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Systems Engineering Approach to Development of Advanced Residential Buildings

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Kohta Ueno

Abstract:

This is a report describing the test methodology and results for experiments run on two test houses at the Bonita Springs development in Fort Myers, FL. The goal was to determine the effect of attic ventilation in a hot-humid climate; previous work had shown that little to no benefit is derived from ventilation in terms of energy use, and that it is detrimental for moisture control. Two houses with identical orientations and plans were compared; one was ventilated at the typical 1:300 ratio, and the other had sealed vents. This work was conducted in order to move houses in hot-humid climates forward in technology in their building envelope and HVAC systems.

BUILDING AMERICA

SYSTEMS ENGINEERING APPROACH TO DEVELOPMENT OF ADVANCED RESIDENTIAL BUILDINGS

8.A.04B FINAL REPORT: PULTE FORT MYERS

RE: TASK ORDER NO. KAR-8-18412-05

UNDER
TASK ORDERING AGREEMENT NO. KAR-8-18412-00

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NOVEMBER 8, 2000

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EXECUTIVE SUMMARY

This is a report describing the test methodology and results for experiments run on two test houses at the Bonita Springs development in Fort Myers, FL. The goal was to determine the effect of attic ventilation in a hot-humid climate; previous work had shown that little to no benefit is derived from ventilation in terms of energy use, and that it is detrimental for moisture control. Two houses with identical orientations and plans were compared; one was ventilated at the typical 1:300 ratio, and the other had sealed vents. This work was conducted in order to move houses in hot-humid climates forward in technology in their building envelope and HVAC systems.

Temperatures and relative humidities of attic and house air, and temperatures of roof tile, roof sheathing, and insulation top were measured for a two-month period (September through October). Outdoor conditions were also recorded; power consumption was not directly monitored.

After this monitoring period, several conclusions could be drawn in regards to the effect of venting on thermal and moisture performance. The temperatures of roof components (tile, sheathing, and insulation) were slightly elevated in the unvented house, but the effect on building durability appears to be minimal.

Attic air temperature was increased (maximum peak difference of 10° F) in the unvented house; however, the overall energy effect of this change is minimal. The elimination of attic venting reduces latent load, as well as infiltration and exfiltration due to wind pressures acting on the leaky ceiling plane. Therefore, overall energy performance may be improved by eliminating attic ventilation. The unvented roof showed superior moisture performance, as humid outdoor air was no longer being introduced through vents.

Overall, more study is recommended. Data will be collected again at the end of the winter, and at the end of the following summer.

BACKGROUND

The effect of attic ventilation on cooling performance and moisture levels has been a matter of particular study for the past two decades. Burch and Treado (1979) found that attic ventilation is not an effective energy conservation procedure for houses with insulation thicknesses of 4 in and 6.5 in; this even proved true with the air conditioning supply ductwork in the attic.
The typical code 1:300 ventilation ratio is geared towards prevention of moisture condensation buildup in cold climates during the heating season. In hot-humid climates, attic ventilation is detrimental to moisture-related performance, and energy benefits from ventilation are questionable.

Work by Rudd and Lstiburek (1997) used a finite element computer model to predict energy use, roof temperatures, and moisture behavior in Orlando, FL (hot-humid) and Las Vegas, NV (hot-dry) climates. Results showed that a "cathedralized" attic, which places both the air barrier and thermal barrier at the roof deck (resulting in a 'conditioned attic'), served to minimize or eliminate moisture accumulation potential in hot-humid climates without an energy penalty. The impact of an unvented unconditioned attic (an attic where insulation is located at the ceiling plane; i.e., a 'typical' attic but without ventilation) on energy usage was examined; it showed some increase in peak ceiling heat flux. However, moisture performance of this system was not investigated.

This work compares an unvented unconditioned attic with a standard construction vented attic in a hot humid climate (Fort Myers, FL). Temperatures and relative humidities of attic and house air, and temperatures of roof tile, roof sheathing, and insulation top were measured for a two-month period at the end of summer. Outdoor conditions were also recorded; power consumption was not directly monitored.

Test Methodology

Two houses with the same orientation and floor plan were selected in a new construction subdivision in Fort Myers, FL (see Photos of Test Houses).

In one house (Lot 12; Unvented house; 9164 Spring Run Boulevard), attic ventilation was closed. The openings for the upper tile vents were covered with rigid insulation board and airsealed; the perforated aluminum soffit vent was sealed with a heavy elastomeric paint (see Photos Of Ventilation Closure, Unvented House). Although this sealed the perforations, some openings remained (for instance, at the J-channel intersection). In the other house, (Lot 8; Vented house; 9148 Spring Run Boulevard) the ventilation was retained, at the 1:300 ratio, as per SBCCI requirements.

