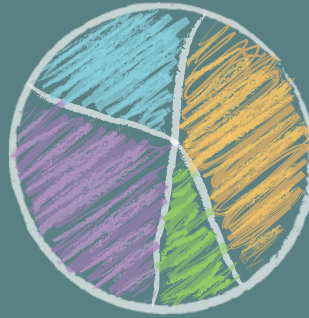


Typical yearly energy use in FL portable classroom

44% Cooling
41% Lighting
13% Heating
2% Other



Improving Energy Efficiency

in Relocatable Classrooms

Chuck Withers and Ian LaHiff



Southern Energy-Efficiency Center
Building Energy Solutions for the South

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Top Priorities to Improve Existing Portable Classroom Energy Efficiency:

The most cost-effective measures that should be considered before replacement is needed are noted below. Due to cost, many things that can save a lot of energy may not be practical unless replacement is warranted. See the section titled, *Top Priorities for Reducing Energy Use in New Portables* for many more suggestions towards the end of this document.

Cooling and Heating

Schedule- Use timer schedule or occupancy sensor control to turn off units when unoccupied.

Ventilation

Efficiency - Use Enthalpy Recovery Ventilator (ERV) to help transfer cool dry energy of exfiltrated air to incoming ventilation air.

Control - Use carbon dioxide (CO₂) controls technology to minimize over-ventilation by modulating outdoor air damper. Annual periodic calibration of sensors is also important.

Envelope

Air tightness - In general commercial-type buildings should be around 4-6 ACH50. Since portable classrooms have a high ventilation density, they can still perform well around 10 ACH50. The average portable air tightness is a very leaky 23 ACH50! Much of this is due to ceiling space and floor space leakage. Airtighten penetration points such as the wall-mount AC unit, electrical and plumbing. If there is a vented attic space, the ceiling should not be acoustical tile. Also realize that the leakier the building is, the harder it is to control moisture during unoccupied periods.

Windows - Consider adding awnings to shade windows and doors.

Electric Lighting

Type - Revamp lighting as follows: Eight fixtures having three T8 32W lamps each, three fixtures having one T8 32W lamp each, total of twenty ballasts and three 15 W CFLs keep interior power density to 0.9 W/ft² for the average size portable. The outdoor entry is lit by one 15W CFL controlled by a photo sensor.

Control - Use occupancy sensor or time of day to turn off lights after hours.

Daylighting

Considering that portables have very little overhang over windows, sidelighting through windows in walls is not a great option. Glare issues and local comfort must be controlled with interior blinds if exterior awnings are not present. With the right circumstances, photo sensor control could be added with dimmable ballasts that would allow energy conservation through daylighting when ample ambient light is present.



Top Factors Impacting Energy Performance of Portable Classrooms

Introduction

Portables or “relocatable” classrooms have been used for years to accommodate growing school populations, especially in the southeastern United States. There are large numbers of these units in service and many of them are old needing significant improvement or replacement. An estimated 36 % of the nation’s schools use portable classrooms (Lewis, Et al., 2000). Estimates based on information from the current 5 year plans of Florida school districts puts approximately 20,000 portable classrooms still in service with plans to replace about 8,500 units (<http://www.fldoe.org/edfacil/workplanlibrary.asp>).

Energy costs for these structures exceed \$20 million a year - or about 11 % of all energy-related expenditures for educational facilities. The side bar to the left is one example of how big an impact “temporary” classrooms can have on the energy footprint of a school.

Energy Saving Opportunities for Existing Portables

As early as 1997 The Florida Solar Energy Center (FSEC) began studies to document energy reduction from retrofits in portable classrooms. One particular study involved retrofits in two existing portable classrooms in Central Florida that achieved measured energy use reduction of 40 % (Callahan et. al., 1999). *FSEC-CR1133-99*

