Demonstrated Energy Savings of Efficiency Improvements to a Portable Classroom

Michael P. Callahan, Danny S. Parker, John R. Sherwin, Michael T. Anello
Florida Solar Energy Center

ABSTRACT

Florida has over 25,000 portable classrooms in use around the state. Energy costs for these structures exceed $20 million a year – or about 11% of all energy-related expenditures for educational facilities. Research has also shown interior ventilation rates in these classrooms typically fall far below the recommended levels in ASHRAE Standard 62-1989.

Our goal in this project was to reduce energy use and to improve the physical learning environment in portable classrooms. A middle school in Volusia County Florida was chosen for the two year study. Two portables were highly instrumented and a year of base-line data was collected before a series of retrofit measures were sequenced into the classrooms.

Introduction

The purpose of this study was to determine if portable classrooms in the hot and humid climate of Florida can be made more energy efficient either by retrofit or at the time of new portable construction. Secondary objectives were to see if the learning environment could be improved as part of the efficiency measures. This included thermal comfort, ventilation and illumination quality. The evaluation was accomplished through test of chosen measures in occupied classrooms. Since economics were important both energy savings and costs were tracked.

Two adjacent classrooms were monitored for a year to collect baseline data, then energy efficiency measures were installed to analyze the effectiveness of each retrofit over time.
Retrofits included:

- Lighting: T12 lamp-magnetic ballast lighting system replaced by a more efficient T8 lamp-electronic ballast lighting system.
- Roofing: Gray asphalt shingle roof replaced with a reflective white metal roof to reduce cooling loads related to heat transfer from classroom ceilings.
- Heating, Ventilation and Cooling (HVAC): A three ton wall hung heat pump was replaced with 2½ ton higher efficiency model.
- Ventilation: Enthalpy recovery ventilation system added to provide greater outdoor air while controlling indoor humidity and energy impacts.
- Automated Controls: Occupancy based controls to turn off space conditioning when the classroom is unoccupied.

Background

Demands for increased classroom space against budget restrictions have resulted in a greater number of installed portable classrooms in the Florida school system. Where these relocatable classrooms were once thought to be temporary structures, it is now accepted that they are more or less permanent (Shedden 1997).[1]

Portable classrooms have typically been judged as substandard educational facilities and have often been poorly received by the community (Stoddard 1997). Such perceptions arose from the portables' bland coloration and their often shabby appearance (Rasmussen et al. 1995).

Florida schools have an average of 9.9 portables with 836 ft^2 of conditioned floor area each (Callahan et al. 1997). There are over 2,500 schools in the state so that means approximately 25,000 portable classrooms are in use. In addition, the same study shows that each portable classroom uses approximately 10,840 kWh per year. This is corroborated by measured energy use at a central Florida elementary school of 360 kWh/day for 12 portables (Sherwin & Parker 1996). Thus, both statistical estimates as well as monitoring shows an average use of about 30 kWh/day for portable classrooms.

Based on such data, portables account for 11% of the energy budget for Florida public schools. We estimated that portable energy use statewide was 250 million kWh costing $20 million annually (Callahan et al. 1997). The annual energy costs for Florida schools in 1995 was $205 million, so portable classrooms contribute significantly to the cost of annual operation.

Simulation analysis in a study of potential portable classroom improvements suggests that energy savings may be reduced up to 23% with a payback of less than 3 years (Brown et al. 1997). However, empirical verification of this potential and demonstration of measured savings in hot and humid climates has been lacking.

To remedy this gap in knowledge, the Florida Solar Energy Center, in conjunction with the Florida Department of Education, chose a school upon which to conduct a real-world test. Silver Sands Middle School has 39 portable classrooms and is located in Port Orange in the Volusia County School District. Volusia County is located on the North East Central Coast of Florida.

Site Description

Two portable classrooms with identical dimensions, configuration and orientation, numbers 035 and 096, were chosen for the study. The portable classrooms were of wood frame construction with shingle roofs and dark beige wood siding with the long axis in an east-west orientation. Table 1 describes the characteristics of the classrooms.

Instrumentation

Each portable classroom was fully instrumented with thermocouples that measured interior space, roof, decking and attic temperatures. The portables were also wired to measure how long the doors were opened. CO_2 sensors measure carbon dioxide concentrations, an indicator of relative occupancy and indoor pollutant concentrations. Generally CO_2 concentrations should be less than 1000 ppm in occupied buildings.

Project instrumentation also monitored total kWh, air conditioning (AC) kWh, and lighting kWh. A weather station at the site measured wind speed, ambient temperature, relative humidity, and solar insolation over a 24 hour period. Data averages and sums were stored by that data logger every

---

[1] A move within Florida is in progress to limit the further expansion of portable classroom utilization through requirement of covered walkways to the facilities.

15 minutes. All this instrumentation was poled by a *Campbell CR10* data logger which downloaded over a dedicated telephone line each night.

Table 1. Description of Portable Classrooms

Overall	
Construction:	Wood frame construction, medium-colored shingle roof, corrugated metal exterior siding. Mounted on metal frame approximately 18 inches
Floor Area:	Above grade without skirting material (i.e., open crawl space)
Glazing:	720 ft^2 (20' x 36' long axis oriented north-to-south 22% of gross floor area, single pane casement
Insulation:	
Roof:	0.09 Btu/h · ft^2 · °F (R-11) [estimated]
Walls:	0.02 Btu/h · ft^2 · °F (R-5) [estimated]
Floor:	None
Baseline HVAC System	
Cooling:	Packaged wall-mounted, direct expansion (DX) heat pump 3.0-ton nominal capacity
Air Distribution:	Constant volume
Supply Fan Control:	Continuous fan operation (fan ON)
Thermostat:	
Settings	75°F cooling, 70°F heating
Schedule	8:00 am - 5:00 pm, "off" night and weekends
Internal Gains (peak)	
Occupancy:	30 ft^2/person (approximately)
Lighting:	2,150 watts (3.0 W/ft^2), fluorescent bulbs with prismatic fixtures
Receptacles:	<100 watts (periodic usage of overhead projector, computer, etc.)
Schedule:	8:25 am - 3:30 pm weekdays, with some teacher occupancy before and after regular class hours

Baseline Energy Use and Related Characteristics

Baseline energy data was collected from both portables from September of 1997 until May 20th of 1998. This essentially gave an entire school year of data on the relative performance of the portables. A basic summary of the energy use data is shown in Figures 1 and 2.

