The Big Report Card: Energy Use in Florida Schools

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ABSTRACT

A detailed survey of energy use and energy use characteristics of Florida's public schools was completed. The mailed survey instrument was sent to over 2,500 schools over the state in March, 1996. Some 1,298 surveys were returned with 677 having 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 efficiency.

Introduction

Over the last four years, the Florida Solar Energy Center (FSEC) has assisted the Florida Department of Education (FDOE) to identify energy saving strategies. In 1993-1995 a detailed simulation study was performed outlining how efficiency could be improved for *new* construction (McIlvaine et al., 1994). During subsequent workshops, many participants requested similar information for improving energy performance of existing schools similar to that available elsewhere (Webster et al., 1986; Dunn, 1998). Toward that end, an extensive survey was launched in early 1996 to assess energy use in Florida's public schools.

Our objectives were threefold: 1) to develop detailed information on the energy-related characteristics of Florida schools, 2) to develop a ranking of schools based on relative energy use, and 3) to analyze the statistical association of school characteristics and energy use.

Data Collection

Research staff designed an extensive, six-part, hundred item questionnaire targeting key energy profile information for Florida educational facilities. After review, the draft document was mailed to all Florida's public schools in early March 1996. The survey also called for schools to forward 1995 utility records with the response.

Over 900 schools submitted a response to the questionnaire by late August, 1996. A 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%. Of these schools a subset of 677 submitted the requested utility data.

The original source report contains the tabulated frequencies and descriptive statistics for responses to each survey question (Callahan et al., 1997). We briefly summarize the highlights:

School Type and Characteristics

- Responding facilities
  - Elementary schools: 58%
  - Middle/Jr. High schools: 18%
  - High Schools: 14%
  - Vocational: 3%

- Floor Area
  - 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
  - 4% have a pool
  - 97% have a cafeteria facility
  - 36% have athletic facilities with showers

- Student/Faculty and Staff
  - Students: Avg = 981
  - Faculty: Avg = 57
  - Administrative: 26

Discussion: The survey respondents are weighted towards elementary facilities since these comprise the largest overall group within the Florida school system. Figure 1 shows how middle schools and high schools are both larger and use more energy. High schools and vocational schools use disproportionately more energy than their conditioned floor area would indicate.

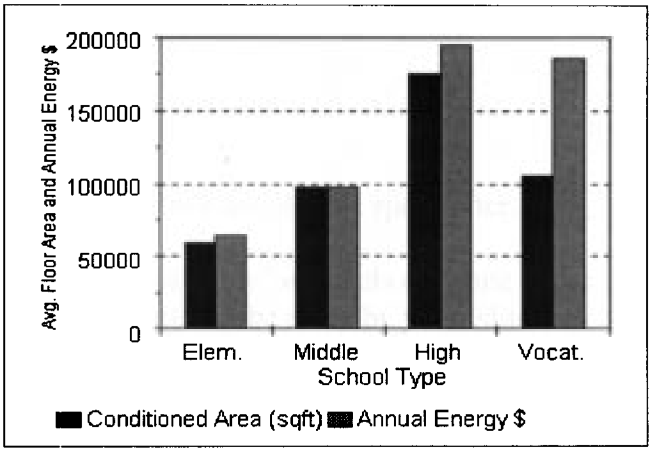

Figure 1. Variation of conditioned floor area and annual and annual energy cost by school type.

Operation and Schedule

- School Year
  - Avg of 186 student days
  - Avg of 19 teacher work days
  - Only 9% year round schools
  - 58% summer school programs
  - 25% night school/adult education
  - 87% yr. round administrative operation

- Air Conditioning Operation during Non-School Periods
  - 45% during non-school hours
  - 41% during non-school days
  - 41% over summer break/holidays

- Areas Air-Conditioned during Non-School Days
  - 34% classrooms are conditioned
  - 51% library or media center
  - 9% gymnasiums
  - 53% administrative offices
  - 26% cafeterias

- Cooling Thermostat Temperatures
  - Classroom facilities: 74.8°F
  - Classrooms non-occupied: 77.8°F

