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Authors

Moyer, Neil
Chasar, Dave
Hoak, Dave
Chandra, Subrato

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Assessing Six Residential Ventilation Techniques in Hot and Humid Climates

Neil Moyer, Florida Solar Energy Center
Dave Chasar, Florida Solar Energy Center
Dave Hoak, Florida Solar Energy Center
Subrato Chandra, Florida Solar Energy Center

ABSTRACT

The addition of mechanical ventilation air to "tight" homes in hot and humid climates may adversely impact health, building durability, comfort and energy use by raising indoor humidity levels (RH) above 50%. High indoor humidity has been linked to microbial growth, building material decay, discomfort, and increased energy use (Moyer, et al, 2001). High indoor humidity in "tight" homes with mechanical ventilation has been documented in various Building America projects in hot humid locations (Rudd 2003).

The research described here quantifies the energy use, and humidity impacts of six mechanical ventilation strategies installed serially in a new, Energy Star Manufactured home laboratory (MHLab) with typical air tightness (5.4 ACH50) and simulated occupancy for a period of 14 days. Only one strategy (Case 4-Dehumidifier) provided ventilation meeting ASHRAE Standard 62 and maintained the indoor humidity lower than 50%.

Introduction

In the past three decades, concentrated efforts have been made to conserve energy by making buildings "tighter" (i.e., less prone to air leakage). With tighter building envelopes, there is wider acceptance of the need for mechanical ventilation as recommended by the American Society of Heating, Refrigeration, and Air Conditioning Engineers in ASHRAE Standard 62-1989 and its current revision 62.2 (ASHRAE 1999). Mechanical ventilation systems have the potential of improving indoor air quality by removing contaminants and reducing indoor humidity.

However, in hot humid climates, ventilation with outside air may actually increase interior moisture levels potentially doing more harm than good since multiple incidences of building failure, discomfort, and poor indoor air quality have been linked to elevated interior humidity levels (Moyer 2001, Cummings, et al, 1991).

This phenomenon has been observed in the US Department of Energy's Building America Program (www.buildingamerica.gov) where teams of researchers and building scientists work with members of the home-building industry to produce high performance homes that use less energy without costing more to build. The BA teams have adopted the position, consistent with ASHRAE, that to improve the indoor air quality of a home; an active ventilation strategy should be incorporated into the design of the home. However, it has been noted that some houses built under this program in the hot and humid climate and equipped with a dedicated ventilation system were reported to have longer periods of elevated interior relative humidity (RH > 60%) relative to conventional houses without dedicated ventilation systems (Rudd 2003).

In other research, the Building America Industrialized Housing Partnership conducted field tests in moisture distressed manufactured houses in coastal, hot and humid climates. High indoor humidity levels (RH>60%) were identified as contributing factors in material degradation and collapse, indoor thermal discomfort, and mold growth (Moyer 2001).

In hot humid climates, ambient ventilation air presents a much greater latent load on the building than a sensible one. A comprehensive ventilation approach requires not only air exchange but also indoor humidity control. The home building and manufacturing industries need guidance on how to achieve appropriate indoor humidity levels while also providing adequate air exchange in accordance with ASHRAE Standard 62.

Research Approach

In general, distinctions among ventilation system types arise from air exchange method and air treatment/distribution options.

Exhaust Only Systems:	Systems that only remove (exhaust) air from the house depend on infiltration to replace exhausted air with outside air seeping back in through cracks and holes in the walls, floor, and ceiling (envelope). Example: Spot ventilation such as bathroom and kitchen fans.
Supply Based Systems:	Systems that only add (supply) outside air into the house directly or via the mechanical system duct work thereby increasing indoor pressure and pushing household air out through cracks and holes in the envelope. Example: Passive outside air (OA) ducts connected directly to the return or supply side of an air handler.
Balanced Systems:	Systems that both supply air to the house and exhaust air from the house in equal volumes. Example: Energy Recovery Unit with supply air stream, exhaust air stream,
Options:	Supply based and balanced systems can be coupled with and heat and/or enthalpy recovery and stand alone dehumidification equipment..