Monitoring equipment was installed at both houses; measurements included:

- Attic air temperature (3 measurements)
- Attic air relative humidity (2 measurements)

- Return air temperature (2 measurements)
- Return air relative humidity (2 measurements)

- Tile top temperature
- Plywood roof sheathing temperature (underside)
- Insulation top temperature

Data was recorded as hourly averages; hourly standard deviations were also recorded. All building assembly temperatures were recorded on the worst-case (west-facing) side. In addition, outdoor temperature and relative humidity were recorded. Data was recorded from late August 2000 through late October 2000; equipment was left in place to record winter results.

PHOTOS OF TEST HOUSES

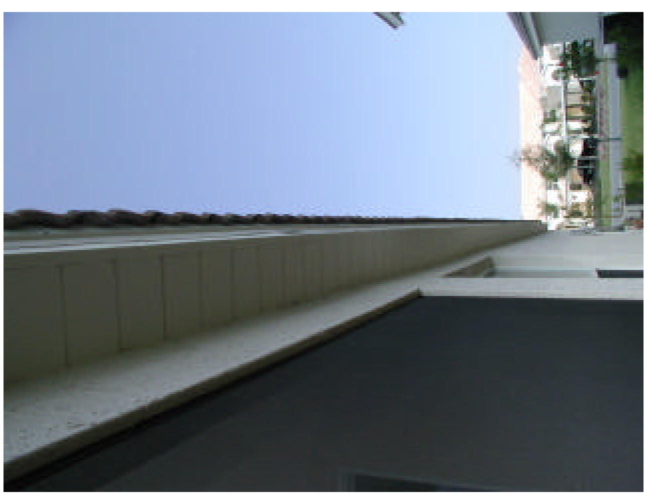
Lot 8; Vented house (9148 Spring Run Boulevard)

Lot 12; Unvented house (9164 Spring Run Boulevard)

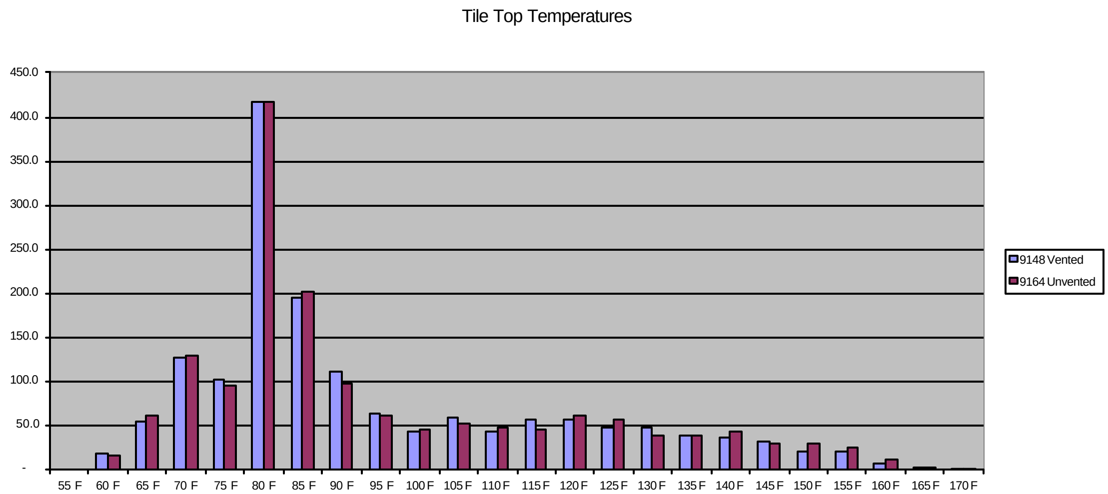
PHOTOS OF VENTILATION CLOSURE (UNVENTED HOUSE)


Center-front corner


Right-hand side (towards rear)