Figure 1 shows that the measured total energy use in Portable 035 averaged 31.4 kWh per day – very similar to the average measured in previously cited studies. The majority of energy consumption

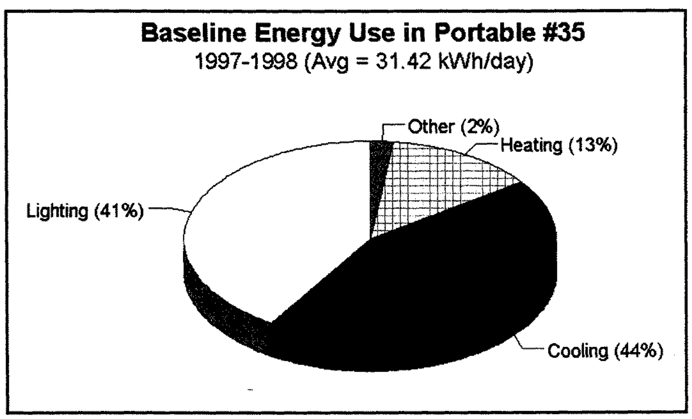

Figure 1. Energy End-Use in Portable 035 in Baseline Data Collection Period (October 1997 - May 1998)

in the portables was for space cooling and lighting. Some 17.6 kWh per day or 56% was used for space conditioning. Of this, 14.0 kWh/day (44%) was consumed by space cooling and 3.6 kWh (13%) was used for heating. Mean lighting energy use was 13.1 kWh/day or 41% of total consumption. Plug loads for projectors, computers and an outdoor night light averaged 0.7 kWh/day or just 2% of total use.

Figure 2 shows a similar presentation of energy end-use analysis for Portable 096. Total energy use, averaging 19.1 kWh/day, was considerably less than Portable 35. Space conditioning energy use was much lower at 8.7 kWh/day (45% of total), partly due to higher temperatures maintained inside and a poorly functioning cooling system. The cooling system was the subject of a number of complaints from the instructor. Space cooling consumption was 6.7 kWh/day (35%) and heating was 10%. Lighting energy use at 9.5 kWh/day (50% of total) was also lower due to the teacher's frequent habit of turning off the perimeter lighting when using an overhead projector. Plug loads averaged 0.9 kWh/day or 5% of consumption.

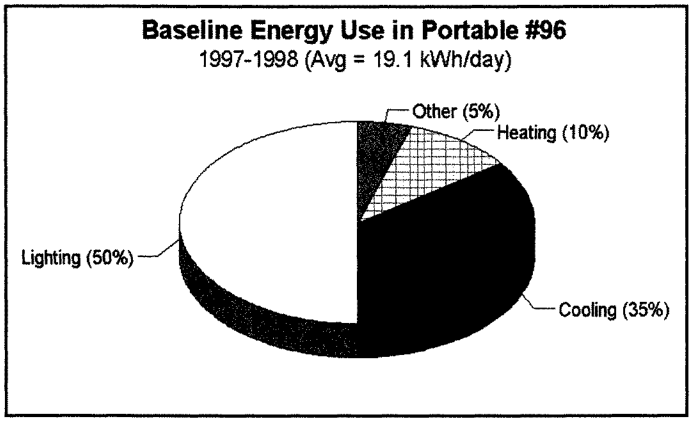

Figure 2. Energy End-Use in Portable 096 in Baseline Data Collection Period (October 1997 - May 1998

Heating, Ventilation and Air Conditioning (HVAC)

Inefficient lighting and roof solar absorptance increase sensible cooling loads. Generally, space cooling use makes up one-third of a school's energy budget. A poorly sized or poorly maintained cooling and heating system could lead to major problems with indoor air quality, bacterial contaminants, viruses, mold, spores, and pollen (Rasmussen et al. 1995).

In a recent survey (Callahan et al. 1997), 252 schools of 655 schools with utility data had an average of 7.9 cfm per student, but with a highly bi-modal distribution with many schools having a ventilation rate of 5 cfm/student while others had a ventilation rate of 15 cfm/student. The schools HVAC systems with a ventilation rate of 5 cfm/student were likely older, especially in older portables that were not brought up to the new ASHRAE 62-1989 standard. This new standard might contribute to indoor air quality (IAQ) problems since a higher outdoor air ventilation rate often produced greater moisture problems since control was difficult in such densely occupied spaces.

Evidence suggested ventilation provided in portable classrooms was considerably worse. Cooling systems in portable classrooms are predominantly wall-hung through-the-wall cooling systems, often observed to provide no outside air due to closed or inoperable dampers.

The average air conditioning electric demand for the two portables on weekdays during the school year was 20.3 kWh/day for Portable 035 and 11.2 kWh/day for Portable 96. The higher demand at Portable 035 was due to it's operation during non-occupied hours. These data suggests that automated controls may provide beneficial energy savings when used in portable classrooms.

Interior Humidity Levels

Average interior temperatures and relative humidity indexes were important as widely varying indoor temperatures could be a source for student and instructor complaints and high humidity levels were correlated with perceived indoor air quality problems (Arundel et al. 1996; Callahan et al. 1997).

Ventilation Effectiveness

Typical average weekday CO_2 concentration in the two classrooms was similar. The average CO_2 during occupied periods was 1412 parts per million (ppm) for Portable 035 and 1323 ppm for Portable 096. Carbon dioxide concentrations were a key parameter describing relative classroom ventilation rates. Research indicated that a 15 cfm/student ventilation rate was necessary to hold CO_2 rates below a recommended maximum of 1,000 ppm (Downing and Bayer 1993). CO_2 concentrations in both portables readily exceeded the 1000 ppm level by 11 AM and were sustained at over 1500 ppm from noon until 3 PM. We also observed that the CO_2 levels at Portable 035 dropped off more quickly than Portable 096 post occupancy due to door opening frequency.

