Investigation of Cooling and Dehumidification Energy Use and Indoor Thermal Conditions in Polk County Schools Permanent Replacement Classroom Buildings

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ABSTRACT

Increasing enrollment in grades K-12 coupled with the spiraling costs of construction has pushed school boards to develop more cost-effective classrooms, from the perspective of initial cost, long-term energy consumption, and ease of maintenance. To this end, the Florida's Polk County School Board has developed a four-quad permanent replacement classroom building. Each classroom is equipped with a package terminal heat pump (PTHP) with a thermostat control with a four-hour crank timer. The objective of this research was to compare the energy consumption and interior conditions of the autoclaved aerated concrete (AAC) construction with an unvented roof assembly to that of the conventional metal framing and concrete panel buildings. Four buildings, 2 metal-framed and 2 AAC buildings with dehumidifiers were chosen for extensive testing and monitoring. The goal was to maintain a relative humidity of 50% as well as an interior temperature of 75°F.

BACKGROUND

Increasing enrolment in grades K-12 coupled with the spiralling costs of construction has pushed school boards to develop more cost-effective classrooms, from the perspective of initial cost, long-term energy consumption, and ease of maintenance. To this end, the Polk County School Board has developed a four-quad permanent replacement classroom (Figure 1).

Figure 1 Typical quad classroom building

Building Description

The classroom building is approximately 5000 ft2 and consists of four classrooms, four bathrooms, and a central teacher's preparation area. Each classroom is equipped with a package terminal heat pump (PTHP) with a thermostat control located near the teacher's preparation area. The thermostat has been placed in series with a "crank" timer that limits the total operational time of the PTHP unit to four hours without human intervention. Ventilation air is introduced into the classroom space via the PTHP (Figure 2).

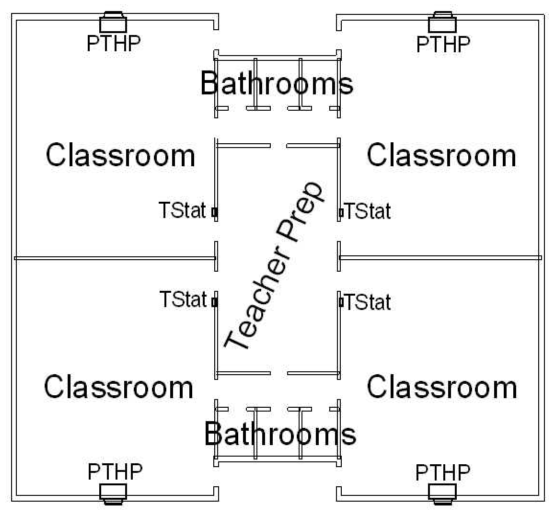

Figure 2 Typical layout of a "quad".

Currently, this building is built using one of three different construction types. Each type has the same basic floor plan, uses a standing seam metal roof system, and exterior finish of either brick veneer or stucco. The differences lie in the wall construction, the roof deck construction, and building airtightness.

The primary construction types are:

- Type 1 - Conventional metal stud wall framing with batted insulation and ceiling insulation lay upon a reinforced radiant barrier approximately 2 feet above the suspended ceiling.

- Type 2 - Similar to first except with a solid concrete panel wall construction.
- Type 3 - Autoclaved aerated concrete (AAC) construction -- both walls and roof system -- with an unvented roof assembly. The AAC creates both the thermal barrier and the air barrier of the building, and provides the structural integrity as well. (Figure 3)

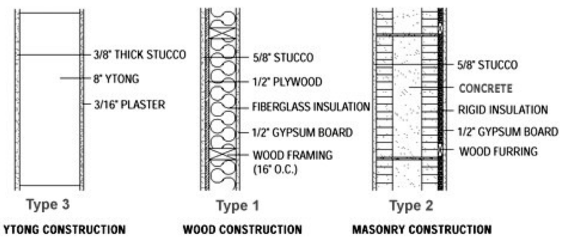

Figure 3 Typical wall construction details. Wood construction and metal frame construction are similar.