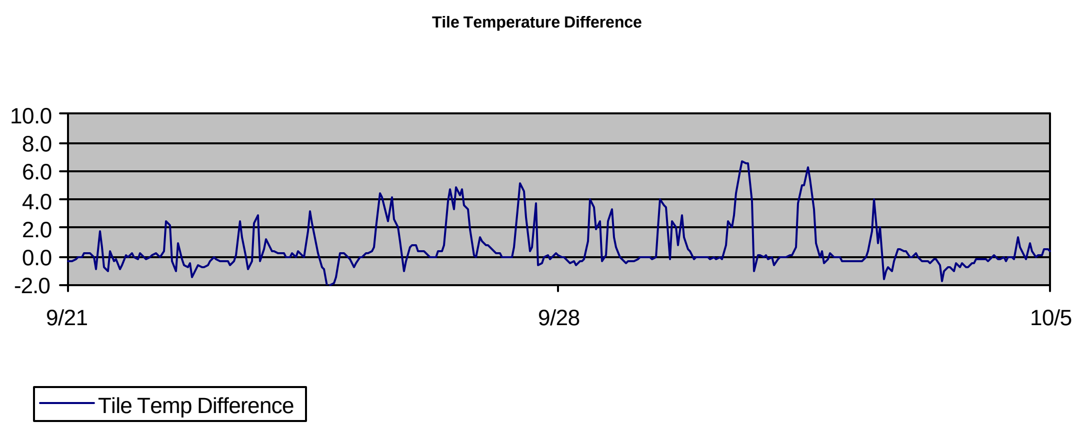

Left-hand side (towards front)

RESULTS: BUILDING ASSEMBLY TEMPERATURES



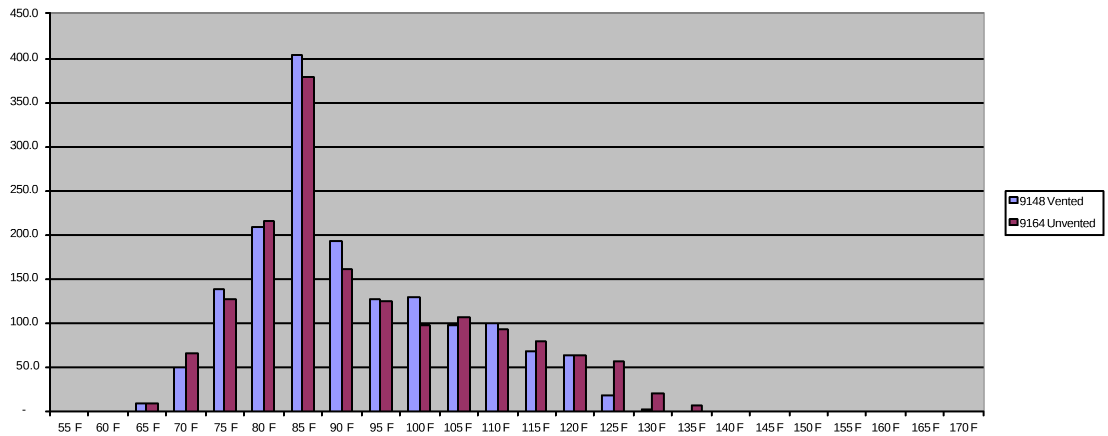
Tile Temperatures	Vented	Unvented	Difference
Mean	91.8	92.3	(0.5)
Maximum	166.0	165.9	0.1
Minimum	56.7	56.5	0.3
Standard Deviation	23.4	24.2	(0.8)

The tile top temperatures were very similar. This response is consistent with the fact that tiles are "self-venting" with the air space formed underneath them in a typical installation. Furthermore, this space 'uncouples' the roof tiles from the rest of the roof system.



The graph above shows the difference in temperature between the roof tiles in the two houses. It is near zero at night, and has daily peaks from noon to early evening (6 PM); peak temperature differences were approximately 5-7° F. As seen in the graph, the tile temperature in the unvented house is occasionally lower than the vented house (below zero).

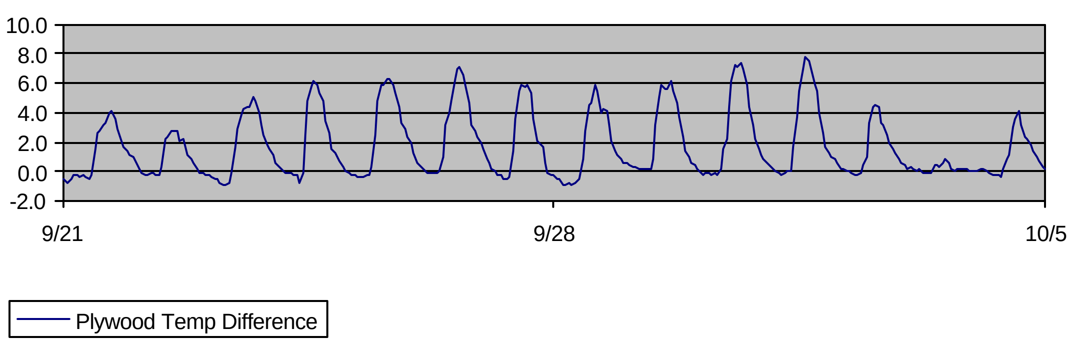
Plywood Underside Temperatures



Plywood Temperatures	Vented	Unvented	Difference
Mean	89.0	90.5	(1.5)
Maximum	128.6	135.0	(6.4)
Minimum	61.2	61.2	(0.0)
Standard Deviation	13.4	15.3	(1.8)

Plywood roof sheathing temperatures showed a slightly greater difference average temperature of 1.5° F. Difference in maximum temperatures was 6.4° F.