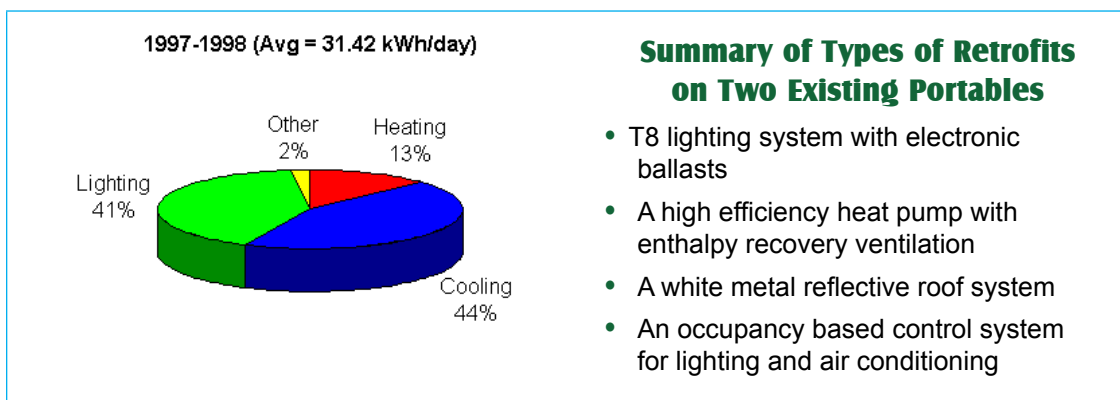


Figure 1: Typical Florida portable classroom yearly energy use distribution

Figure 1 illustrates that during a school year-long period of baseline monitoring, a typical Florida portable classroom used an average of 31.4 kWh/day. Space conditioning accounted for 57 % of energy use and lighting 41 %. These portables had inefficient T12 lighting systems with a power density of 3.0 W/ft². The fact that lights tended to be left on after hours along with a large light power density results in a building with a much greater percentage of building energy used by lighting than newer portables, or those where lights are turned off more consistently. This combination of factors makes lighting retrofits very cost-effective.

It was learned that the baseline ventilation rates in these two classrooms were only about 2.6 cfm per student with daily carbon dioxide (CO₂) concentration peaking near 2,500 ppm. This finding required increasing the ventilation rate substantially, which in turn required more energy to condition the additional ventilation air, thereby diminishing measured space conditioning savings for these units.

Consider This:

Odyssey Charter School in Brevard County, FL was built to be energy efficient and is a 2007 Energy Star Rated School. Due to student growth, portable classrooms were brought on to the campus.

Even though the site-built school had 3½ times the floor area and 5 times the volume as all the portables, the portables still used 4 times more energy than the site-built building.

This shows it is possible for portable classrooms to represent the largest fraction of energy use on some school grounds even though the total floor area is substantially less than that in site-built buildings.

Energy was monitored before and after retrofits. Some retrofits completed one at a time and others were done together as a group.

- Lighting upgrade from T12 lamp with magnetic ballasts to T8 lamp with electronic ballasts energy use by 1679 kWh/yr) and had a simple payback of less than three years using a rate of \$0.10/kWh.
- Installing occupancy control on both the HVAC system and lighting system saves energy by turning equipment off when it is not needed. The savings from lighting control was 876 kWh/yr and savings from HVAC control was 1,643 kWh/yr. Combining HVAC system occupancy control with a lighting efficiency upgrade saved 2,519 kWh/yr and is estimated to cost \$360 today which is a simple payback of about 1.4 years. The savings from occupancy controls will depend upon how much lights are typically left on when they are not needed.
- HVAC / Roofing Grey asphalt shingle replaced with reflective white metal roof to reduce cooling load. The wall-mount heat pump was replaced with higher efficiency heat pump and enthalpy recovery ventilation. Recall that ventilation had to be increased by five times and in spite of this large AC load increase, these retrofits saved 910 kWh/yr. This type of retrofit is expensive and is more reasonable when these items need replaced. The reported increased cost of efficient measures compared to existing measures was \$1,735 with about \$700 of this for the metal roof.

Energy Saving Opportunities for New Portables

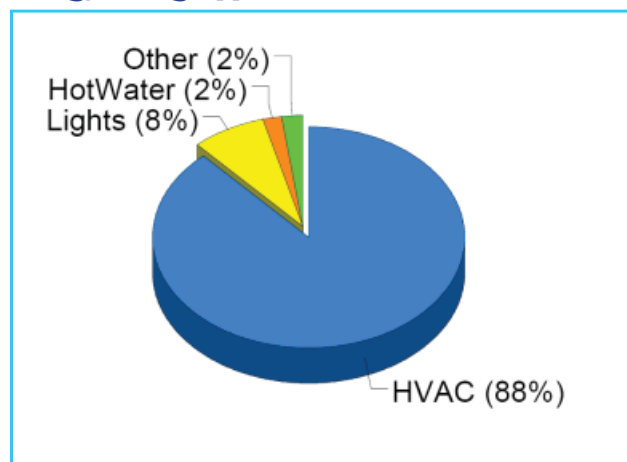


Figure 2: Measured electricity use in North Carolina control portable.