Objectives

The objective of this research was to compare the energy consumption of the AAC construction to that of the other types. The AAC buildings had one dehumidifier per classroom installed to control interior relative humidity. For one phase of this project, we limited our testing and monitoring to two buildings of type 1 and two buildings of type 3 construction. In addition to energy comparisons, we also compared indoor relative humidity levels between the type 1 and type 3 buildings.

SHORT-TERM TESTING

Twelve different classroom buildings (type 2) were chosen for a short-term sampling of temperature, relative humidity, and building airtightness testing. The purpose of this phase was to sample the interior conditions of temperature and relative humidity over a 24-hour period.

Three sets of four buildings were monitored during the summer of 1999 from March to September using a portable temperature and relative humidity datalogger for each location measured. The interior temperatures ranged from a low of 64°F to a high of 87°F and the relative humidity varied from 24% to 92% (Figure 4).

The blower door tests done on the twelve (type 2) buildings indicated that they were fairly leaky, averaging 25.8 ACH50 (Cummings, 1996) (Figure 5 & 6). This prompted the search for the source of the leak, especially since the walls were constructed on

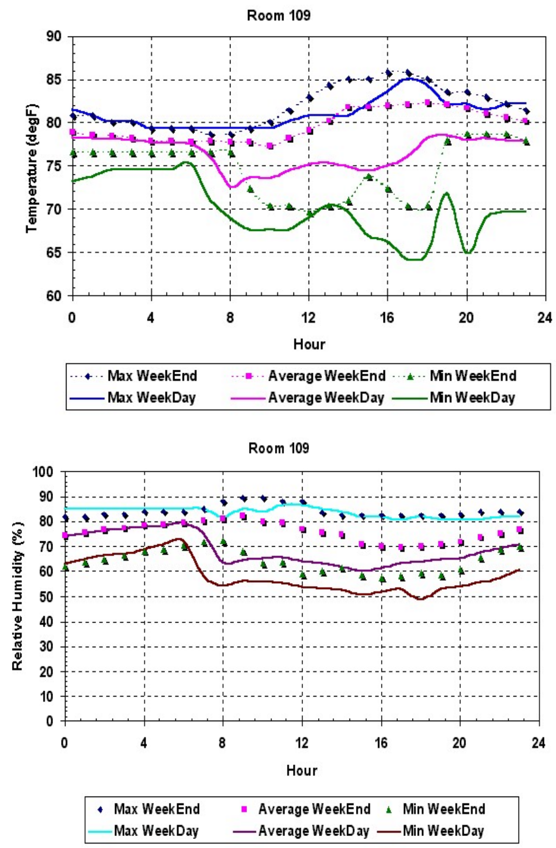

Figure 4 Typical hourly temperature and relative humidity hourly profiles.


Figure 5 Blower door testing being completed on one of the classroom buildings.

solid concrete. The leak paths that existed were in two general locations.

- Ceiling plane - consisting of a t-bar assembly, an air space of approximately 18 inches, a metal grid covered with a radiant barrier material, and

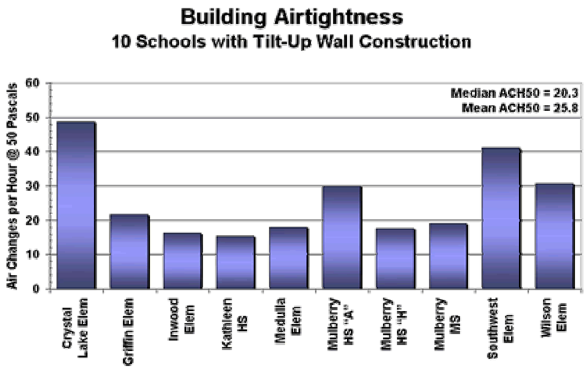

Figure 6 Graphic view of building airtightness in 10 schools.