This study quantifies the energy use, and humidity impacts of six commonly implemented mechanical ventilation strategies (1 Exhaust and 5 Supply) compared to the base case of “no ventilation system”. One of the strategies (Case 6) incorporates energy recovery. The six systems were installed serially in a new, Energy Star Manufactured home laboratory (MHLab, Figure 1), with typical whole house air tightness (5.4 ACH50) and simulated occupancy for 14 day periods. The two fundamental research questions for this study were:

- How do houses in a hot and humid climate perform with respect to humidity control without mechanical ventilation? This constitutes the base case (Case 1, *see list below*) for the study
- What are the indoor humidity effects of different mechanical ventilation strategies? This is the comparative element of the study (Cases 2-7, *see list below*)

Figure 1. Manufactured Housing Laboratory

Test Cases

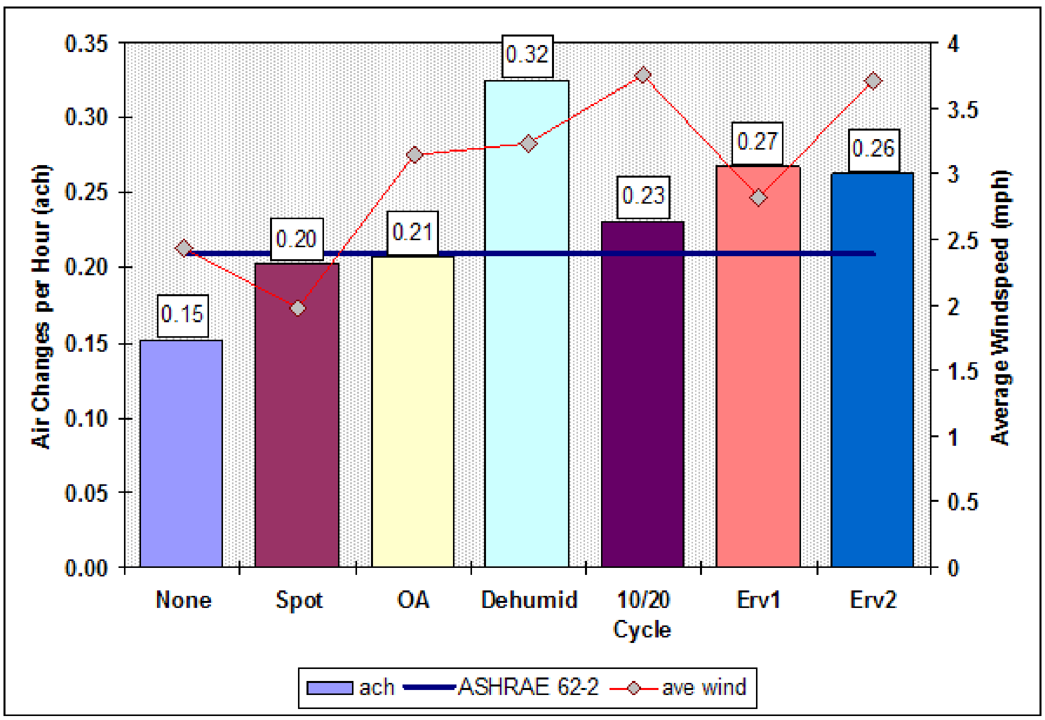
Six strategies (plus a non-ventilation base case) were evaluated with the thermostat set at 75°F. When outside air is called for, the flow rate was set to deliver 50 cfm to the return plenum of the air handler unit.

The ventilation strategies considered included:

1. None (Base Case): No ventilation strategy.
2. Spot Ventilation (Exhaust Only): Bathroom and kitchen exhaust fans. Operation scheduled for 30 minutes after a simulated moisture producing event such as a shower or oven use.
3. Outside Air (Supply Based): Air drawn directly from outside through a filter and into the return plenum through a dedicated duct when the heating or cooling system is operating. The quantity of ventilation air provided depends on air handler run-time.
4. Outside Air plus 10/20 Cycle and Dehumidification (Supply Based): Same duct configuration as Case 3, with an added air handler fan controller (10-minute on – 20-minute off minimum duty cycle). Provides scheduled ventilation when no cooling or heating is called for. A stand alone room dehumidifier (set to approximately 50% RH) located in the general vicinity of the return air grill.
5. Outside Air plus 10/20 cycle (Supply Based): Same as with #4, but without the room dehumidifier.
6. Energy Recovery Ventilator (ERV1 & ERV2): Two different enthalpy transfer media are used. Outside air was drawn in through the ERV at a rate to meet the ventilation requirements.
7. Outside Air plus Humidistat (Supply Based): This is a modified air handler fan speed control. When dehumidification is called for by the humidistat, the air handler fan is operated at lowest speed for enhanced latent control. A higher speed is selected when sensible cooling is needed. Ventilation air supplied via outside air duct – with air handler fan operation controlled as in #4.