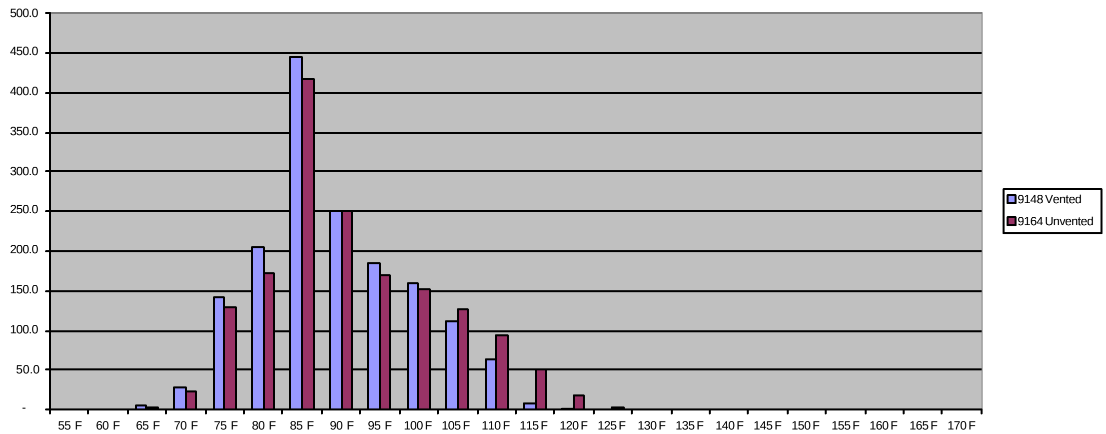
Plywood Temperature Difference



The instantaneous temperature differences between the two houses were computed over the test period. The average of the differences was 1.5° F; the maximum was 7.8° F. The graph above shows the temperature difference; peaks typically occurred in the late afternoon (4 to 6 PM).

Rate of aging and lifespan of building components are related to absolute temperature (TenWolde and Rose, 1999). The 7.8° F peak difference translates to less than a 2% difference in absolute temperature; over the life cycle of the building envelope, this appears to be a minimal effect.

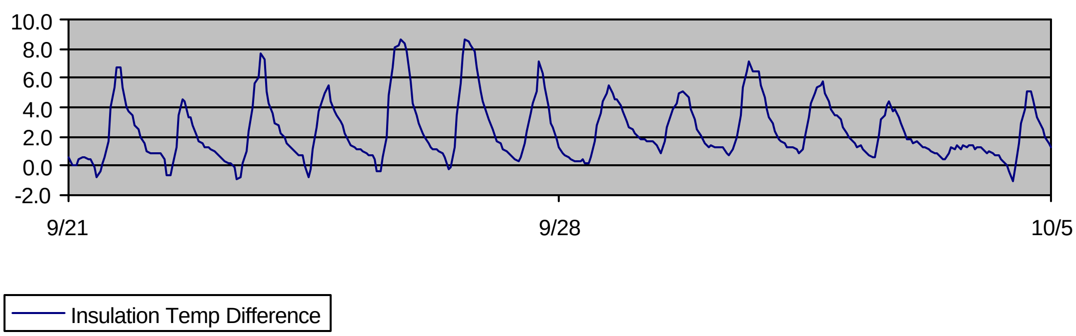
Insulation Top Temperatures



Insulation Top Temperatures	Vented	Unvented	Difference
Mean	86.6	88.7	(2.0)
Maximum	115.5	121.2	(5.7)
Minimum	62.8	64.0	(1.2)
Standard Deviation	9.7	11.2	(1.5)

Temperature was measured at the top of the insulation (just under the surface); as in the previous measurements there was some difference (~2° F average) between the two houses. The difference of maximums was 5.7° F.