Lighting Energy Use

Lighting represents a large portion of the total annual energy consumption for Florida schools. Lighting fixtures also produce a great deal of heat during their normal operation which increases the interior classroom sensible cooling load by an estimated average of 23% annually (Floyd et al. 1995). Portables predominantly used T12 lamp-magnetic ballast lighting systems in their classrooms because they were the most inexpensive. However, newer slim-line T8 lamp-electronic ballast systems perform best in both commercial and educational facilities (Sherwin & Parker 1996). These lamps combined with electronic ballasts consume less energy than T12 lamps with magnetic ballasts (58 W versus 90 W respectively in two-tube fixtures). They could also provide better desktop illumination than T12s with enhanced color rendering (McIlvaine et al. 1994).

The average peak demand was similar (1200 Watts or approximately 1.7 W/ft^2) but the consumption in Portable 096 (13.2 kWh/day) was lower than Portable 035 (17.5 kWh/day), particularly after regular school hours. This indicated a behavioral difference between the portables in the tendency for consistent shutdown of overhead lighting during unoccupied evening hours.

Roofing

The portable classrooms monitored had A-frame roofs with gray asphalt shingles over 3/4" plywood decking. This was a common type of roofing used in portable classrooms around Florida. The south facing segment of the roof was 36.25 x 11.75 ft. and the north facing segment was 36.25 x 15.75 ft. The north-facing section provided an overhang for a handicap accessible entranceway on this side of the building.

Roof replacement was performed since previous studies have shown that roof solar absorptance significantly impact interior temperatures and space cooling energy use even with ceiling insulation in place (Givoni 1976). Dark roofs with low reflectivities increase peak interior plenum temperatures by 20 - 25°F and thus increase the need for space cooling by 15% or more in Florida's hot climate.

Even light colored asphalt shingles absorb solar radiation readily. The reflectivity of light gray asphalt shingles was 22%, black asphalt shingles was 5%, but for a white metal roof was 67% (Anderson et al. 1991; Parker et al. 1993). In a series of twelve before/after experiments, (Parker et al. 1995) demonstrated a space cooling electricity reduction of approximately 19% in residential buildings changed to a reflective roof system. This suggested beneficial impacts for this project.

Results

Lighting Retrofit

The lighting system originally in place in the portables was a T-12 lamp-magnetic ballast lighting system with 24 two-tube F40CW fixtures (~90 W each). The connected lighting load was approximately 2.16 kW. The T8 lamp-electronic ballast lighting system was installed in Portable 035 on May 21, 1998 and in Portable 096 on November 23, 1998. The new two-tube T8 fixtures drew about 58 Watts with ballasts.

As shown in Figure 3, the energy savings from the retrofit of lighting system in Portable 035 was 35% or 4.6 kWh on two matched days. The energy savings due to the retrofit of Portable 096 was very similar (Max load = 2,152 W for old system versus 1,276 W for new system).

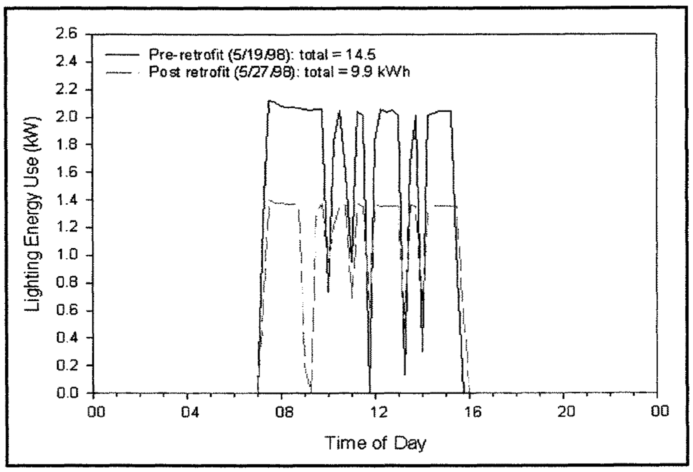

Figure 3. Graph of Lighting Energy Use Over the Course of Two Matched Days for Portable 035

A comparison of energy use for the portables on March 10, 1999, which was during the post retrofit period for both portables showed that portable 096 used 58.9% (6.4 kWh) less over the course of the day than Portable 035.[2]

Not only did the T8 lighting system cut energy use by 35 - 40%, it also provided better illumination. Light level readings were taken before and after lighting retrofit. Minimum classroom desk-top illumination levels are 53.8 decalux (50 foot candles; 1.076 decalux = 1 foot candle) and Illuminating Engineering Society (IES) recommended lighting levels are approximately 75.3 decalux for fine reading tasks (IES 1988). Pre-retrofit average desk-top illumination for the lighting in Portable 035 was 89.9 decalux while post retrofit average brightness was 93.3 decalux for a 4% increase in the average light level. The T8 system also provides excellent color rendering resulting in a better quality of illumination. Illumination can have physiological affects on student's ability to learn, (McKinley 1991). Classrooms with superior illumination and particularly those with better daylight may provide a better educational environment (Hathaway et al. 1992).

[2] Generally, the instructor in Portable 096 operates fewer banks of lights during the day based on personal preference and extensive use of an overhead projector.

Heating, Ventilation and Air Conditioning

Significant improvements in energy use and ventilation were obtained by replacing the space cooling and heating system. The original *Crispaire AVP36HPA* 3 ton wall-mount unit was changed out to a *Bard WH301-A* 2½ ton unit based on the estimated reduced sensible cooling load from lighting and the roof/ceiling. The system was replaced in Portable 035 on June 17, 1998 and in Portable 096 on August 31, 1999. The actual field performance of air conditioning system at Portable 035 was audited before and after change out of the unit. This was accomplished by measuring the power use and latent and sensible cooling of the equipment pre and post retrofit. A return air temperature of 76°F was maintained in both tests.