A whole house air infiltration test, using sulfur hexafluoride (SF_6) as a tracer gas, was completed during each ventilation strategy to determine if it met the ASHRAE 62-2 Standard. An initial concentration of SF_6 was injected into the conditioned airspace and allowed to decay for approximately 2 hours. The rate of decay, after adequate mixing, was used to determine the air change rate of the building. Testing was done during similar ambient conditions for each strategy. Not all ventilation strategies met the ASHRAE Standard, as shown by a horizontal line on Figure 2. The spot ventilation strategy did not meet the standard on a daily basis as the runtime was not long enough. The OA method was marginal in meeting the standard, while the remainder of the other strategies did. However, this is most likely a result of the consistent interior sensible loading, and right-sizing of the air conditioning system for temperature differences that existed across the envelope.

Figure 2. Results of tracer gas decay testing indicating infiltration rates measured for each ventilation strategy.



Note: Windspeed averaged over infiltration test – 2 hours

Experimental Procedure

All tests were conducted in a controlled unoccupied building, the Building America Industrialized Housing Partnership (BAIHP) Manufactured Housing Lab (MHLab).

BAIHP MHLab. The MHLab is a research and training facility at the Florida Solar Energy Center (FSEC). The MHLab is a 1600 ft2 ENERGY STAR® manufactured home with two separate heating and cooling systems: 1.) an overhead duct system connected to a package unit air conditioner with electric resistance heating and 2.) a floor-mounted duct system connected to a split system air conditioner also with electric resistance heating. Only the floor mounted duct system was used in this study.

Occupancy. The MHLab simulates a typical family of four using computer control. The electronic thermostat is set to hold the interior space at a constant temperature of 75°F with the air handler fan in the "auto" setting.

Automated, computer controlled devices, such as appliances, showers, and lighting, simulate the sensible/latent heat generation and carbon dioxide (CO_2) production of a family of four persons with periodic showers, cooking and cleaning.

The average daily energy consumption used by interior devices was about 25.5 kWh, which included heat lamps in the living room, guest bath, and master bedroom used to simulate sensible occupancy load. Additionally, there were two humidifiers which provided water vapor to the conditioned space to simulate the latent load for four people.

The simulated latent load from occupancy (breathing, bathing, cooking, and laundry) was achieved by adding 14 to 15 pounds of water per day based on documentation of "average" household operation (Christian 1994). Water vapor was injected into the space using a vaporizer at a rate of approximately 0.4 lbs per hour continuous and an additional 0.4 lbs per hour during the evening hours.

Data Collection. The MHLab features an extensive data retrieval and collection system powered by a Campbell CR10 data logger. Data is collected and averaged over a fifteen minute period then downloaded via an internet modem several times daily to FSEC's mainframe computer system, where it is processed and made available via the internet. For this study, the following data are measured:

- total building power
- exterior & interior CO_2 levels
- air conditioner compressor power
- ambient weather conditions
- space heating power
- pressure difference across envelope
- air handler fan power
- ventilation airflows
- dehumidifier power
- ventilation fan power (if separate)
- interior temperature & relative humidity
- ventilation cycle times

RESULTS AND EVALUATION

Whole House and Duct System Air Tightness

A series of air tightness tests was completed on the home between each ventilation setup. In order to compare the relative tightness of buildings, it is useful to adjust (or normalize) test results for the size of the building (The Energy Conservatory 2003a). These data are normalized by dividing the whole house air leakage measured at a test pressure of 50 Pascals (e.g. CFM50) by the floor area of the building, Equation 1.

Equation 1. Normalized CFM50

$$\text{CFM50 per Square Foot of Floor Area} = \frac{\text{CFM50}}{\text{Square Feet of Floor Area}}$$

The average whole house air leakage (CFM50) was 1224 (ACH50 of 5.4). With a square footage of 1600, the normalized average whole house leakage (CFM50/Area) was 0.77. This falls within the range of expected tightness for new construction, 0.75 and 1.

Similarly, measured duct leakage (CFM25) is often normalized by conditioned area (Equation 2) for ease of comparison (The Energy Conservatory 2003b).

Equation 2. Percent Duct Leakage

$$\text{Duct Leakage as a \% of Floor Area} = \frac{\text{Duct Leakage @ 25 Pa (cfm)}}{\text{Floor Area (square feet)}} \times 100$$

The target normalized duct leakage for the Manufactured Home Energy Star program is $Qn \leq 6\%$ (MHRA 2001). The total duct system leakage in the MHLab averaged $CFM25_{(total)}=75$ or $Qn_{(total)}=5\%$ with average leakage to the outside measured to be $CFM25_{(out)}=45$ or $Qn_{(out)}=3\%$.