Portable Classrooms Have High Energy Density

The standard new relocatable classroom in the southern U.S. uses about 53 kWh/day. The energy density is about 6.3 kBtu/ft² per month. This use is 62% more than the average site-built school in DOE CBEC database and about 110% more than an Energy Star rated school which uses about 3.0 kBtu/ft² per month.

A 2002 study found as much as an 88% reduction in energy consumption of improved design of new portables compared to standard portable design. The climate zones studied were cold (New York), mixed (North Carolina), and hot and humid (Florida). As seen in Figure 2, it was found that a large majority of annual energy requirements were for heating and cooling, with lighting being less than 10% of the total. The distribution of energy used in portables is quite different than that in site-built schools. The top three energy uses in Florida educational facilities are cooling (33%), interior lighting (32%) and ventilation (10%).

The monitored energy savings of these improved efficiency portables, which were called "Portable Enhanced Relocatable Classrooms" (PERCs), were 46% in North Carolina and 81% in Florida. While the savings vary, they demonstrate huge potential for reducing energy consumption.

The efficiency measures varied by climate zone to provide the most effective improvements for each climate. Some of the most notable differences between the Florida and North Carolina PERC studies are that the Florida PERC had a more air tight ceiling space with insulation at the roof deck, a reflective white roof

and tubular style skylights. This design also places the duct system within the primary air and thermal barriers of the building which reduces duct losses. A tight ceiling space is especially important when acoustic tile ceilings are used. More details on each classroom can be found in the report FSEC-PF-382-04 online at www.floridaenergycenter.org.

Top Priorities for Reducing Energy Use in New Portables

Cooling and Heating

Use heat pump wall mount units with 12 SEER and 7.5 HSPF. Duct and air handler leakage to outside tested at 25 Pa of pressure should be less than 5% of the maximum rated airflow.

Variable Capacity - Use units capable of operating at least at two-different capacities (two-stage compressor). Downsize auxiliary strip heat on heat pumps to prevent excessive morning use of inefficient resistance heating. This also helps to avoid thermostat “overshoot” during morning temperature recovery.

Schedule - Use time of day/week schedule control to turn off units overnight and weekends. Noise Reduction-Use vibration reduction isolation between unit and wall and a ducted supply.

Thermostat - Try implementing a cooling set point goal of 74°F-78°F (This will be easier in improved newer portables with well-insulated and sealed envelopes.)

Ventilation

Amount - Follow ASHRAE Standard 62.1- 2007 which calls for 10 cfm/person AND 0.12 cfm/ square foot of classroom space. This is about 15 cfm per person for the average classroom with about 25 occupants.

Efficiency - Use Energy Recovery Ventilator (ERV) to help transfer cool dry energy of exfiltrated air to incoming ventilation air.

Control - Use carbon dioxide (CO₂) controls to minimize over-ventilation by modulating outdoor air damper. The damper can be set to a minimum that will meet the 0.12 cfm/ft² during school hours with little or no occupancy and then go to maximum when CO₂ levels reach about 1,000 parts per million (ppm). The damper will go to the closed position during after hours while the unit is off.

Envelope

Roof - Use white reflective membrane roof instead of shingles since composite shingles have much lower reflectivity.

Insulation - R-30 insulation in ceiling, R11 insulated walls and R19 insulation under floor deck.

Airtightness - In general commercial-type buildings should be around 4-6 ACH50. Since portable classrooms have a high ventilation density, they can be around 10 ACH50. The average portable airtightness is a very leaky 23 ACH50! Much of this is due to ceiling space and floor space leakage. Ceiling space should be reasonably airtight with no intentional venting to outdoors. Expanding insulating foam was used in the Florida PERC to provide air tightness and insulate the ceiling cavity.

Windows - $U = 0.28$, $SHGC = 0.39$ and $VLT = 0.71$. The U-value is the inverse measure of thermal resistance so U-value of 0.28 has R-value of about 3.5. The solar heat gain coefficient (SHGC) is a measure of how well the window restricts solar radiation. The lower the number, the more radiation is restricted. Visible light transmittance (VLT) is how much of the visible portion of solar radiation is transferred. The higher the number, the more light that comes through. Also consider using roof overhang or awnings to shade windows and doors from direct sunlight.