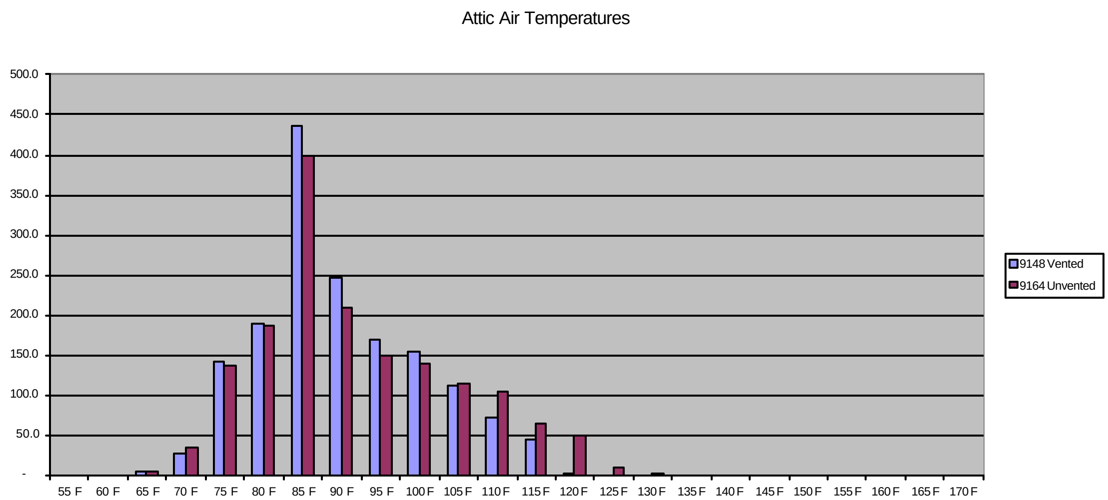
Insulation Top Temperature Difference



In the instantaneous differences, the average was 2° F, and the maximum instantaneous difference was 10.7° F. In the graph of temperature differences, peaks were mostly in the range of 6-10° F; they occurred in the early evening (6-7 PM).

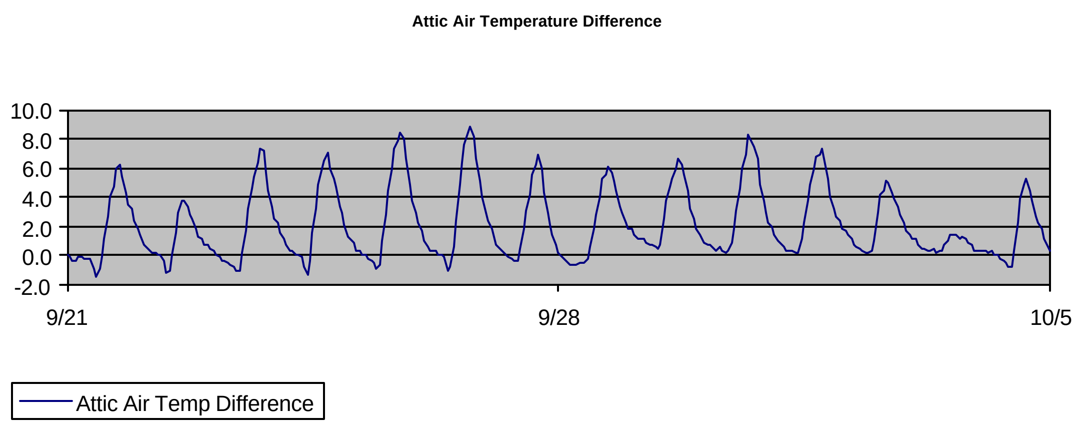
Slight differences in cardinal orientation, shading, and sensor placement between the two houses could have an effect on some of the temperature measurements. More measurements in more locations would provide more detailed information, however, we would not expect a change in the trends presented here.

RESULTS: ATTIC AIR TEMPERATURES



Attic Air Temperatures	Vented	Unvented	Difference
Mean	87.5	89.3	(1.8)
Maximum	117.8	126.3	(8.5)
Minimum	62.3	62.8	(0.5)
Standard Deviation	10.7	12.7	(2.0)