Building performance as a function of ventilation strategy

The comparison of the various ventilation strategies and their effects on the various building performance parameters is seen in Table 1. The ambient conditions including temperature, relative humidity, and rainfall are included to show the slight variance that existed during the tests.

Interior relative humidity. A digital thermostat maintained interior temperature at 75 degrees Fahrenheit. Interior temperature and relative humidity sensors are located on the same wall as the thermostat, at approximately the same height from the floor. Dedicated interior relative humidity control was only available with the dehumidifier strategy, and was a byproduct of cooling coil operation in the other strategies.

Table 1. Average Ambient and Building Conditions

Strategy	Case 1 None	Case 2 Spot	Case 3 OA	Case 4 Dehumid	Case 5 10/20	Case 6		Case 7 Hstat
						ERV1	ERV2	
Indoor Temp (°F)	74.5	74.5	74.7	74.9	74.0	74.1	74.4	74.8
Indoor Temp Max (°F)	75.0	75.2	75.5	76.0	75.0	74.9	75.4	76.0
Indoor RH (%)	49.2%	45.7%	49.5%	47.9%	49.1%	47.8%	47.2%	45.7%
Indoor Dewpoint (°F)	52.4	54.2	54.5	53.9	53.7	53.1	53.0	52.4
Outside Temp (°F)	78.6	78.6	78.4	82.1	79.8	79.3	80.8	79.2
Outside RH (%)	89.2%	79.5%	87.7%	83.4%	87.0%	90.0%	86.9%	88.1%
Δ Temp (°F)	4.3	4.0	3.7	7.1	5.8	5.1	6.5	4.4
Δ Dewpoint (°F)	18.6	20.7	19.5	22.4	21.4	22.7	23.3	22.6
Solar Rad. (kWh/sqm)	53.5	107.3	68.9	76.3	86.8	66.3	101.9	77.1
Rainfall (Inches)	3.6	0.5	4.7	0.1	4.0	5.1	3.2	4.9
Condensate (lbs)	617	905	920	1131	1118	1034	1685	1282
Δ P WRT Out (Pa)	-0.2	0	0.1	0.4	0	-0.2	-0.2	0.1

As might be expected, interior relative humidity had the least variance with the dehumidification system, Table 2; it had a low of 46% and a high of 51%. Note also that the dewpoint difference across the building envelope was almost 23°F, whereas the first three cases were nearly 3°F less.

Table 2. Interior relative humidity statistics for various vent strategies

	Case 1 None	Case 2 Spot	Case 3 OA	Case 4 Dehumid	Case 5 10/20	Case 6 ERV1	Case 6 ERV2	Case 7 Hstat
Mean	46.1	49.2	49.5	47.9	49.0	47.8	47.2	45.7
Std Deviation	1.272	1.471	1.673	0.845	1.231	2.194	2.108	3.07
Range	11.2	16.3	7.4	4.8	12.1	20.6	13.7	21.7
Minimum	42.1	38.8	45.8	46.2	46.3	44.2	39.3	39.7
Maximum	53.3	55.2	53.2	51.0	58.4	64.8	53.0	61.4

Figure 3 shows the distribution of the relative humidity levels for each of the ventilation strategies during the test period in 2% increments showing disaggregation of the data.

The best performing system, Case 4 (10/20 cycle plus dehumidifier), was able to maintain the relative humidity nearly constant for almost 80% of the test period. The next best performers were Case 2 (spot ventilation) and 6b (energy recovery ventilation). Humidity levels during the test period are graphed in Figure 4.