- an R-19 fiberglass batted insulation. The perimeter vertical section between the t-bar ceiling and the radiant barrier covered grid did not usually have a good air barrier, especially over the bathrooms (Figure 7).
- PTHP assembly - the unit is slid into place without a seal between the wall and unit. This gap varied in size depending on rough opening dimensions of wall and closeness of the unit to the wall (Figure 8).

Figure 7 Incomplete air barrier at connection of wall assembly to ceiling.

LONG-TERM TESTING

Four buildings were chosen for extensive testing and monitoring. Phase 2 is the detailed monitoring of 4 buildings – two of type 1 and two of type 3 – for a period of approximately one year (April 1999- May 2000) to compare the energy consumption, equipment operation and interior conditions. This was divided into three parts.

- Interior temperature of the four buildings was set at 75°F and the 4-hour crank timers were disconnected. This set-up allowed the cooling

Figure 8 Exterior view of PTHP unit with grille assembly removed. Approximately 1 inch of clearance exists between the unit and the wall

equipment to operate as needed to maintain temperature. The adjustment dampers of the ventilation air in the PTHP units were closed to minimize outside air entry. No other modifications were done. (May'99 - Jun'99)
- The two metal-framed buildings were retrofitted and monitoring continued. Again, the temperature was held at 75°F, crank timers still disconnected and the ventilation air damper in the closed position. (Jun'99 - Augt'99)
- The 4-crank timers were reconnected and control of HVAC equipment was relinquished to the teachers and maintenance personal. Normal school operations resumed. (Aug'99-May'00)

Building Description

Floral Ave Elementary School (Bartow, FL) and Eagle Lake Elementary School (Eagle Lake, FL) are of similar construction; the only difference is in the color of the roof. The buildings are constructed with metal-framed wall studs and a metal roof truss system. The exterior wall finish is brick. The standing seam metal roof deck has approximately 1 inch of vinyl coated fiberglass insulation directly beneath. A white roof covers Floral Ave and a blue roof covers Eagle Lake. The ceiling is a typical t-bar suspended assembly supported by the metal truss rafter system. A layer of radiant barrier foil was laid between the trusses to support the R19 fiberglass insulation.

Spook Hill Elementary (Lake Wales, FL) and Elbert Elementary (Winter Haven, FL) were constructed with Ytong autoclaved aerated concrete panels. The white standing seam metal roof system is attached to the topside of the AAC panels. Exterior wall finish is brick. There is a suspended t-bar ceiling assembly that divides the classroom space below from the unvented space above. The AAC panels that make up the roof deck also provide the air and thermal barriers isolating the inside environment from the outside. The space above the suspended ceiling is, in fact, part of the conditioned space.

All buildings are slab on grade with the surrounding grade sloped slightly away from the building. The entrances and windows of the four classrooms are protected from both the sun and rain by an overhang that extends out approximately 8 feet. There are no windows or openings on the ends of the buildings. The floor covering is a hard surface material consisting of tile laid directly on the concrete slab.

The heating, cooling and ventilation needs of the building are provided for with the use of four (4) PTHP (Package Terminal Heat Pump) units - one in each classroom. The Crispaire Corporation of Cordele, GA., manufactured the units, the product line is the Marvair and the model is the Scholar II. Secondary supply ducts are run from the supply plenums of two of the units to provide air to the centralized teacher planning area. Separate thermostat control is provided for each of the PTHP units located on the wall near the doorway that leads to the central prep room. There are four-hour timers connected in line with the thermostats to limit PTHP runtime. Ventilation air is brought into the classroom via the PTHP unit. The outside air is filtered and delivered to a space between the evaporator coil and the return air filter. There is also a filtered pathway for exhausting air through the PTHP. In addition to the air exchange that occurs through the PTHP unit, there are exhaust fans in each of the bathrooms and janitor's closet. These fans are interlocked with the light switch and have a preset timed delay before they turn off.

Test Results

A series of testing was completed on the 4 buildings. Infiltration rates and building airtightness testing, as well as long-term energy and interior conditions were monitored.