- Heating Thermostat Temperatures
  - Classroom facilities: 71.7°F
  - Classrooms non-occupied: 69.5°F

- Interior Temperature Regulation[1]
  - Manual thermostats: 67%
  - Central thermostats: 40%
  - Locked thermostats: 37%
  - Clock thermostats: 18%
  - Energy management system: 50%

- Ventilation
  - Avg. ventilation rate: 7.9 cfm/student
  - Windows used for natural ventilation: 52%

- HVAC System/Problems
  - System Age: 10.8 years
  - Problems with humidity: 53%
  - Poor indoor air quality complaints: 59%
  - Complaints on 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: Eighty-seven percent of Florida schools administrative offices were open during summers even though only nine percent of facilities surveyed were "year round schools." Even during non-school days, most air condition a good portion of the facilities. Although this is understandable for media centers and libraries, reducing the cooling of classrooms during unoccupied periods may offer saving potentials. This was 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°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.

The average design ventilation rate was 7.9 cfm per student although with a bi-modal distribution; many schools had 5 cfm/student while others had 15 cfm in correspondence to the new *ASHRAE Standard 62-1989*. Some 52% of respondents reported using operable windows for ventilation rather than air conditioning at some time during the year. This runs counter to the prevailing wisdom in design circles that natural ventilation cannot produce adequate comfort.[2]

Over half of the surveyed schools reported problems with indoor humidity and 59% indicated complaints regarding indoor air quality (IAQ). Interestingly, complaints of poor IAQ increased with grade level. Elementary and middle schools recorded complaints from 57% and 60% respectively, but with high schools this rose to 72%. There was strong correlation between IAQ concerns, complaints of humidity, 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. Older schools appeared to have the fewest problems which may have to do with lower ventilation rates, operable windows or other identified qualities.

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[1] Note: total is > 100 due to multiple control strategies at some schools.

[2] A very detailed study in Hawaii schools concluded that good thermal comfort can often be achieved within a tropical setting without air conditioning (Kwok, 1997).

Energy Systems

- Building/Roof
  - 34% have uninsulated roofs/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
  - 16% have skylights
  - 27% of glass has tint or other solar control

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

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

Discussion: Although we expected walls to be uninsulated in many existing schools (66%); we were surprised to find that 34% had an uninsulated roof or ceiling. 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; 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 the other half. Constant volume air distribution was typical with a few systems using advanced technologies (heat pipe dehumidification, demand ventilation control etc.). Most schools had standard fluorescent fixtures, although about 44% had some fixtures with electronic ballasts. Some 21% had occupancy sensor lighting controls 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.

Energy Data

- Primary Heating Fuel
  - Electricity: 53%
  - Oil: 7%
  - Combination: 13%
  - Natural gas: 13%
  - Propane: 5%
  - Unanswered: 6%

- Primary Water Heating Fuel
  - Electricity: 39%
  - Oil: 5%
  - Combination/other: 13%
  - Natural gas: 24%
  - Propane: 12%
  - No hot water: 1%

- Cooling Fuel
  - Electric: 99%
  - Natural gas: 1%

- Total Annual Energy Costs
  - Avg was $93,823 per year ($1.24/ft^2)
  - Range varied from $1,282 to $428,288

Graphical Summary: Figure 2 shows a histogram and statistics of the 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 3 provides a similar presentation for natural gas consumption (therms = 100 cubic feet of gas = 10^5 Btu).

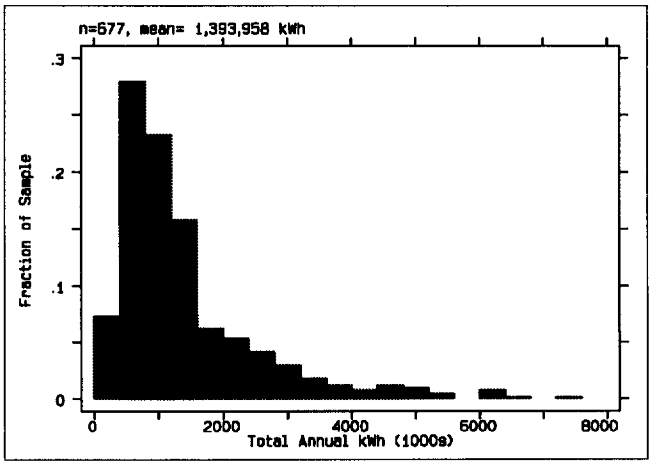

Figure 2. Histogram of total annual kWh of all schools.

