBtu/ft^2 or 22.4% less). Analysis of covariance revealed that there was some association between those schools reporting the use of windows for ventilation and those using ceiling fans, but that both factors were even more significant when an interacted term (ceiling fans and operable windows) was introduced to the statistical analysis. Reported thermostat settings were 0.66 F^o higher in schools with ceiling fans -- a fact significant at the 90% level. Given the unusual nature of our finding, we examined other characteristics of schools using ceiling fans. Although such schools were often older, we repeated the analysis for facilities less than ten years old and found similar results. Beyond our study, there are practical concerns with advocating widespread ceiling fan use: strobe-like flicker from fans below lighting fixtures and air movement with desk-top papers. Even so, our analysis suggests this is an issue that should be examined further.

Lighting

Questions posed on lighting systems revealed mixed influences. Parking lot and outdoor security light appeared to lead to elevated annual consumption, although there was no statistically significant difference between schools with standard controls and those using motion sensor controls. We did see, however, that clock controls for lighting appeared to increase energy use, likely because clock controls will lead to increased hours of operation against discretionary manual operation. We found no statistically significant differences in lighting energy consumption between standard flourescent and newer systems using electronic ballasts. We repeated this analysis with the data censured to schools built in the last ten years on the chance that building age was confounding our results. Again, we found no statistically significant difference in normalized energy use based on reported lighting system type.[(16)]

Another seemingly contradictory finding was that schools reporting the use of occupancy sensor controls showed elevated energy use. We believed it possible that this finding is due to the fact that schools with automated controls often have other systems which may increase energy use: chillers and higher ventilation rates. To provide greater resolution, we censured the data to only schools built in the last five years. In doing so, we still found no statistically significant difference for buildings with occupancy sensor lighting controls.

It should be kept in mind, that two evaluations performed in the last three years for FDOE with metered lighting energy use found relatively low savings associated with the use of occupancy sensors in school facilities (Floyd et al., 1995, Floyd et al., 1996). In one study with metered lighting energy use in a Pasco County school, the savings in lighting energy was approximately 10%. In another study of a second elementary school (Sherwin et al., 1996), the use of occupancy sensor controls lead to increased lighting energy consumption. Based on work elsewhere, we believe this is due to increased lighting on-time hours with automated controls where effective manual control was previously used (Pigg et al., 1996). Further, both Florida studies found that without proper set up and commissioning of such systems, potential savings can be greatly reduced. We believe that the findings from our two investigations, as well as from this survey data, questions the general use of occupancy sensors in classrooms. Even so, a large scale study in the Pacific Northwest suggests that this technology may be quite beneficial in common areas in educational facilities (bathrooms, copy rooms, storage, hallways etc.) where occupancy rates are relatively low and potential savings are greater (Richman et al., 1994).

Perhaps the most intriguing finding of the overall statistical results was that facilities with windows in classrooms had 18% lower energy use than those without. This is likely due to diminished need for artificial lighting in these spaces. A previous FSEC project has already shown that daylight dimming system can reduce lighting needs in classrooms by 27% (Schrum, et.al., 1995). If occupants turn lights off when daylight is abundant, the effect would likely be similar but to a lesser degree.

Energy Awareness Programs

Many schools and districts around Florida now administer energy awareness programs to reduce their energy consumption through more vigilant operation of controls and improved operation and maintenance practices. Our analysis indicated that these programs have a small, but statistically significant impact on energy use. Schools which had such a program had about a 4% lower annual energy use than those schools that did not. On average, this saved \$0.095 $\pm$0.055 per square foot per year. We estimate that the average energy awareness program can save a typical facility \$5,000 - \$12,000 in annual operating costs.

Caveats

The results presented above should be considered approximate for a variety of reasons. Firstly, the survey responses were necessarily inexact on many items; there are likely errors in many of the estimates provided by the respondents. Some questions were poorly understood, even fundamental ones such as conditioned floor area. Thus, the fact that roof insulation level did not show up as an identified characteristic does not mean that insulation is unimportant. It rather indicates that the reported accuracy of the response or other interactions may obscure the true effect. Many respondents had no idea whether the roof was insulated.