At an outdoor temperature of 80°F, the existing *Crispaire* three ton unit drew just over 3,950 Watts, producing a 19.3 degree temperature drop across the cooling coil and a sensible cooling rate of 18,933 Btu/hr. Return and supply air flow were measured with a Shortridge flow hood, indicating 981 cfm – considerably lower than the 1200 cfm which should be indicated for a three ton machine. Measured latent heat removal was 7,048 Btu/hr for a total capacity of 25,980 with an EER of 7.6 Btu/W with a sensible heat ratio (SHR) of 0.73.

Under similar outdoor conditions, the new 2½ ton *Bard* unit with the ERV drew 3,730 Watts producing a drop across the evaporator coil of 16.7 degrees with a coil air flow of 1,099 cfm. This represented a sensible cooling capacity of 18,353 Btu/hr with a latent heat removal measured at 7,909 Btu/hr for a total capacity of 26,260 Btu/hr. The estimated SHR was 0.70 – showing the superior latent heat removal of the new unit. The indicated EER was 8.7 Btu/W with the ERV in operation. Thus, the replacement unit showed a similar cooling capacity to the larger original HVAC with a 6% drop in electrical demand even with greater outdoor air being introduced.

For Portable 035 the typical savings were 45% on similar occupied school days. However, as shown in Figure 4, much of the savings in Portable 035 are due to the automated control of the HVAC unit.

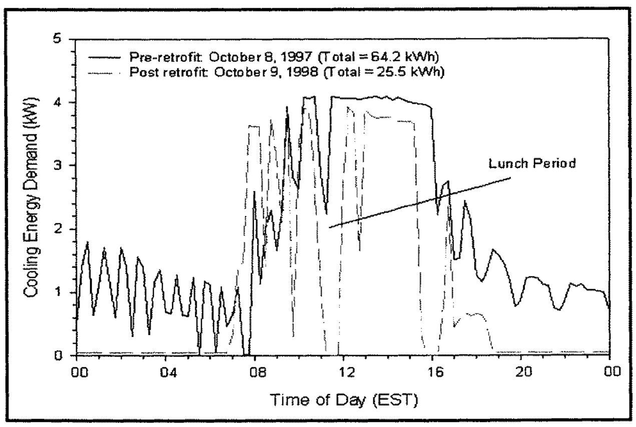

Figure 4. HVAC Power Use for Portable 035

Our study also found that physical HVAC installation quality in portable classrooms may be poor. Prior to the retrofit, the HVAC's poor performance could partly be attributed to poor installations with some of the cool air being distributed to the exterior of the classroom, however after the retrofit, this supply leakage problem was solved and all the cool air was effectively delivered to the interior. This problem underscores the need to perform quality control on HVAC installations on portable classroom space conditioning systems.

Occupancy Controls

The occupancy sensors functioned to turn the HVAC and lighting on when the portable was in use and consistently turned off during unoccupied periods. The setup used two occupancy sensors (DT-100L and DT-200) manufactured by *Wattstopper Inc*. The controls used passive infrared and ultrasonic sensing to control the lights and HVAC operation. One control was located at the front of the classroom and another at the rear to ensure complete coverage of the space.

The majority of the energy savings came during the unoccupied periods when the HVAC was off after the retrofit, while during the pre-retrofit period the HVAC was cycling on and off 24 hours a day. However, during peak time the new unit used about 5% less energy (~180 W) than the old unit. Also, much of the overall reduction was likely due to the roofing change and lower internal heat from the lighting, although the individual impact was difficult to separate in this analysis.

Figure 5 depicts the air conditioner use on the two portable classrooms on a teacher work day where the classroom was only occupied for a few hours. Note the difference in energy use during unoccupied periods before 7 a.m. and after noon. The occupancy sensor control on the system in Portable 035 turned off the HVAC when the classroom was unoccupied while the unit on Portable 096 cycles on and off during these periods because there was no automated control. This illustrates the importance of automated controls in energy reductions because during these periods Portable 035 used 7% less energy than 096. During the occupied periods, the energy use of the portables was similar.

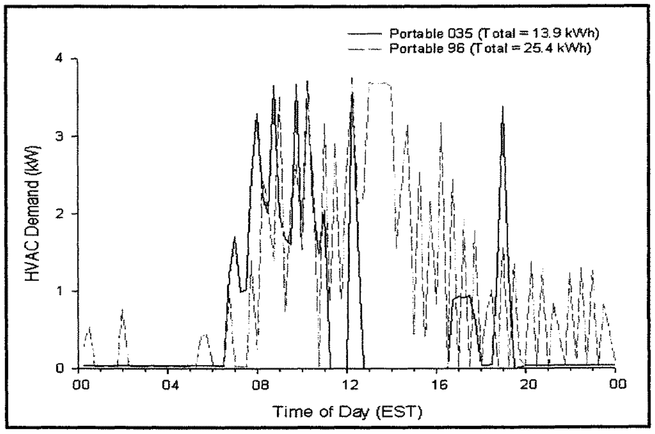

Figure 5. HVAC Energy Use Comparison for Both Portables on August 14, 1999

Ventilation

Interior carbon dioxide levels in densely occupied classrooms were a good indicator of potential for pollutant concentrations as well as ventilation quality. Previous experience has shown both elevated CO_2 levels >2,500 ppm in portable classrooms as well as indoor air quality complaints (IEQ Stratagies 1997; Shirey et al. 1997).

The superior CO_2 control of the replacement HVAC was provided by the enthalpy recovery wheel which adds a large volume of outside air which was first cooled and dried by exhaust air prior to being introduced into the classroom. A comparison test of the air conditioning units was performed by measuring the rate of decay of a tracer gas (sulfur hexafluoride - SF_6) by a sensitive gas sampling unit (Figure 6.)