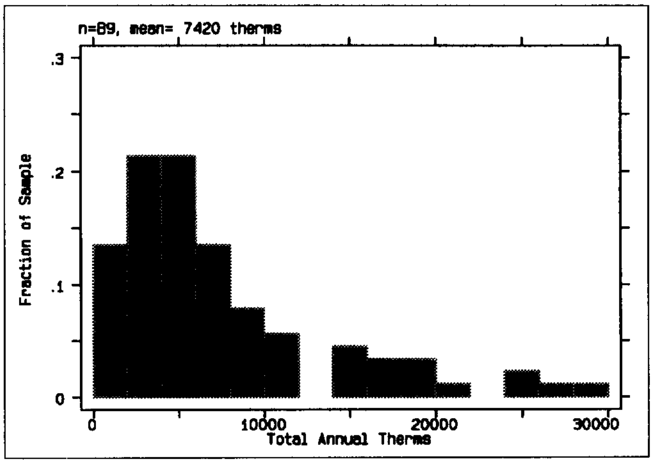

Figure 3. Histogram of total annual therms of natural gas.

Figure 4 shows a bar chart presenting the monthly average electricity use in the surveyed schools. The influence of time of year, including summer break, is obvious; 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 energy consumption.

Figure 5 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 – approximately $1.24 per square foot per year. The typical school pays approximately $0.047/kWh with monthly demand charges of $5.90/kW.

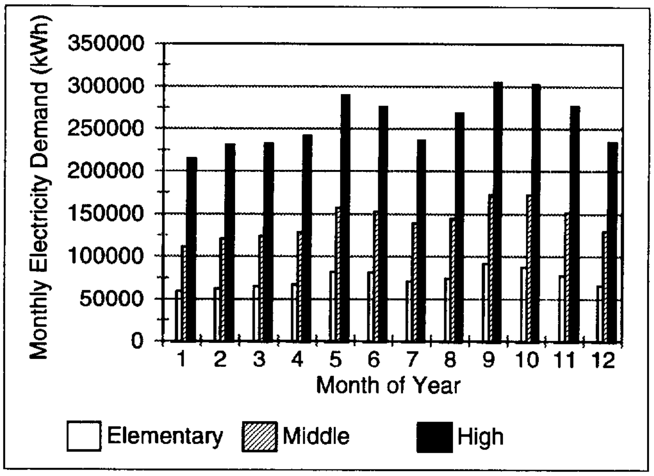

Figure 4. Average monthly electricity use by school type.

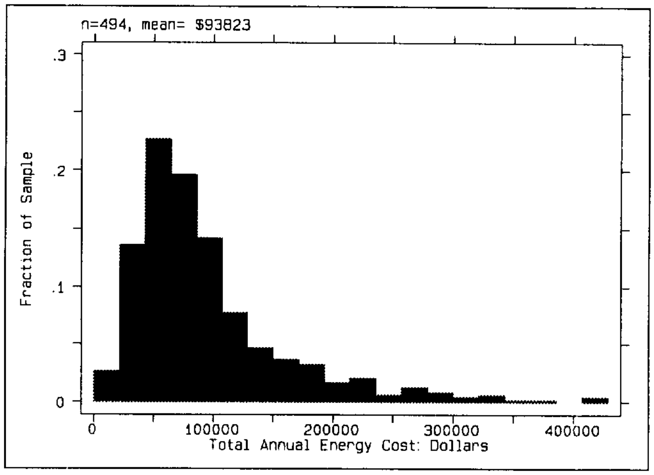

Figure 5. Histogram of energy costs in all schools.