Readers must also be cautioned that some of the identified factors in the model may not be truly responsible for the differences observed by the regression. Some may be statistical "carriers by association" where the true causal factor is not identified, but is rather associated with the chosen explanatory variable. An example might be the finding that demand controlled ventilation increases energy use. This ventilation system tends to be on newer type buildings which may use more energy due to increased ventilation. Thus, the chosen indicators by the regression may be associated with other causal factors, such as ventilation level, which are unreported (or poorly characterized) by the survey responses.

Another point must be emphasized: the fact that variables were excluded from the regression does not indicate they are unimportant. A good example is the impact of light colored roofing. These do not show up as significant in the regression so long as its polar opposite, dark roofing is included; they do show up when that variable is excluded. The relationships discovered also do not explain why influences were significant. A good example is the finding that schools with classrooms with windows used significantly less energy than those without. We do not know why those with windows perform better. It could have to do with reduced electric lighting from daylighting, possibility for mild season ventilation, both, or association with some other hidden causal influence.

Finally, there are real limitations with multiple regression methods that make the statistical model necessarily inexact. These included collinearity between independent variables, omitted variables, non-linear relationships and a host of other problems. A thorough discussion is provided by Mosteller and Tukey (1977). Regardless, we do believe that most of the reported influences above are robust; they will turn out to be of statistical significance regardless of how the data are analyzed.

VI. Conclusions

A detailed survey of energy use and energy use characteristics of Florida's public schools has been completed. The mailed survey instrument was sent to over 2,500 schools over the state in March, 1996. Some 1,298 surveys were returned by December 31, 1996 -- a response rate of approximately 52%. Of these some 677 had matching utility data. The survey data was analyzed to create a profile of energy use at Florida schools as well as characteristics that may influence their relative efficiency.

Given the average operating energy use by school type, we were able to estimate overall energy costs to the Florida school system at \$205 million per year. The typical Florida school used 1.4 million kWh and 7,400 therms of natural gas in 1995 at an annual expense of $94,000. We also ranked schools with complete data (654 facilities) by their energy use per square foot. The Energy Use Index (EUI, $kBtu/ft^2$) was used to sort schools based on their energy related performance. The EUIs varied from 2 - 226 Btu/ft^2. The top 10% of consumers (the 65 schools who used most per square foot) were identified for potential future retrofit projects to reduce their energy consumption.

Finally, an analysis was performed to examine the statistical influences on energy use in schools based on the responses to the survey questionnaire against the matched utility data. The analysis contained some surprising influences:

- Floor area and number of students and faculty were significant factors in annual energy use. High schools and vocational schools used more.
- Schools with light colored roof used 6 - 7% less energy than those with dark roofs.
- Schools that were conditioned on non-school days and after school hours, used more energy. Interestingly, schools with occupancy sensor lighting controls or operating EMS systems did not use less than schools with manual controls. Cooling set points were shown to have strong influence. Each ^{o}F the cooling system thermostat was increased was shown to decrease annual energy consumption by 20,000 kWh/yr.
- Classrooms with windows used 20% less energy than those without them. This may be due to reduced need for interior lighting, available ventilation during mild weather, or both.
- Schools relying predominantly on packaged cooling equipment rather than central chillers used 24% less energy. In part, this stems from the fact that chillers in older schools evidenced of very poor performance; newer chillers installations did not show this tendency. Elevated consumption associated with chillers may also reflect the potential for zoned cooling as well as the need for increased energy efficient chiller sub-systems such as pumps, air handlers and cooling towers.
- Heating system choices other than electric resistance heating were shown to be beneficial. This includes heat pump systems, although water loop systems showed less advantageous performance.
- Schools with a history of humidity problems used more energy (likely from electric reheat). Indoor air quality (IAQ) problems were strongly associated with humidity complaints and increased ventilation levels. Conversely, classrooms opening windows for ventilation reported a much lower incidence of IAQ problems.
- Facilities with ceiling fans in classrooms showed lower energy needs. The reasons behind this finding are unclear. Although, the statistical influence is quite pronounced. One partial explanation is cooling thermostat setting. The 155 schools reporting the use of fans gave a cooling thermostat setting of 75.2^{o}F against the 74.8^{o}F without fans -- a finding significant at the 99% level.
- Schools with low temperature air distribution systems or newer demand controlled ventilation systems used considerably more energy and also had higher annual energy costs even when normalized by floor area.
- Demand controlled ventilation may be associated with higher energy use because of increases to the effective minimum ventilation rate.
- Energy awareness programs resulted in measurable reductions to annual energy use.