Building Airtightness

The two metal-framed buildings (Floral Ave and Eagle Lake) averaged 17577 cfm to achieve 50 Pascals (CFM50=17577) or about 3.3 CFM50 per square foot of conditioned floor area. The AAC buildings (Spook Hill and Elbert) had an average CFM50 of 4874 or 1.0 CFM50 / square foot. Next, the leakage, both intentional and unintentional, associated with the PTHP was isolated from the building by temporarily sealing the entire exterior grills. The results were very similar in all buildings, an average reduction of 2433 cfm at 50 Pascals (Figure 9)

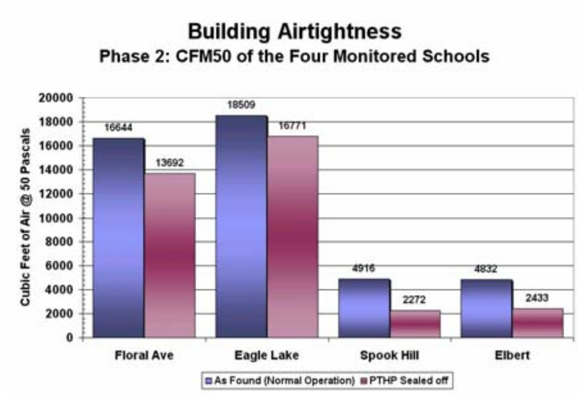

Figure 9 Building airtightness before and after sealing the PTHP.

Figure 10 Typical insulation void approximately 25% to 30%.

Figure 11 Vent pipe passing through the vertical wall section. Air and thermal barriers have been compromised

Figure 12 Attic space after foam was installed It can be seen along the bottom of the truss

The airtightness of Floral Ave was reduced by 32.5 % and Eagle Lake was reduced by 37.5 % by air sealing around the PTHP units and ceiling space (Figure 10-12). The buildings were maintained at a constant 75 ^{o}F temperature and the energy use of the PTHP units was reduced in Floral Ave by 11.0% (assuming a 10^{o}F temperature difference between the conditioned space and outside ambient) and Eagle Lake Elementary had a 17.5% reduction.

<u>Interior Conditions</u>

In a comparison of the metal-framed buildings and the AAC buildings, the goal was to maintain a relative humidity of 50% as well as an interior temperature of 75^{o}F. Classroom temperatures in the AAC buildings averaged 74.5^{o}F (56.4^{o}F dewpoint) and the metal-framed buildings averaged 75.9^{o}F (65.6^{o}F dewpoint).

In an effort to control interior moisture conditions within the AAC buildings created by material drying and internal people loads, dehumidifiers (Figure 13) were installed. These units were set to maintain a relative humidity within the space of approximately 50%. A humidistat is located on the dehumidification unit, which was set based on a scale of high to low. The final position of the humidistat was arrived at by some trial and error settings until the building was operating in the range of 50% to 55% RH. There are four dehumidification units in each building - one for each classroom. Each unit has its supply and return hard ducted to the classroom, however, the humidistat control is located at the unit and is sensing the air surrounding it. This does not appear to have much effect on humidity control since the ceiling space is very well connected to the classroom space below. The dehumidifiers installed were the Ultra-Aire model manufactured by Therma-Stor Products. It has a rated capacity of 100 pints/day (80oF - 60% RH) and draws 6.8 amps on a 115-volt circuit. The dehumidifiers were maintaining the relative humidity (and dewpoint temperature), but with an energy penalty of about 750 watts per dehumidifier when they are operating. Additionally, the heat given off by the dehumidifiers was ejected into the conditioned space where it was removed by the PTHP units. The dehumidification units operated an average of 77.2% (2.3kWh/day) of the time in Spook Hill and an average of 52.7% (1.3kWh/day) of the time at Elbert. Assuming a 10^{o}F temperature difference across the envelope, the two AAC buildings used on average 9.8% more PTHP energy than the metal-framed building at Floral Ave and 19.4% more than Eagle Lake.

Figure 13 One of four dehumidifiers installed in the ceiling space of a quad classroom building.