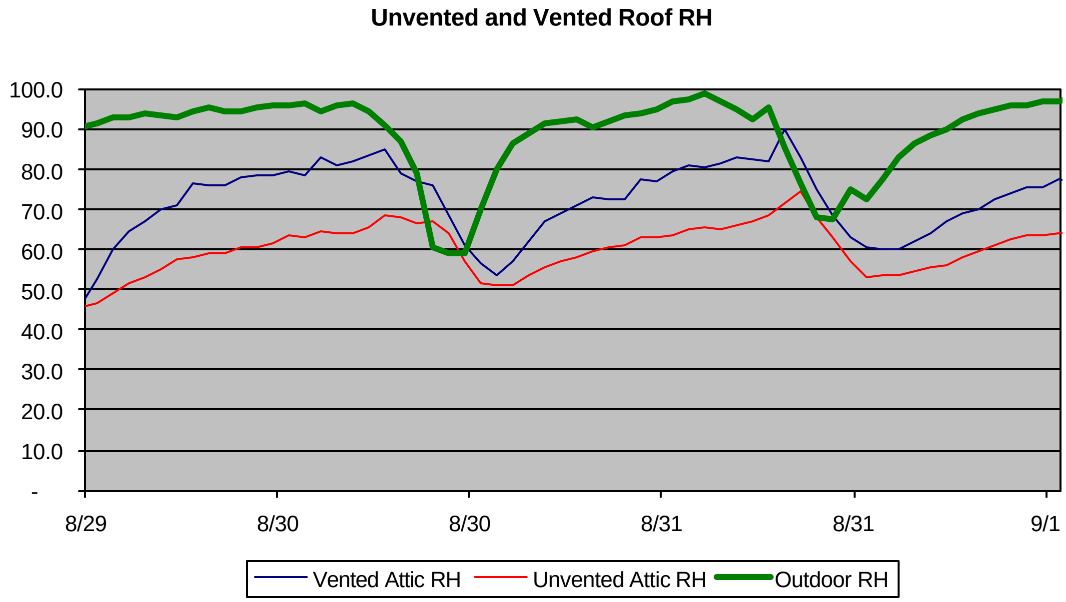
As with the roof assembly materials, there was a temperature difference; the difference in averages was 1.8° F; difference of maximums was 8.5° F. In computing the instantaneous differences, average difference was 1.8° F; maximum instantaneous difference was 10.1° F.

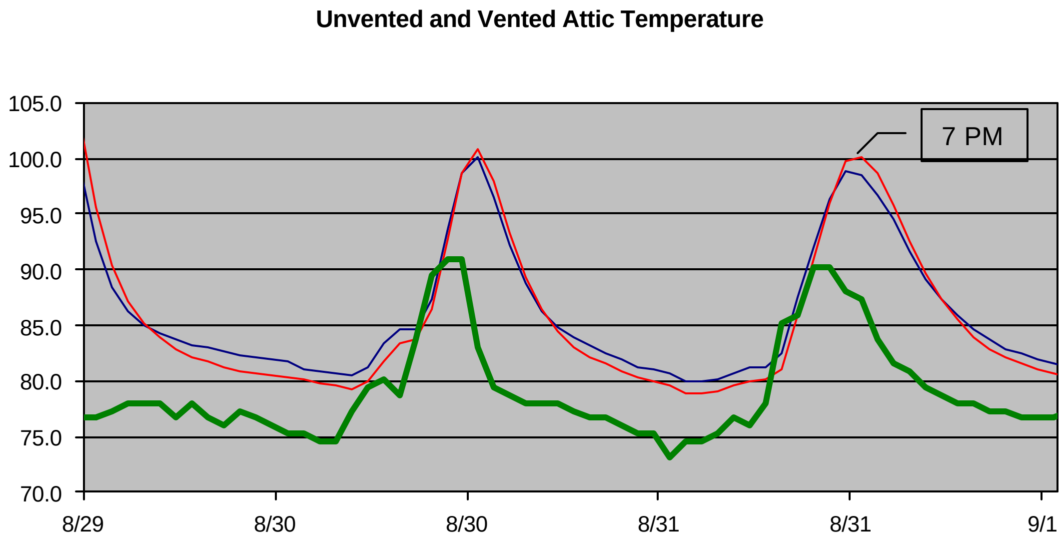


Attic air temperature differences also followed a daily sinusoidal pattern; peaks occurred around 6-7 PM, mostly in the range of 6-8° F. Note the "phase-shifting" effect, as compared with tile and plywood temperature differences. The attic air and insulation typically experience the peak difference an hour or two after the plywood.

RESULTS: ATTIC MOISTURE BEHAVIOR

A basic presentation of the results is graphs of attic air relative humidity and temperature, as shown below.





The unvented attic relative humidity was consistently lower than the vented attic. Peaks in temperature were in early evening (5-7 PM) and peaks in humidity were coincident with lowest temperatures. Some of the difference in relative humidity is attributable to the difference in temperature (i.e., higher temperatures result in lower relative humidity), however, an 80 to 78° F temperature drop is only equivalent to ~5% or less RH change. Therefore, there is a difference in absolute moisture content, as shown by measurement of the attic air dew point.