Figure 3. Relative humidity frequency distribution for each strategy

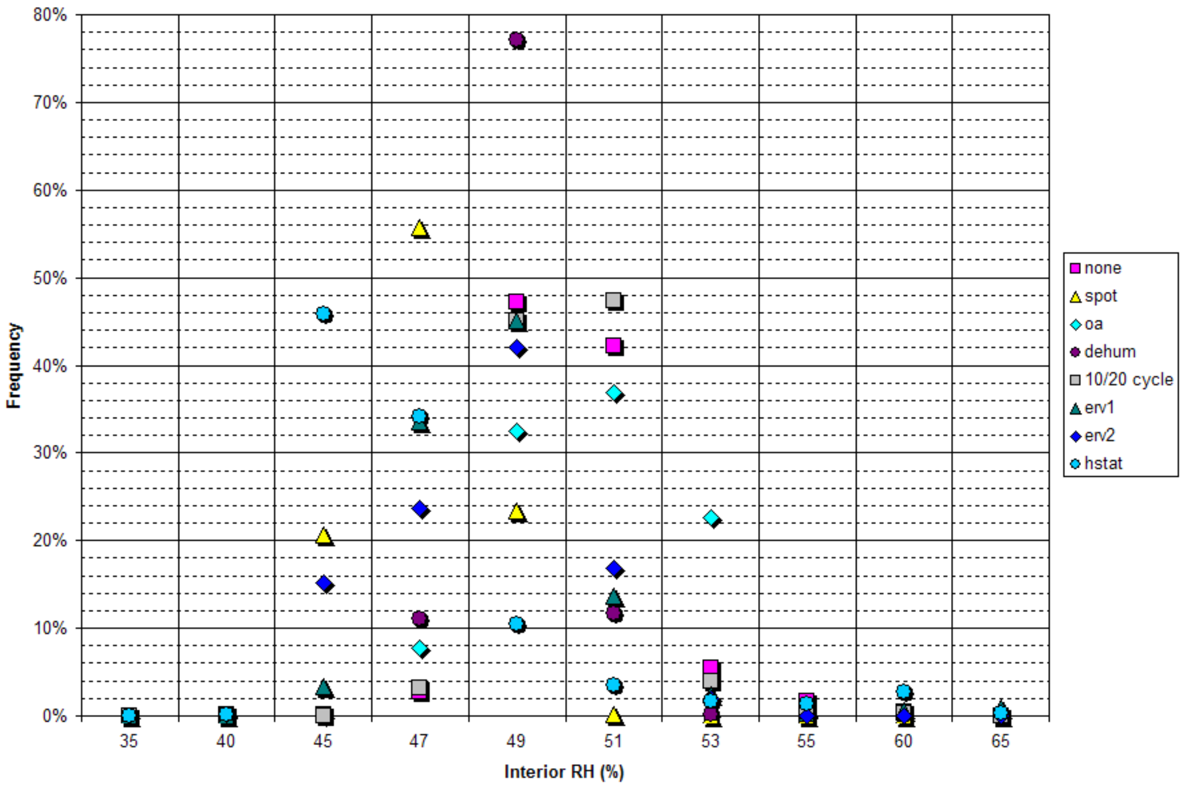
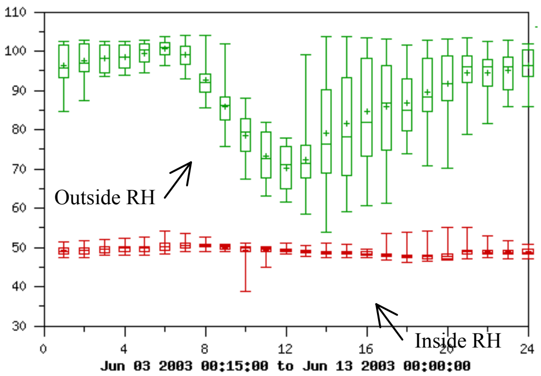
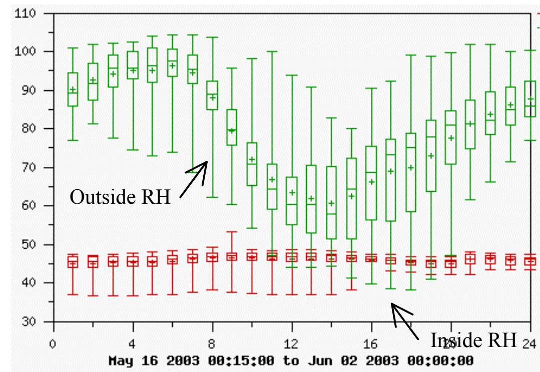


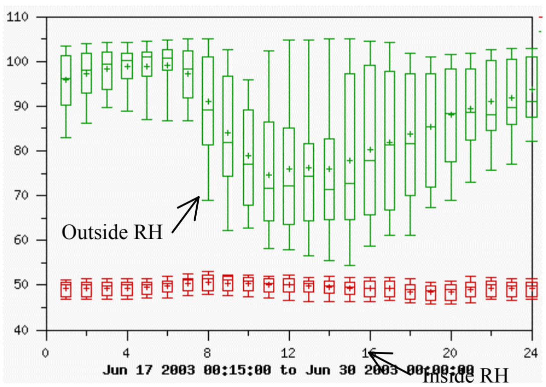
Figure 4. Average hourly relative humidity profiles for each strategy