Table 1. Selected School Characteristics by School Type

	Elementary	Middle	High
Conditioned floor area	59,908	97,385	175,248
Number of portables	10	11	12
Maximum number of students	769	1,116	1,688
Average number of faculty	48	62	93
Average monthly kW	323.7	548.2	871.5
Average monthly kWh	74,144	141,885	241,376
Total dollars	64,002	121,333	195,016
Dollars/ft^2	1.18	1.55	1.20
EUI	64.7	69.4	74.4

Analysis

We found a strong association between floor area and annual energy use. Figure 6 presents a scatter plot of the relationship between school floor area and electricity consumption by school type. 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 by the scatter, there is still considerable variation in energy use that is not accounted for by floor area.

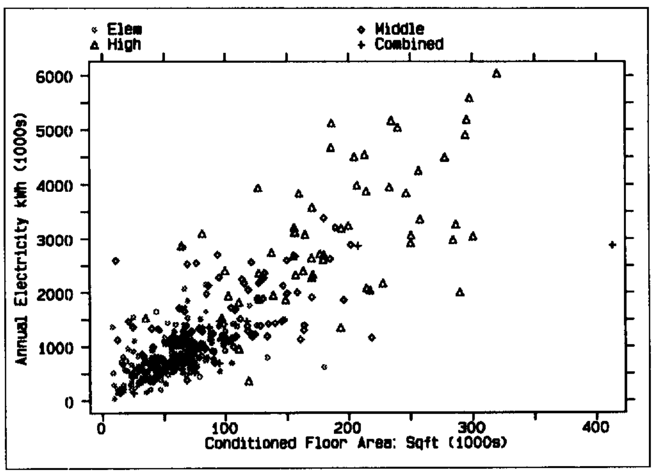

Figure 6. Relationship of annual electricity use to floor area by school type.

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 and other studies have used similar indices for assessment (Landmen and Haberl 1998).

We computed EUI for the 654 schools which had valid floor area and energy consumption data (utility data for all fuels). Figure 7 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 use. Those with lower EUIs are associated with closed facilities.

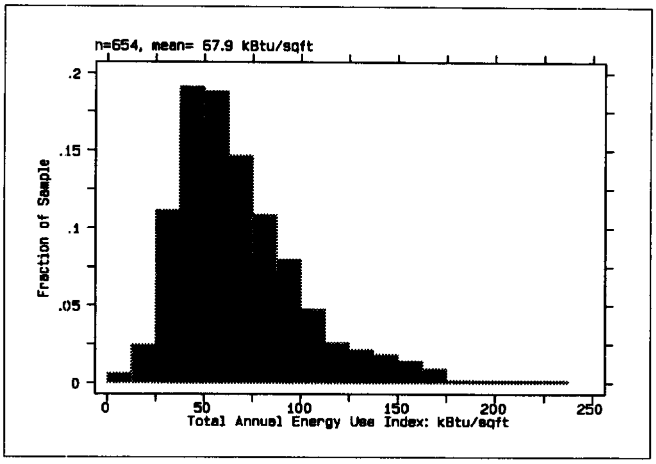

Figure 7. Histogram of energy use index (EUI) for all schools.

We ranked the top 10% of the ranked facilities (65 schools) with the *highest* EUIs. These facilities likely represent good opportunities for further energy audits, renovation and retrofit. The benefits of such activity was shown in a Florida elementary school which found a 15% overall energy savings from a series of installed retrofit measures (Sherwin and Parker, 1996). Generally, in commercial building retrofit projects, those facilities can save most whose energy costs are currently elevated (Piette et al., 1994).

Statistical Analysis

School characteristics, schedules and equipment efficiency 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 was to create a list of significant factors 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.[3]

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. 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 satisfy the critical F-ratio (2.0).

In our analysis, 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. The multiple regression analysis results are presented in the

[3] EUI was used in the analysis to control for the largest factor influencing energy use – floor area – so that false correlations would not be drawn from factors associated with this variable.

source report. We summarize the highlights from the statistical analysis in Figure 8.

Although statistically significant coefficients are provided in Figure 8, 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.