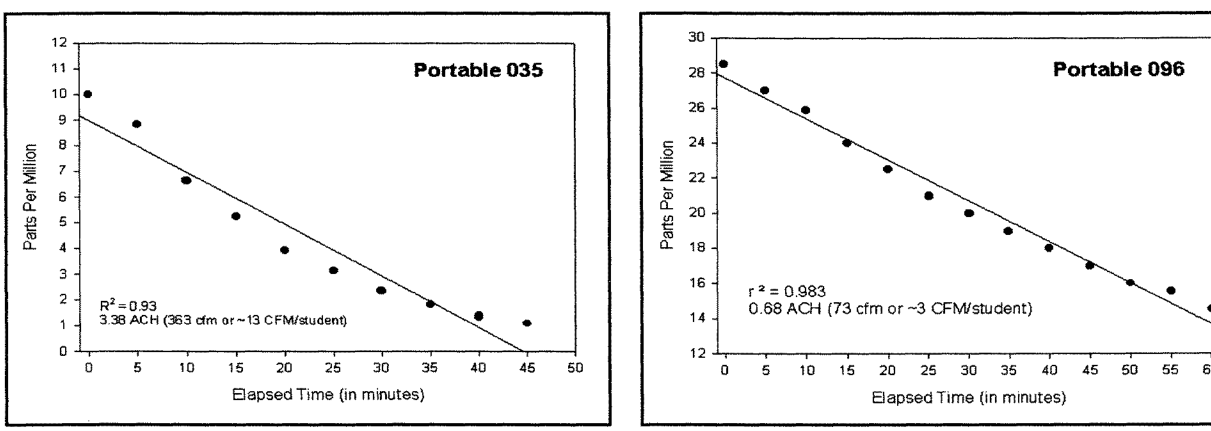

Figure 6. Measured Interior Carbon Dioxide Concentration in Portable 096 Before and After Greater Outdoor Ventilation Air was Provided by ERV

The pre-retrofit AC unit provided a ventilation rate of 0.68 air changes per hour (ACH) while the new unit with the ERV had a ventilation rate of 3.38 ACH, an increase in effective ventilation of almost 500%! This translated to approximately 2.6 cfm/student for the old unit and 13.0 for the replacement system which much more nearly complies with the ASHRAE 62-1989 standard.

The impact of the superior ventilation was demonstrated in Figure 7. The CO_2 concentrations (in parts per million) in Portable 096 decreased by 43% after the introduction of the ERV.

Despite this large increase in volume of ventilation air added to Portable 035, the interior relative humidity increased by only 7%. Typically interior relative humidity would be raised by 10-15% by such an increase in outdoor air. However, the enhanced moisture control through the use of the enthalpy recovery system prevents this.

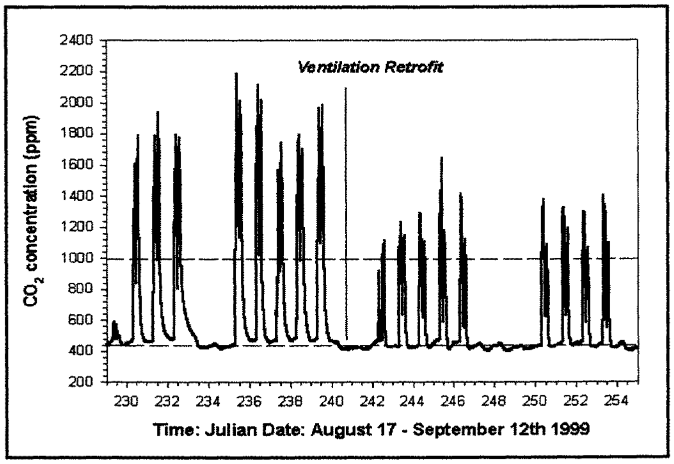

Figure 7. Measured Indoor Ventilation Rate in Two Portable Classrooms after the Ventilation System was Installed in Portable 035

Roof Retrofit

The roofs originally had gray asphalt shingles that were torn off and replaced with 5V-crimp reflective white metal roofing. Roof replacement for Portable 035 was completed in June 1998 and for Portable 096 the end of September 1999.

As shown in the plots below (Figure 8), the peak plenum temperatures above the classroom associated with the gray asphalt shingle roof were quite high. This was due to high solar irradiance combined with high solar absorptance of the shingles. The roof surface temperatures reached over 150°F. Roof plenum temperatures can have a substantial impact on both ceiling heat transfer and student comfort. Note how peak plenum temperatures were reached just after noon.

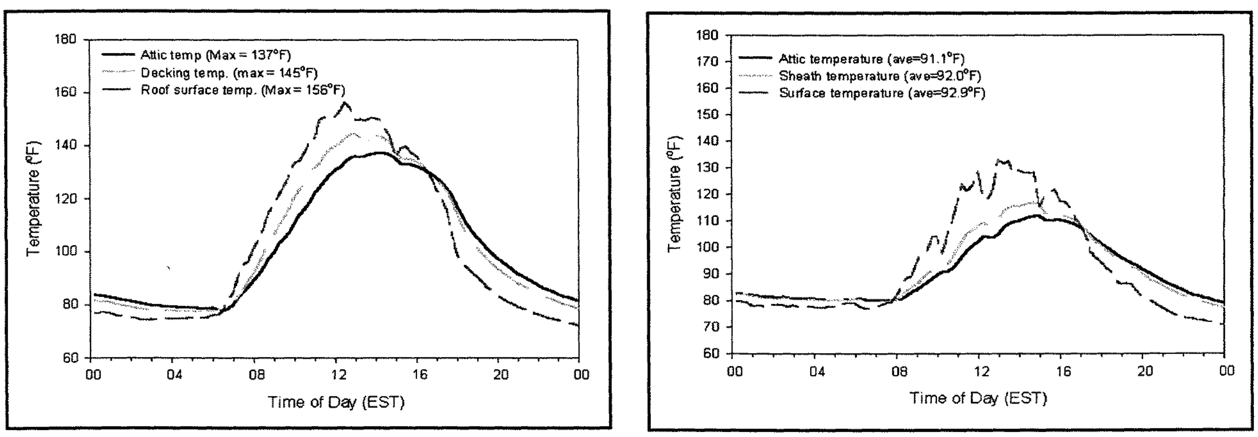

Figure 8. Attic and Roof System Temperatures Pre and Post Retrofit of Reflective Roof System October 97 - May 98 and October 98 - May 99

The roof system temperatures evidenced a dramatic decrease after roof replacement. The reduction in peak plenum temperatures with the new roof system were over 25°F reducing the need for mechanical cooling and improving thermal comfort in the classroom below.