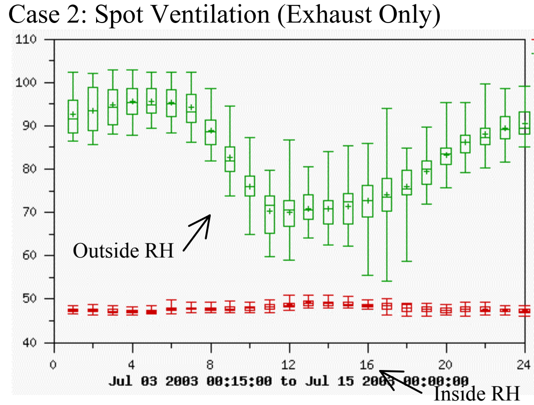
Case 1 No Ventilation



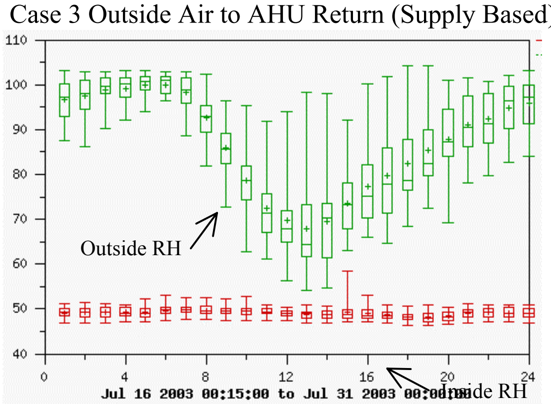
Case 2: Spot Ventilation (Exhaust Only)



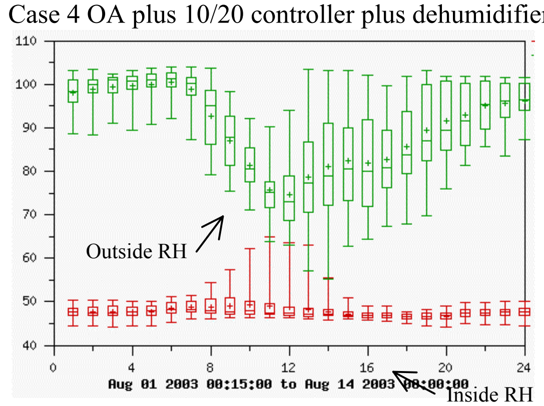
Case 3 Outside Air to AHU Return (Supply Based)



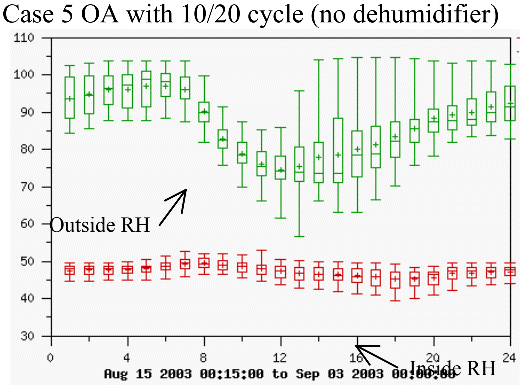
Case 4 OA plus 10/20 controller plus dehumidifier



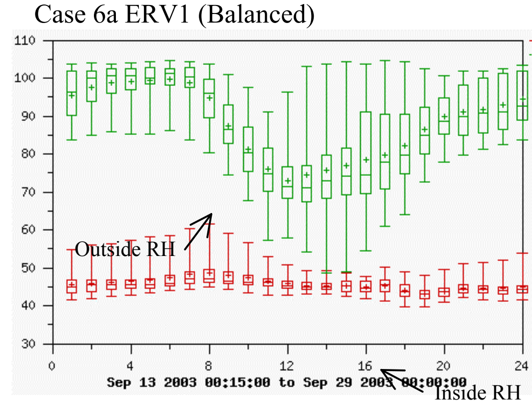
Case 5 OA with 10/20 cycle (no dehumidifier)



Case 6a ERV1 (Balanced)



Case 6b ERV1 (Balanced)



Case 7 OA with humidistat controller (Supply Based)

Cooling/ventilation power usage. With all mechanical ventilation systems, additional energy use was expected from both increased conditioning loads (ventilation air) and fan power (when used). The split system with the floor duct system is a 12 SEER system with a rated cooling capacity of 30.2 kBtu.