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.[4] We found each additional hundred students added to a facility's enrollment could be expected to increase annual energy use by about 1.3%.

On average each portable classroom increased facility energy use by about 10,840 (±5141) kWh per year. An average school had about ten portables with an area of about 856 (±18) square feet each. On an annual basis, portable classrooms used about 12 kWh/square foot. The difference between energy use for permanent building floor area and that of portables was not statistically significant.[5] Although the energy use of portable and permanent classrooms was the rate at which portables are added can serve to significantly increase facility energy use over time. Thus, energy use for portable classrooms in the state is very large: 250 million kWh and costing about $18 million dollars in their operation. A research project is currently underway to evaluate how efficiency in Florida portable classrooms might be improved (Callahan et al., 1997). Simulation analysis 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., 1996).

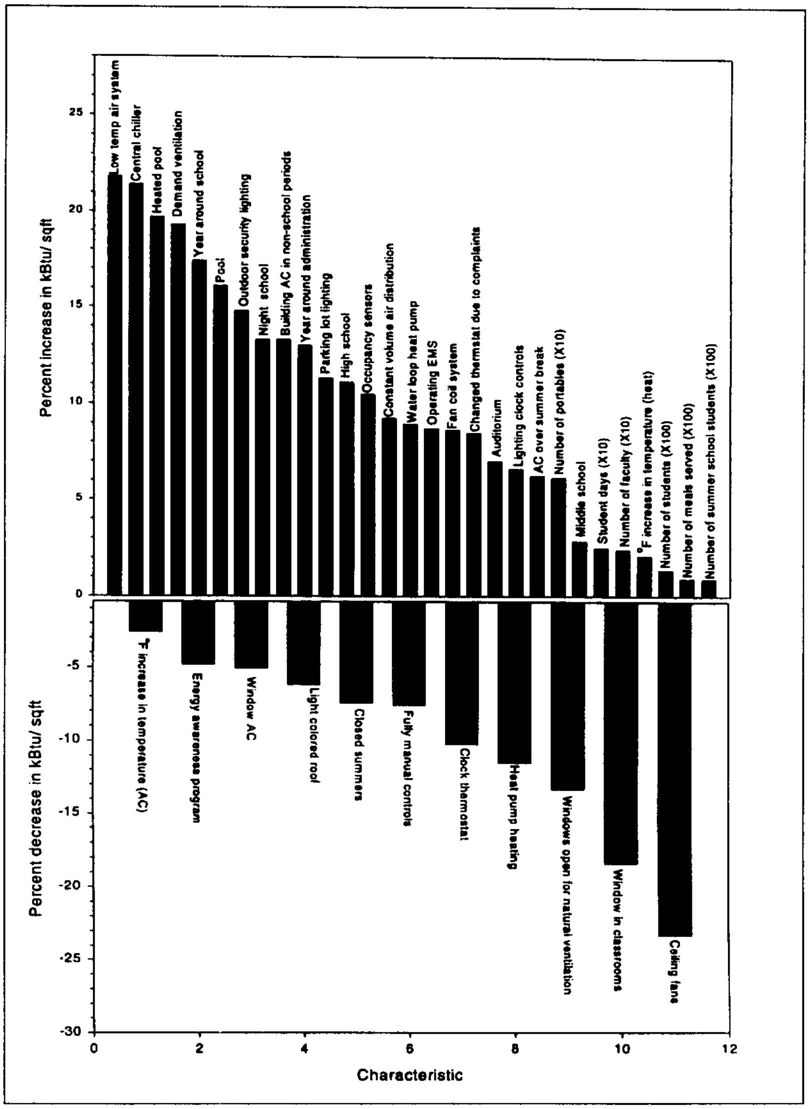

Figure 8. Statistically significant influences on annual energy consumption.

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

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[4] All uncertainties for differences in means were assessed and/or reported at the 90% confidence level.

[5] 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.

statistically significant. These facilities are typically better insulated with more modern equipment. 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 vintage itself.

Analysis verified that year round schools used more energy – particularly during June and July – than did those closed during the summer. Similarly, schools reporting open administrative offices 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 or use of automated thermostats to reduce conditioning.