Appendices

Appendix A: Sample Completed Survey
Appendix B: Survey Statistics and Frequencies by School Type
Appendix C: EUI Ranking of All Schools

VII. Acknowledgments

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1. Duplicate requests from a portion of those receiving the survey, and some requesting the survey who were not included in the original mailing, complicates the process of determining the actual number of schools to whom the instrument was mailed. However, the initial Department of Education mailing list exceeded 2500.

2. Note: All percentages (%) refer to percentage of total schools responding.

3. Note: total is >100 due to multiple control strategies at some schools.

4. This agrees well with prevailing electricity rates for the GSD class for Florida Power and Light Company, the largest Florida utility. In September 1995, this rate was $0.039/kWh with monthly demand charges of $6.25/kW.

5. EUI was used in the analysis to control for the largest factor influencing energy use- floor area- so that false correlation would not be drawn from factors associated with this variable.

6. Multi-variate analysis is a complex subject. Those looking for a more thorough explanation are referred to Mosteller and Tukey's Data Analysis and Regression. Addison-Wesley, 1977.

7. All uncertainties for differences in means in the report were assessed and/or reported at the 90% confidence level.

8. One factor may be uncontrolled air flow in school buildings where roof/plenum air is able to bypass insulation making it ineffective (see Cummings, et.al., 1996).

9. A Chiller installation in inappropriate circumstances may result in increased chiller run hours because a single building/classroom or office needs cooling when the rest of the facility does not. With packaged equipment, only the appropriate packaged equipment is powered, but with a chiller when a single thermostat unit is activated and calls for cooling, the entire chiller (or one of its large compressors) are powered to serve a small cooling load with result that part load efficiency suffers. This doesn't mean that chillers are not appropriate for schools, but it does likely indicate that a combination of chillers and constant cooling for dehumidification, etc. However, within schools with chillers, the central chillers may be operated the entire summer just to maintain these spaces when a dedicated packaged system would spare the operation of the larger system.

10. A good example comes from FSEC's own new facility in Cocoa, Florida. On July 17, 1997, a hot summer day, the metered chiller daytime loads were 98 kW to produce about 120 tons of cooling. This implies a chiller efficiency of about EER = 14.7 Btu/W. However, at the same time the air handler loads averaged about 27 kW and pumps, drives, and cooling tower used 13 kW more-- a 41% increase in the cooling system energy use and a reduction in EER to 10.4 Btu/W. On the other hand, a good portion of four and five ton unitary equipment have EERs of 12 Btu/W or better.

11. The specifics of this analysis are as folows:
Chillers in facilities < 15 years old (+3.82 {$\pm$ 9.11} kBtu/ft^2)
Chillers in facilities > 15 years old (+17.64{$\pm$ 4.85} kBtu/ft^2)

12. We used analysis of covariance (ANCOVA) to identify true carriers for the observed variance where two factors were strongly associated and both were found to lead to elevated energy use.

13. Since we did not ask a question about thermal storage systems we were not able to examine this specific system.

14. A monitored assessment performed for the Florida Energy Office has shown that a properly functioning EMS in a Florida elementary school can provide a 16% reduction to measured HVAC energy use (Sherwin et al., 1996).

15. The reported design ventilation rate varied from 3 to 30 cfm per student.

16. This does not indicate that flourescent lighting systems with electronic ballasts do not use less energy (an established fact), but rather that our statistical analysis could not conclusively establish the fact.

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