The impact of the reflective roof was assessed by examining how the cooling energy load varied during the week before and after the roof system retrofit in Portable 096. The roof replacement was performed in late September, 1999. No other changes were made to the portable during this time and temperature conditions were consistent pre and post to allow a reasonable comparison.

Figure 9 shows how the air conditioning load profile varied in the two weeks under similar weather conditions. Loads from midnight until 7 a.m. were very similar. Savings begin at approximately 9 a.m., greatly increasing in the period after lunch when average reductions of over 1400 Watts were observed in cooling peak demand. Cooling demand was also reduced during the early evening hours due to the lower plenum temperatures above the classroom. Based on the analysis, overall cooling energy savings were over 33%.

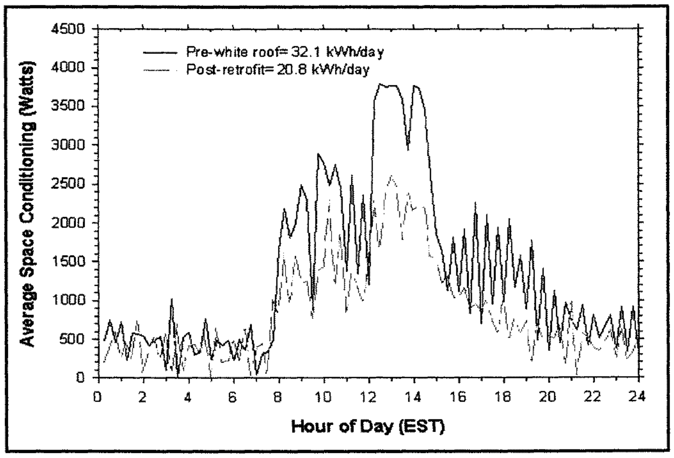

Figure 9. Average Air Conditioning Loads in Portable 096 in the Week Pre and Post Reflective Roof Retrofit at the End of September

Seasonal Variation In Savings

Comparison's for several months of the year were made for energy and lighting use for Portable 035 since post retrofit was available over an extended period. Figures 10 and 11 show the comparable results for each month for HVAC and lighting, respectively. Generally lighting savings were greatest in winter months and HVAC reductions in cooling dominated months.

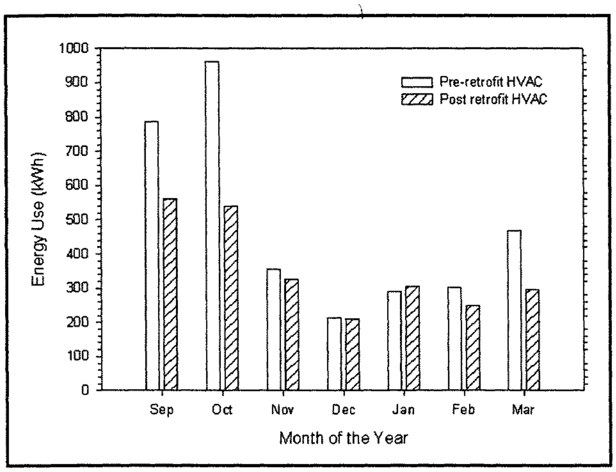

Figure 10. Monthly Variation in Space Conditioning Energy Savings

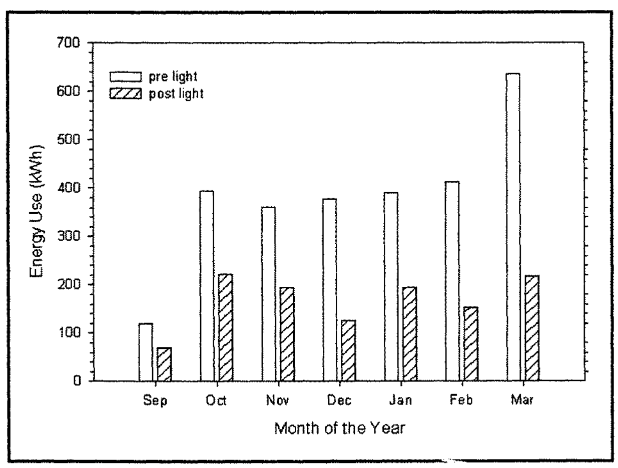

Figure 11. Monthly Variation in Lighting Energy Savings

Total savings were highest in absolute terms in February at 794 kWh (44%), with lighting making up the vast majority (659 kWh; 63%). The HVAC savings were highest in absolute terms in October when schools often have their highest utility bills. Savings of 405 kWh (44%) were experienced in this month.

Lowest overall savings were experienced in December at 140 kWh (32%) with only 1 kWh (2%) savings for HVAC. The minimal savings of the HVAC were primarily due to the ability to use natural ventilation for the month of December.

The general trend for HVAC savings also followed the trend of HVAC use. Savings were high in September and October, falling dramatically in the period of November through February. These months were generally cooler and the need for cooling energy use was decreased and natural ventilation could also be used. Energy use and savings then began to increase again beginning in March.

The energy savings for the 2½ ton HVAC system varied more than lighting by month due to the variation in cooling energy demand and the changing impact of the reflective roofing system.

Annual Performance and Economics

Below in Table 2 we summarized the monitoring results for each technology monitored within the project. We also described the incremental expense of each measure based on installed costs collected within the project. Finally, we estimated the simple payback for each application, both for new portable classrooms and for existing ones.

Table 2. Energy Savings of Each Efficiency Measure Projected Over a Year for a Single Portable Classroom

Efficiency Measure Description	Annual Energy Savings kWh	Cost New	Simple Payback Yrs.	Cost Exist	Simple Payback Yrs.
T8 Lighting System	1,679	$50	0.4	$400	3.0
Occupancy Control*					
Lighting	876	$300	4.3	$400	5.7
HVAC System	1,643	$300	2.3	$400	3.0
Both	2,519	$300	1.5	$400	2.0
AC/ Ventilation Package					
Hi-efficiency Heat Pump w/ ERV ventilator	NA	$1,035	NA	$3,045	NA
White metal roof	NA	$ 700	NA	$3,100	NA
Total HVAC Package	910	$1,735	24.0	$6,145	NA
TOTAL PACKAGE	5,110	$2,085	5.0	$6,945	NA

All costs are incremental costs over lowest cost competing system.