Added insulation was not a statistically significant factor for differences in school energy consumption. This finding was true for both roof and wall insulation. The unimportance of wall insulation was expected based on simulation analysis (McIlvaine et al., 1994). However the lack of importance of roof insulation was surprising. 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 $\pm$ 4.54 kBtu/ft^2 – without statistical significance. Thirty five percent of schools reported no ceiling or roof insulation.

One envelope-related factor did appear to be influential: schools reporting a light colored roof showed 6%-7% lower energy use than dark colored roofs. This reinforced 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 18% lower normalized annual energy use. The observed difference, 12.28 $\pm$5.38 kBtu/ft^2, was highly significant. Since building energy simulations indicate that added window areas in school facilities increase cooling loads, we hypothesize that the effect of windows in classrooms was to reduce the need for electrical lighting through daylighting.[6] 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. A project already performed for the Department of Education has shown that daylight dimming lighting systems have the potential to 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 consideration of pool pumping in the design of new facilities and solar heating in facilities which provide heated pools.

Cooling

Simulation analysis of energy use in a prototype Florida school has estimated that consumption associated with space cooling and ventilation is responsible for about 43% of total consumption (McIlvaine et al., 1994).[7] A surprising find was that schools with central chillers used more energy than those relying on packaged systems. The reason may have to do with both efficiency and zoning. A chiller installation

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[6] Tinted windows or solar control glass did not show up as a statistically significant energy reduction factor.

[7] By way of contrast, a study of 60 schools in Texas found cooling to be 24% of electric load (Dunn 1998).

in inappropriate circumstances may result in increased chiller run hours because a single building/library/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) operates with resulting low part load efficiency. Thus, a combination of chillers and packaged units may make for the best efficiency.

Further, 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.[8] 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 energy 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 discovered that the elevation of energy use by chillers 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 pronounced.[9] Newer chiller installations are much more efficient than older systems which may also be in poor operating condition. This likely indicates a large opportunity to reduce school facility energy use by replacing aging chillers or proper re-commissioning of systems.[10]

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 additional ventilation requirements with *ASHRAE Standard 62-89*. The increased ventilation rates 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 down costs.

Other Heating, Ventilation and Air Conditioning (HVAC) Equipment. HVAC equipment other than chillers demonstrated significant impact on annual energy use. Constant air volume systems showed higher use. 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.

Also, schools which relied primarily on window air conditioners 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

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[8] A good example comes from FSEC's own new facility in Cocoa, Florida. On July 17th, 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 average and 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.

[9] The specifics of this analysis are as follows:

	t-test of mean EUI
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

[10] 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).

in commercial buildings with uncontrolled air flow (Cummings et al., 1996), i.e. unintended heat gain to duct or piping systems located in roof/ceiling plenums.

Heat pump systems showed lower annual energy use than electric resistance systems. 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 the cooling tower associated with such systems. As expected, schools using natural gas for heating showed lower usage in annual electricity. However, when examining total energy consumption, including the use of natural gas, systems with gas furnaces appeared comparable.

A finding of considerable interest was that low temperature distribution systems, typically with thermal storage cooling systems, were associated with the largest elevation in normalized energy use of any characteristic identified in the analysis. Often these systems are operated with a time of use (TOU) rate to take advantage of their ability to reduce facility monthly demand charges. 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. 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 this contention.

HVAC Controls

One of the most important opportunities with energy using equipment is examination of the ways in which the equipment is controlled. The reported preference for an annual cooling temperature for educational facilities had a mean value of 74.8°F, but varied from 65 - 82°F. Individually, many schools reported frequent 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 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 the thermostat setting will increase annual space cooling energy use by an average of 7%.

From a heating perspective, each degree rise in thermostat setpoint increased normalized annual energy use by about 2%. This influence was lower for the group of schools using heat pumps for heating than those using resistance electric heat.

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 $\pm$6.7% greater annual energy use than those facilities relying on other control systems. We speculate 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.[11] 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.