Concrete modular classrooms have existed for awhile in Florida and have merits such as: They are relocatable; High mass roof, floor and walls slows heat transfer minimizing peak load; They can be stacked on top of one another minimizing ground footprint and heat load on ground unit. Some manufacturer models even meet Florida hurricane building code.



*Figure 5 Portable classroom being lifted into place.
Photo courtesy of Royal Concrete Concepts, Inc.*

Electric Lighting

Type - For a typical twenty five student classroom consider eight fixtures having three T8 32W lamps, three fixtures having one T8 32 W lamp each, total of 20 ballasts and three 15 W CFL keep interior power density to 0.9 W/ft². The outdoor entry is lit by one 15W CFL controlled by a photo sensor.

Control - Use occupancy sensor or time of day to turn off lights after hours. Photo sensor control used with dimmable ballasts allows energy conservation through daylighting.

Daylighting - Considering that portables are located in close proximity to each other, side-lighting through windows in walls may not be the best option. Minimizing windows allows more wall space for instructional use. Clerestory window design works well, but orientation is important and especially difficult to control in relocatables. Height during transportation is also an issue for clerestory design. Skylighting has been demonstrated to work well. Tubular-style skylights with a controllable light damper allow interior illumination control during use of different types of instructional media. Six 21 inch diameter skylight tubes work well in a 900 ft² portable.

In a study completed in Fresno Unified School District there was an estimated 1.1kWh/ft² potential savings (annually) from adding photo sensor controls to rooms that already have side-lighting. In new construction the estimate is closer to 0.88 kWh/ft² for using photo sensor controls in top-lighting or skylighting. The PERC study measured lighting energy reductions of about 2.9 kWh/day (69%) while more than doubling the average desktop illumination from 9AM to 3 PM.

Improved Academic Performance Levels?

Daylighting not only allows for energy savings due to the electric lighting being turned off more often, but may also enhance student performance. The most recent studies by the Heschong Mahone Group of daylighting and student performances have shown different results. A study in Capistrano Unified School District showed 21 % improvement in learning rates; however a following study completed in Fresno Unified School District did not show any meaningful improvement related to daylighting. What was learned in this last study was that the quality of daylighting is much more important than the quantity. Teachers must have adequate control of daylight through shades especially with the use of projected media that is becoming more common than using chalk or white boards.

To optimize the skylight benefits, photo sensors should be implemented to control artificial lighting. Photo sensors work by generating a control signal proportional to daylight and then dim the electric light accordingly. To utilize daylighting, the installed electric lighting in the classroom must include a dimmable ballast (electronic are better than older magnetic). Other available technologies used to control lighting include motion sensors. They work on an infra-red (IR) signal, and generally are used in small areas with line of sight.



Figure 3. Portable with tubular skylights and electric lights off.



Figure 4. Portable with tubular skylights and electric lights on.

Conclusions

In hot, cooling-dominated climates such as Florida and southern Georgia, measures which reduce lighting and its internal heat generation show greatest promise to reduce building energy needs. Daylighting is effective in this region as it reduces lighting energy and can substantially reduce space cooling if low SHGC products are used. In this region, insulation is important, but light reflective exterior surfaces and solar control glazing should be a bigger priority. Exterior and interior shading of windows is very important. Increasing floor insulation beyond R-19 is not cost-effective. While cooling efficiency is a bigger priority than heating system efficiency, heat pumps should still be used. A tight air duct system, ventilation control, and occupancy sensor control of lights and HVAC are very important in all regions.

Mixed climates, such as the Carolinas and Tennessee, must consider measures that address heating loads more than in the hot climate region. Insulation with a radiant barrier appears to be a good strategy for the roofing system as it helps control both heating and cooling needs. Daylighting is an effective option and SHGC of window is a lower priority than in hot climates. SHGCs as high as 0.62 could be considered reasonable in this region and would allow more heat into space which is a benefit in the winter. Increased insulation is more of a priority than reflective surfaces., Specification of a heat pump is important for controlling heating costs.

More work needs to be done to establish better cost data estimates of the improvements used in the PERC study and those recommended here. This task is difficult because of the different ways customers are charged for portables. Many districts lease portables instead of purchasing them. The reported incremental construction cost of the experimental Florida PERC was about \$24,000. This cost could of course be substantially lowered with an increase in demand or legislature mandating improved portable efficiencies. Assuming that the improvements could be mainstreamed into the construction process and there was enough market demand for energy efficient portables, additional costs could range from \$8,500 to \$11,000 with potential energy savings of \$1,825 per year. This means the added costs could be recovered within 6 years.

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