The ventilation strategies that required the use of the air handler fan, an energy recovery ventilator, or the dehumidifier had the energy use added to the cooling energy. The dehumidifier strategy did use the most energy for cooling; however, it should be noted that this test also occurred during the hottest ambient conditions. The additional power of the added ventilation equipment was, on a daily average, as follows: Case 4 (dehumidifier) = 5.7 kWh, ERV1 at 1.2 kWh, and ERV2 at 0.9 kWh.

The cooling energy required to maintain the 75°F interior set-point varied as a result of the temperature difference across the envelope. A linear regression analysis was performed to find the best fit line in order to compare energy use of the ventilation strategies (Figure 5). Consider the power use at the average temperature difference of five degrees Fahrenheit as shown in bold on, Table 3. Case 4 (the dehumidifier system) has the highest average power at 1592 watts, followed by Case 7 (humidistat controlled fan speed) at 1485 watts. Case 5 (10/20 cycle controller) appears to use the least power at 1315 watts. Also note that when the outside temperature is below the interior set point, that the HVAC power is less in Case 5 (10/20 cycle) and 6 (ERV).

Table 3. Cooling and ventilation power (watts) usage as a function of temperature difference across the building envelope

ΔTemp (°F)	Case 1 None	Case 2 Spot	Case 3 OA	Case 4 Dehumid	Case 5 10/20	Case 6		Case 7 Hstat
						ERV1	ERV2	
-5	487	499	475	499	411	459	367	526
0	924	911	949	1046	863	915	880	1006
5	**1361**	**1324**	**1424**	**1592**	**1315**	**1370**	**1393**	**1485**
15	2236	2150	2372	2685	2219	2280	2418	2443

Summary

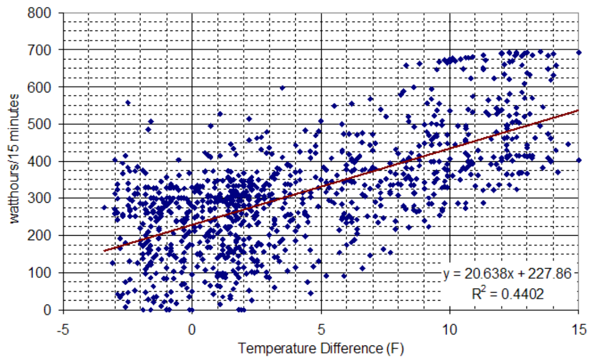
The operation of a correctly sized air conditioning system with a supplemental dehumidification system to pre-condition the outside air, and provide additional dehumidification of the space, appears to provide the best interior humidity control with only a slight increase in energy usage – about 200 watts. Only this strategy was able to maintain the interior humidity conditions in a range of less than 5%.

The 10/20 cycle and Energy Recovery strategies removed interior heat slightly better than the other strategies when the outside temperature was below interior set point.

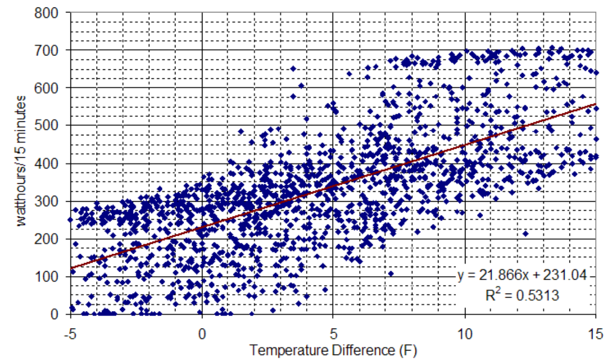
Though all of the strategies did provide some humidity control over the test period, it is most likely a result of the run time afforded by the correctly sized air conditioning system and the consistent simulated interior sensible load. When an air conditioning system operates for extended periods of time, the removal of moisture from the air stream is enhanced (Khattar, Swami & Ramanan 1987).

Additional testing with other ventilation strategies is currently in progress at the MHLab.

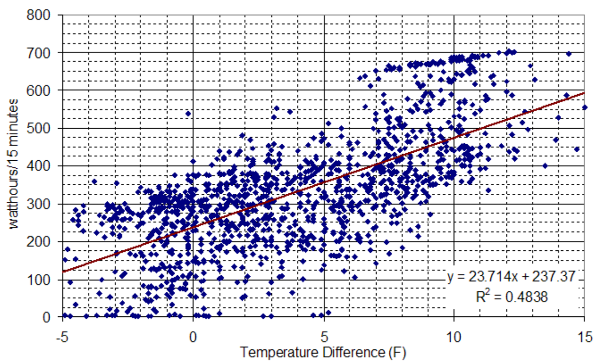
Figure 5. Air conditioner power as a function of temperature difference across the building envelope.