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

Ventilation and Indoor Air Quality

Indoor Air Quality (IAQ) and ventilation rates are a major concern in Florida educational facilities. 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. Some 185 schools reporting a ventilation rate 5 cfm/student and with 52 schools at 15 cfm/student with a range of 3-30 cfm. The better ventilated schools tended to be newer. The higher ventilation rate group 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 significant. Other differences between schools may be associated with the higher ventilation rate. For instance, 65% of schools with 15 cfm/student had chillers against 43% in the group at 5 cfm per student.

Table 2 (at the top of the next page) shows various influences of variables of interest on the frequency of complaints on IAQ. Added 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. This finding may be due to the perceived control over the indoor air quality issue which operable windows provides to faculty and students.

Schools reporting problems with interior humidity were much more likely to report problems with IAQ. The strong association of IAQ with humidity concerns may indicate that schools with larger ventilation rates are more commonly experiencing greater moisture-related problems. 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.

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.

Table 2. Influences of Statistically Significant Variables on Frequency of Perceived Problems with IAQ

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) Windows opened for cooling (670)	63.7% 54.4%	-9.2%***
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: ****

We also found that the 116 schools who claimed to use ceiling fans in classrooms 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 analysis. Reported thermostat settings were 0.66°F higher in schools with ceiling fans – a fact significant at the 90% level.

Lighting

Presence of parking lot and outdoor security lighting showed elevated annual consumption, although there was no statistically significant difference between schools with standard and automatic controls. Also, we found no statistically significant differences in lighting energy consumption between standard fluorescent 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.[12]

Another seemingly contradictory finding was that schools reporting the use of occupancy sensor controls showed elevated energy use. However, schools with automated controls often have other systems which may increase energy use: chillers and higher ventilation rates. We censured the data to only schools built in the last five years, but still found no statistically significant difference.

However, two relevant evaluations performed in the last three years for FDOE found lower savings associated with the use of occupancy based lighting controls 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. This may be 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 are compromised. Taken together, these problems question the general use of occupancy sensors in classrooms. However, a large scale study suggests that this technology may be quite beneficial in common areas (bathrooms, copy rooms, storage, hallways etc.) where occupancy rates are intermittent (Richman et al., 1994).

Energy Awareness Programs

Sixty percent of Florida schools administer energy awareness programs to reduce their energy consumption through more vigilant operation of controls. 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 ±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.

Conclusions

A detailed survey of energy use and energy use characteristics of Florida's public schools was completed. The mailed survey instrument was sent to over 2,500 schools over the state in March, 1996. Some 1,298 surveys were returned with 677 having matching utility data. The survey data was analyzed

[12] This does not indicate that fluorescent lighting systems with electrical ballasts do not use less energy (an established fact), but rather that our statistical analysis could not conclusively establish the influence.

to create a profile of energy use at Florida schools as well as characteristics that may influence their efficiency. 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 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. An analysis was performed to examine the statistical influences on energy use in schools based on the responses to the survey against matched utility data.

- Floor area, number of students and faculty, and occupancy schedules were significant factors in annual energy use. High schools and vocational schools used more energy.

- Due to their number, 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. This indicates that a sizeable portion of the stock of elementary schools have poor energy utilization efficiencies which might be rectified.

- Schools with a light colored roof used 6 - 7% less energy than those with dark roofs.

- Schools with occupancy sensor lighting controls or operating EMS systems did not use less than those with manual controls. Cooling set points had a strong influence. Each °F the cooling thermostat was increased was shown to decrease annual energy consumption by about 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 a lower potential for zoned cooling as well as the need for increased energy efficient chiller sub-systems such as pumps, air handlers and cooling towers.

- 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. A partial explanation is cooling thermostat setting. The 155 schools reporting the use of fans gave a cooling thermostat setting of 75.2°F against the 74.8°F without fans -- a difference 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.

- Energy awareness programs resulted in measurable reductions to energy use.

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References

G. Brown, D. Bjornson, J. Briscoe, S. Fremouw, J. Kline, P. Kumar, P. Larocque, D. Northcutt, Z. Wang, D. Rasmussen, K. Rasmussen and J. Stanard, 1996, "Design and Evaluation of Energy Efficient Modular Classroom Structures," Proceedings of the 22nd National Passive Solar Conference, Washington D.C.