<u>Infiltration/ventilation Rates</u>

Infiltration/ventilation rates measured in the 4 monitored buildings show very low air exchange when the buildings are not occupied (0.03 to 0.07 ach) as measured by using a tracer decay method. However, when all of the PTHP units are in operation, the air exchange is very close to one per hour (average of 912 cfm). The operation of the recirculating (inside) fan was normally left in the auto mode. Therefore the ventilation air supplied by the PTHP was directly proportional to the need for supplemental cooling or heating. This averaged about 70% operational time in cooling months and 10-20% in heating months.

<u>Energy usage</u>

There are over 2500 schools in Florida with an average of 9.9 portables containing 836 ft2 of conditioned floor area each. Statistical estimates as well as monitoring shows an average use of about 30 kWh/day for portable classrooms (Callahan, 1999). This equates to approximately 36 Wh/day/ft2. The

HVAC portion contribution reached up to 57% of the total energy use. (Note: the typical portable classroom is of modular or "mobile home" type construction.)

The total energy use of the buildings can be divided into three major groups:

- HVAC (heating, ventilation, air conditioning),
- lighting, and
- other (this includes computers, water heating, televisions, miscellaneous electrical and electronic equipment).

The average total building energy use was 103.2 kWh/day (20.6 Wh/day/ft2) for the metal-framed buildings and 119.1 kWh/day (23.8 Wh/day/ft2) for the AAC building. Spook Hill, the AAC building, did average slightly more total building power, but was kept at a slightly higher wintertime temperature and maintained a relative humidity of 50% through the use of a separate dehumidification system. Additionally, the total energy to provide supplemental heating in the metal buildings was slightly offset by the warmer attic conditions. Especially at Eagle Lake which is the only one with a blue colored roof

The average interior classroom temperature during the occupied school days was kept around 75°F for all schools. This equates to about a 10°F difference across the building envelope in both a cooling and heating mode of operation. The average January ambient temperature was in the low 60°F range and the average September temperature was in the low 80°F range. Most of the school year was relatively mild with the average ambient temperature during occupied hours. The average highest month was August (87.6°F) and the lowest was January (61.3°F).

The dehumidifier use during the occupied school year averaged 29.9 kWh/day (5.9 Wh/day/ft2) for Spook Hill while maintaining an average interior relative humidity of 49.8% twenty-four hours a day, seven days a week. Elbert used an average of 23.0 kWh/day (4.6 Wh/day/ft2) and interior relative humidity averaged 54.1%.

CONCLUSIONS

The interior relative humidity of the Type 1 and Type 2 buildings are generally controlled, either by the PTHP unit (occupied hours) or the allowance for the building to come to equilibrium with the ambient temperature (non-occupied hours). The design of the building, choice of PTHP with integrated ventilation air, current control strategy used on PTHP operation, the lack of a ducted forced air system outside the conditioned space and the location of building leaks appears to be a combination that keeps the relative humidity at desired levels.

The AAC buildings showed a decrease in dehumidifier run times over the monitoring period. The duration of dehumidifier operating time is a function of the desired interior relative humidity, moisture of construction, ventilation air and internal gains (from people). The two buildings were maintained at slightly different relative humidity levels (one at 50% and the other at 55%). Originally, one dehumidifier per classroom was required to maintain these levels. Currently, it appears that one unit per two classrooms would maintain the desired level.

The energy usage of the different buildings varies slightly on a normal school day. The AAC buildings are using slightly more energy on a daily average - about 4 kWh. This is most likely the result of dehumidifier use, which controls interior relative humidity on a 24-hour basis.

If the ventilation fans were operated 100% of the time during occupied times, then a couple of things would have occurred. The total energy use of the buildings would have increased, and the interior relative humidity would have increased, especially when exterior dewpoint temperatures are higher. The units with a separate dehumidification system would probably be able to compensate, whereas those without would require cooling to remove moisture. This would probably overcool the space and, at a minimum, cause human comfort problems.

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