Rudd and Lstiburek (1997) noted that the attic dewpoint can rise above the outdoor dewpoint during the day (thus raising the likelihood of condensation) due to sorption and desorption of moisture from the wood framing members in day-night cycles. The process was described as follows:

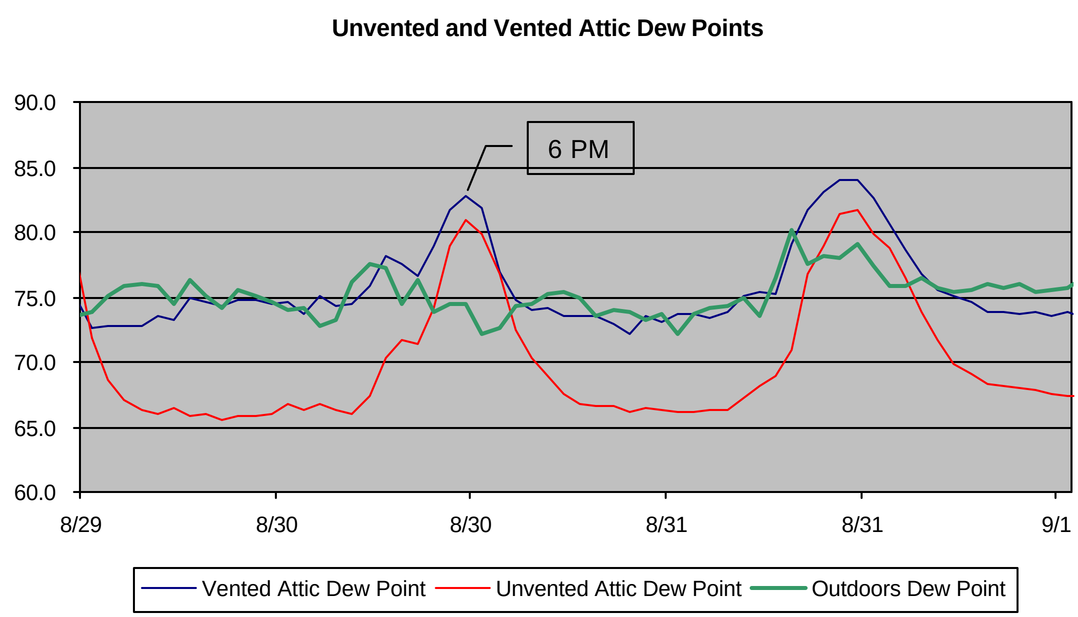
Nighttime

- **high attic air relative humidity due to air exchange with outdoors**
- **lower surface relative humidity of wood framing materials**
- **resulting in moisture being adsorbed by wood framing materials**
- **attic air dewpoint similar to outdoors**

Daytime

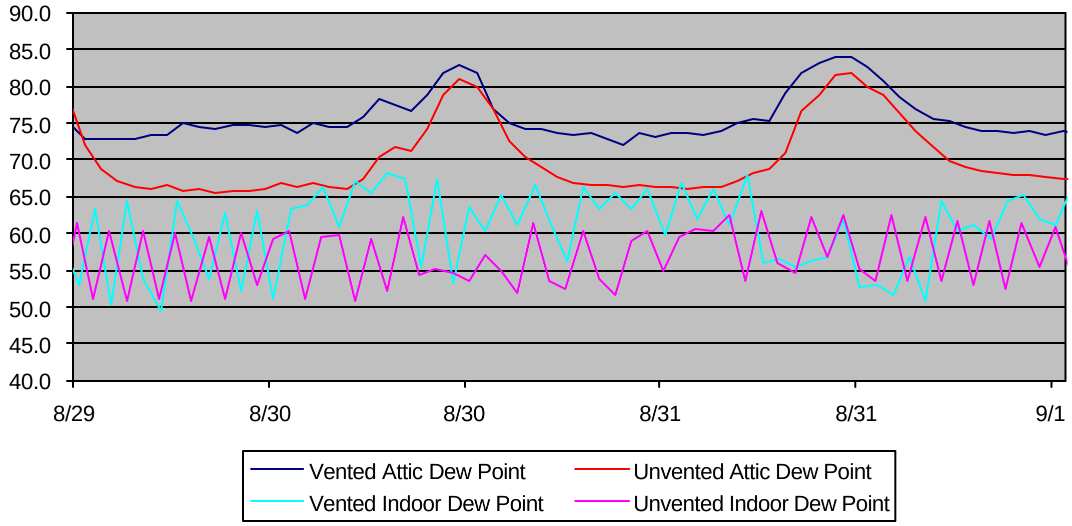
- **lower attic air relative humidity due to sensible solar heat gain**
- **higher surface relative humidity of wood framing materials**
- **resulting in moisture being desorbed by wood framing materials**
- **attic air dewpoint elevated above outdoors**

This behavior is seen in the vented roof in the graph below; attic dewpoint (blue) is greater than outdoors (green), peaking at early evening (~6 PM). During the late evening and morning, attic dewpoint is similar to outdoor dewpoint.