M. Callahan, D. Floyd and D. Parker, 1997. Energy Efficient Improvements to Portable Classrooms, FSEC-CR-939-97, Florida Solar Energy Center, Cocoa, FL.

J.B. Cummings, C.R. Withers, N. Moyer, P. Fairey and B. McKendry, 1996. Uncontrolled Air Flow in Non-Residential Buildings, FSEC-CR-878-96, Florida Solar Energy Center, Cocoa, FL.

B.S. Davanagere, K. Rengarajan, D.B. Shirey III, R.A. Raustad, 1996. Impacts of ASHRAE Standard 62-1989 on Florida Schools, FSEC-CR-856-95, Florida Solar Energy Center, Cocoa, FL.

J.R. Dunn, 1998. "Energy Use and Costs in Texas Schools and Hospitals," Proceedings of The Eleventh Symposium on Improving Building Systems in Hot and Humid Climates, p 428, Fort Worth Texas.

D. Floyd and D. Parker, 1994. "Field Commissioning of a Daylight Dimming System," Proceedings of Right Light Three: 3rd European Conference on Energy Efficient Lighting, Newcastle on Tyne, U.K.

D.B. Floyd, D.S. Parker, J.E.R. McIlvaine and J.R. Sherwin, Energy Efficiency Technology Demonstration Project for Florida Educational Facilities: Occupancy Sensors, FSEC-CR-867-95, Florida Solar Energy Center, Cocoa, FL, December, 1995.

A.G. Kwok, Thermal Comfort in Naturally Ventilated and Air Conditioned Classrooms in the Tropics, Ph.D. dissertation, University of California, Berkeley, CA, Spring, 1997.

D.S. Landmen and J.S. Haberl, 1998. " Development of pre-screening methods for analyzing energy use in K-12 Public Schools," Proceedings of The Eleventh Symposium on Improving Building Systems in Hot and Humid Climates, p 220, Fort Worth Texas.

J.E.R. McIlvaine, M, Mallette, D. Parker, P. Lapujade, D. Floyd, L. Schrum and T. Stedman, Energy Efficiency Design for Florida Educational Facilities, prepared for the Florida Department of Education, Florida Solar Energy Center, Cocoa, FL, 1994.

D.S. Parker, J.R. Sherwin, J.K. Sonne and S.F. Barkaszi, Jr.,1996, Demonstration of Cooling Savings from Light Colored Roof Surfacing in Florida Commercial Buildings: Our's Savior's School, FSEC-CR-904-96, Florida Solar Energy Center, Cocoa, FL, 1994.

M.A. Piette, B. Nordman, O. deBuen and R. Diamond, "Over the Energy Edge: Results from a Seven Year New Commercial Buildings Research and Demonstration Project,"Proceedings of the 1994 Summer Study on Energy Efficiency in Buildings, Vol. 9, p. 243, American Council for an Energy Efficient Economy, Washington D.C.

S. Pigg, M. Eilers and J. Reed, 1996, "Behavioral Aspects of Lighting and Occupancy Sensors in Private Offices," Proceedings of the 1996 Summer Study on Energy Efficiency in Buildings, Vol. 8, p. 161, American Council for an Energy Efficient Economy, Washington D.C.

E. Richman, A. Dittmer and J. Keller, 1994. Field Analysis of Occupancy Sensor Operation: Parameters Affecting Lighting Energy Savings, PNL-10135, Pacific Northwest Laboratories, Richland, WA.

J. Sherwin and D. Parker, FLASTAR: Florida Alliance for Saving Taxes and Resources, FSEC-CR-916-96, Florida Solar Energy Center, Cocoa, FL, October, 1996.

T. Webster, B. Birdsall, R. Kammerund, K. Whitley, A. Mertol and W. Carroll, 1986, "Energy Use in Educational Buildings," LBL-21039, Lawrence Berkeley National Laboratory, Berkeley, CA.