* All cost data for the occupancy control includes $100 for a service call to fine tune time delay and sensitivity for the application in a specific classroom.

The costs were much lower for most items if incorporated at the time of classroom manufacture. A good example was lighting. The base system consisted of 24 two-tube fixtures with a magnetic ballast in each. The retrofit system consisted of the same number of T8 tubes (48) which cost approximately $1 more per unit than the T12 lamps. However, the electronic ballasts in the retrofit system cost twice as much per ballast ($20 each), but were tandem wired so that only one ballast was used for every two fixtures. This reduced the cost in new applications to the incremental costs of the T8 lamps themselves. For retrofit, we assumed that half a day would be required to make the necessary wiring and lamp changes – effort that was not expended when the system was configured in this fashion from the beginning. Thus for new portables the incremental cost for better lighting was only for the lamps themselves.

Note, that the lighting and automated controls were extremely cost effective, both in new as well as existing applications. This indicated that substantial cost effective energy savings were potentially available in Florida's large stock of existing portable classrooms. These two measures alone showed the potential to cut energy use by over 30% (11.5 kWh/day) with combined pay backs of less than three years.

The individual performance of the reflective roofing, more efficient heat pump and enthalpy recovery ventilation (ERV) system cannot be broken apart within the monitoring results. However, we know that the change in demand of the two air conditioning systems was only about 6% when operating and that the ERV, even though recovering both sensible and latent heat from the added outdoor air, was still adding moist, warm ventilation air which would increase cooling loads. Thus, most of the reduction in space cooling was coming from the white reflective roof and the lower level of sensible heat gains from the more efficient lighting. While the HVAC/roofing measures were not so cost effective as the lighting and controls retrofits, the combination was able to provide greater ventilation levels and improved indoor air quality while reducing space conditioning energy costs.

Another advantage of the proposed reflective roofing system was the longevity of the metal roofing. Based on data from roofing contractors, metal roofs of the type used in the project retrofit have a 30 year life expectancy compared with only 15 years for fiberglass shingle roofs (Chiovare 1997). This makes for a lower cost roofing system over the long run, based on re-roofing costs.

The overall package of measures evaluated have an added costs of about $2,100 when incorporated into new portable classroom manufacture. This investment produces energy savings which pays for the added cost within 5 years (equivalent to a 20% rate of return on investment). More importantly, the proposed technologies may improve the learning environment. The effective indoor ventilation rate was increased to comply with ASHRAE Standard 62-1989, while desk-top illuminance levels and color rendering were improved by the more efficient lighting.

Conclusions

Our project conclusively demonstrated that straightforward alterations in portable classroom equipment and roofing could produce very large reductions in total facility energy consumption. A typical Florida portable classroom used about 30 kWh/day as verified by our monitoring. Energy end use was evenly split between lighting and space air conditioning which accounted for more than 95% of total consumption.

Efficiency measures were implemented and were shown to reduce energy use and have the large side benefit of potentially improving classroom indoor air quality and illuminance levels. The overall measured savings of the energy retrofits in the portable classrooms were summarized in three plots.

Figure 12 at the top of the next page shows how the T8 lighting system and occupancy control reduced lighting energy use by an average of 53% (7 kWh/day) from one year to the next. The automated controls were found to be responsible for about 2.4 kWh (19%) of the savings. Total annual savings were estimated at 2,550 kWh, worth about $200 at current electricity prices. Lighting energy savings were fairly consistent year round.

Figure 13 shows how the improved heat pump, white roof and reduced internal heat from the more efficient lighting was able to cut daytime space conditioning electrical demand while providing five times the ventilation air (13 cfm/student) found in the base situation. This cut internal CO_2 levels and with potentially beneficial impact on indoor air quality. Savings in space conditioning during the occupied period were 2.4 kWh/day or about a 14% reduction in daily energy use. The value of the occupancy controls was demonstrated in the large level of savings produced during unoccupied hours. This represented 4.5 kWh/day or a reduction in space conditioning of about 25%. Total reduction in space conditioning energy needs was 39% or about 6.9 kWh/day. Annually, the 2520 kWh savings was worth about $200 in reduced operating costs.

Figure 14 shows the total impact of all the retrofits on overall energy consumption in Portable 035 from the baseline year to the 1998-1999 when all retrofits were in place. Measured annual energy reduction for the overall project averaged 12.6 kWh/day for a reduction of 41%. Although miscellaneous consumption increased slightly in the year post retrofit, the total annual energy savings have a value of about $370 a year in reduced operating expenses.

Our results demonstrated that it was very feasible to alter new portable classrooms in Florida so that they used 40% less electricity than standard practice. The improvements were shown to be cost effective, both for retrofit of existing portables classrooms as well as for re-design of new facilities. Further, our findings showed important side benefits. Better ventilation and potential indoor air quality resulted from the HVAC improvements. Also, the more efficient lighting provided

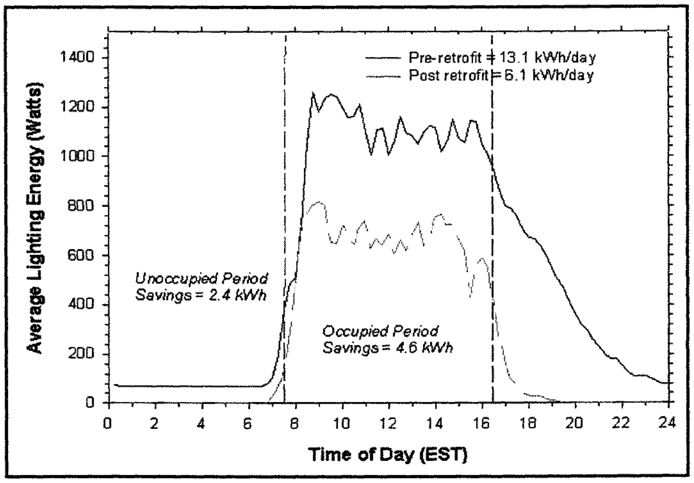

Figure 12. Time of Day Lighting Energy Demand in the Year Before (solid) and After (dashed) Retrofit