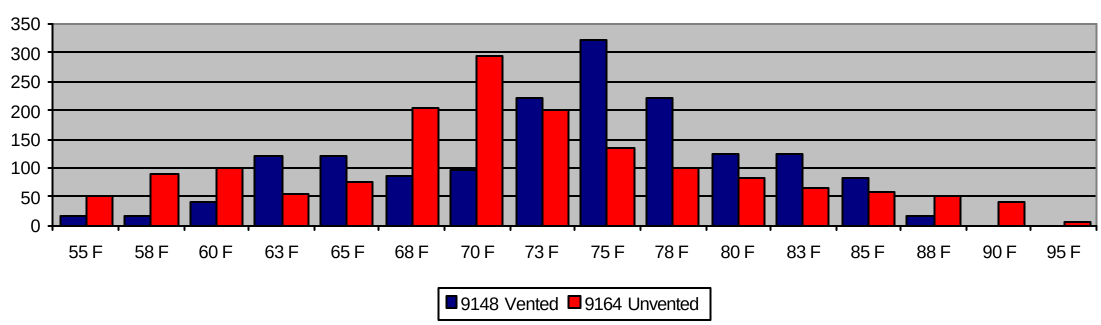
In the unvented attic, however, the attic dewpoint drops below the outdoor dewpoint significantly; this is most pronounced from the evening through late morning. Furthermore, the peak dewpoint measurements are lower than that of the vented attic (although they are greater than outdoor dewpoint measurements).

Attic and Indoor Dew Point Temperatures



This graph repeats the vented and unvented data, with the indoor dewpoint data shown in comparison. The indoor dewpoint is lower and more stable.

Dew Point Temperatures



The following shows the distribution of dew point temperatures in the two attics. The unvented attic shows a consistently lower trend in dew point temperature, but a wider variation (maximum of 91.1° F, vs. 87.1° F for vented).

Dew Point Temperatures	**Vented**	**Unvented**	**Difference**
Mean	72.2	70.0	(2.2)
Maximum	87.1	91.1	4.1
Minimum	52.5	50.1	(2.4)
Standard Deviation	7.0	8.6	1.5

ENERGY IMPACTS OF ROOF VENTILATION

This study did not measure energy consumption directly; however at the conclusion of data collection, utility bills will be interpreted to note any major difference in overall energy use.

The unvented attic will likely give lower energy consumption due to lower air change for house. Attic ventilation allows wind pressures to operate on the leaky ceiling plane, therefore increasing infiltration or exfiltration. There is a minimal thermal penalty for not venting: the sensible load in the unvented house is higher, but it appears to be offset by latent load being lower.

A simple model was used to estimate the difference in sensible load through conduction through the ceiling in these two houses. Hourly average insulation top temperatures were subtracted from a fixed setpoint (75° F); the hourly Btu conduction was computed using the temperature difference, the roof insulation value (R-30), and the ceiling area. The difference over the three months of data collected was approximately 15%. However, this is a simplified calculation that only covers conduction, without thermal storage factors. In addition, the ceiling contribution to the total cooling load is approximately 5-7%, resulting in a whole-house load increase of only 1-2%. Finally, this calculation does not take into account the above-mentioned factors of air change effects of venting, as well as latent load effects.

The relative magnitudes of the combined effects might best be seen by using the measured temperature and moisture data with a computer model to estimate overall energy consumption.

CONCLUSIONS

After monitoring temperatures and moisture conditions in the two test houses over three months (September through October), several conclusions could be drawn about the effect of venting on thermal and moisture performance. The temperatures of roof components (tile, sheathing, and insulation) were slightly elevated in the unvented house, but the effect on building durability appears to be minimal.

Attic air temperature was increased (maximum peak difference of 10° F) in the unvented house; however, the overall energy effect of this change is minimal. The elimination of attic venting reduces latent load, as well as infiltration and exfiltration due to wind pressures acting on the leaky ceiling plane. Therefore, overall energy performance may be improved by eliminating attic ventilation.

The unvented roof showed superior moisture performance, as humid outdoor air was no longer being introduced through vents. The attics showed the sorption-desorption behavior noted by Ford (1982).

Overall, more study is recommended. Data will be collected again at the end of the winter, and at the end of the following summer.

DATALOGGING EQUIPMENT SUMMARY

The following equipment was installed in each house.

Attic:

Omega HX-93 (RTD Temperature & RH)
Onset Computer HOBO (Temperature & RH)
Type T Thermocouples: attic air, tile temperature, sheathing temperature, insulation top temperature.

Return:

Omega HX-93 (RTD Temperature & RH)
Onset Computer HOBO (Temperature & RH)

Data collection:

Campbell CR10X Datalogger

Outdoor conditions were recorded by the following equipment:

Onset Computer HOBO Pro (Temperature & RH)

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About this Report

This report was prepared with the cooperation of the U.S. Department of Energy's, Building America Program.

About the Author

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