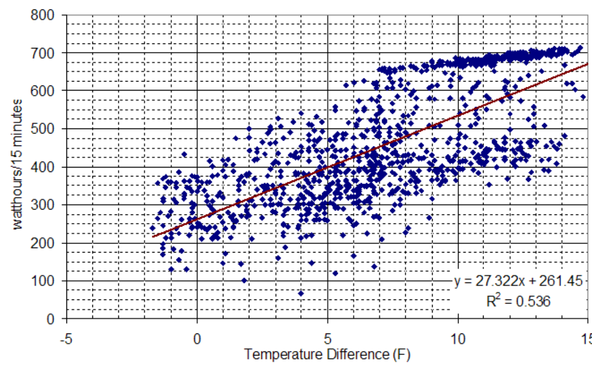
Case 1 No Ventilation



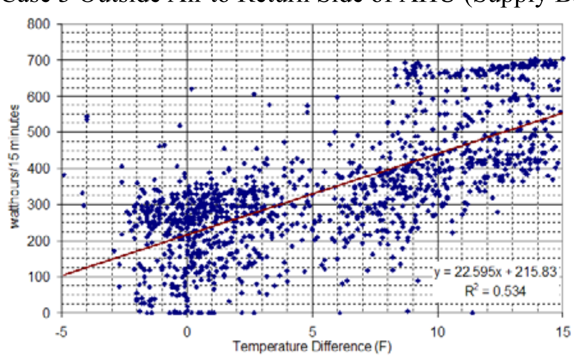
Case 2: Spot Ventilation (Exhaust Only)



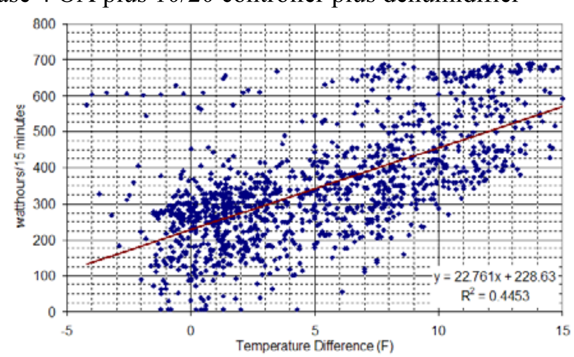
Case 3 Outside Air to Return Side of AHU (Supply Based)



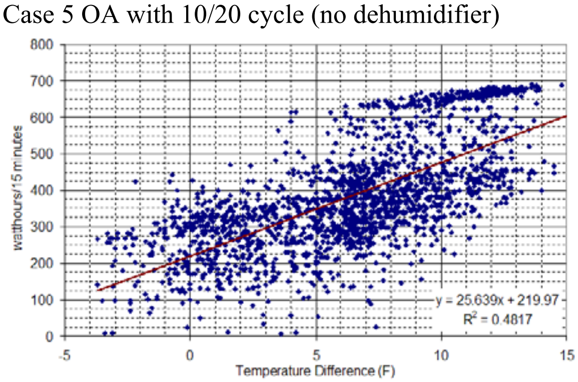
Case 4 OA plus 10/20 controller plus dehumidifier



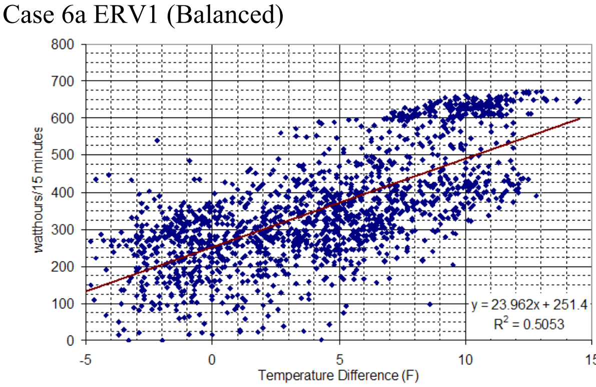
Case 5 OA with 10/20 cycle (no dehumidifier)



Case 6a ERV1 (Balanced)



Case 6b ERV2 – Different media (Balanced)



Case 7 OA with humidistat controller (Supply Based)

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