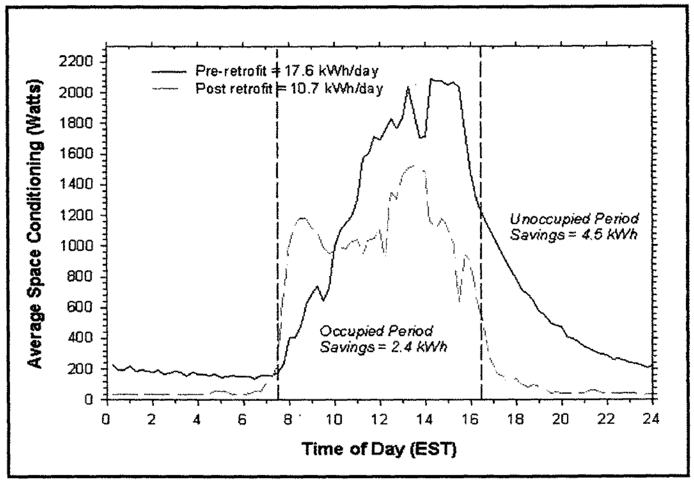

Figure 13. Average Space Conditioning Energy Demand Before (solid) and After (dashed) Retrofit, Savings Come from a Package of Measures

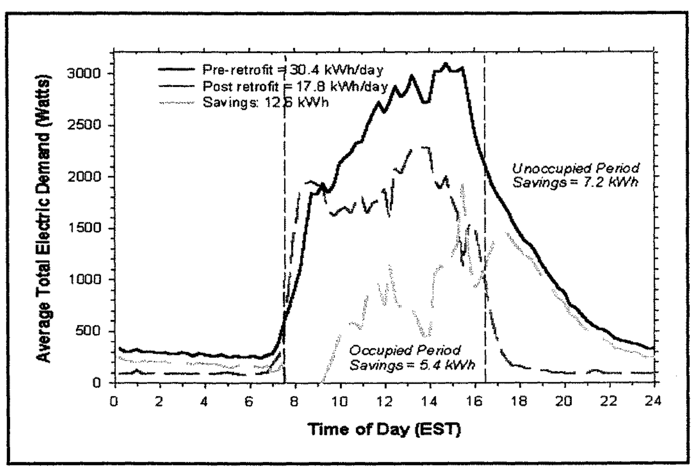

Figure 14. Total Daily Energy Demand in the Year Before (top, solid) and After (middle, short dashed), Time of Day Energy Savings (bottom)

superior desk top illumination. Together, the measures not only saved on energy related operating cost, but could also significantly enhance the learning environment.

References

Anderson, R. W., D. W Yarbrough, R. S. Graves, and R. L. Wendt, 1991. "Preliminary assessment of radiation control coatings for buildings." *Insulation Materials: Testing and Applications, Second volume*. ASTM STP 1116, R. S. Graves and D. C. Wysocki, eds. Philadelphia: American Society for Testing and Materials.

Arundel, A., Sterling, E.M., Biggin, J.H. and Sterling, T.D., 1986. "Indirect Health Effects of Relative Humidity in Indoor Environments." *Environmental Health Perspectives* 65: 351-361.

Brown, G.Z., D. Bjornson, J. Briscoe,S. Fremouw, P. Kumar, P. Larocque, D. Northcutt,Z. Wang, D. Rasmussen, K. Rasmussen, J. Stanard, 1997. *Design and Evaluation of Energy-Efficient Modular Classroom Structures, Phase II.* University of Oregon, Eugene, OR and Modern Building Systems, Inc., Aumsville, OR.

Callahan, M. P., D. S. Parker, W. L. Dutton, and J. E. R. McIlvaine, 1997. *Energy Efficiency for Florida Educational Facilities: The 1996 Energy Survey of Florida Schools*. FSEC-CR-951-97, Florida Solar Energy Center Cocoa, FL.

Tony Chiovare 1997. "Metal Roofing." *Roofer Magazine*: 48-49.

Downing, C. C. and C. W. Bayer, 1993. "Classroom Indoor Air Quality vs. Ventilation Rate," *ASHRAE Transactions* 99 (2). American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

Florida Department of Education, 1999. *State Requirements for Educational Facilities*. Office of Educational Facilities, Tallahassee, FL.

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

The Florida Center of Community Design and Research, 1993. *The use of relocatable classrooms in the public school districts of Florida. (A research report for the Florida Department of Education, Office of Educational Facilities)*. University of South Florida Tampa.

Givoni, B., 1976. *Man, Climate and Architecture*. London: Applied Science Publishers Ltd.

Hathaway, W.E., Hargreaves, J.A., Thompson, G.W. and Novitsky, D., 1992. *A Study into the Effects of Light on Children of Elementary School Age*. Edmonton Department of Education, Alberta, Canada.

IES, 1998. *Educational Facilities Lighting*. RP-3-88, Illuminating Engineering Society, NY.

IEQ Strategies, 1997. *Investigators Look to Improve Ventilation in Portable Classrooms*. Cutter Information Corporation.

McKinley, J., 1991. "New Standards for Classroom Lighting." *American School and University*, May, 1991.

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

Rasmussen, E., K. Rasmussen, J. Stanard, S. Bernhard, G. Z. Brown, J. Briscoe, J. Kline, P. Kumar, and Z. Wang, 1995. *Design and Evaluation of Energy Efficient Modular Classroom Structures*. Modern Building Systems, Inc. Aumsville, Oregon and University of Oregon, Eugene, Oregon.

Shedden, M. 1997. "Portable classrooms may be here to stay." *Florida Today*. March 3.

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

Shirey, III, D.B., R.A. Raustad, and M. Brassard, 1997. *Evaluation of an Enthalpy Recovery Ventilator Installed in a Portable Classroom*, FSEC-CR-972-97, Florida Solar Energy Center, Cocoa, FL.

Stoddard, B.C., 1997, "Public Schools Not Making the Grade." *The Construction Specifier*, September: 29-36.