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ENERGY AND MOISTURE PERFORMANCE OF ATTIC ASSEMBLIES

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ABSTRACT

The effect of natural ventilation in a residential attic cavity has been the topic of many debates and scholarly reports since the 1930s. The purpose of ventilating an attic cavity is to prevent collection of condensate on the structural surfaces and to create a thermal buffer between the conditioned space and the ambient air. Additionally, the energy and moisture performance of attic assemblies can be varied by a large number of construction features that have been recently introduced into the marketplace. Specifically, the introduction of underlayments with highly variable water vapor permeances, the inclusion of a radiant barrier, a cool roof, the amount of ventilation area, and above-sheathing ventilation all can change how an attic performs hygrothermally. The recent use of sealed attics and the movement of the insulation from the attic floor to the rafters can also impact attic performance.

SPEAKER

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ENERGY AND MOISTURE PERFORMANCE OF ATTIC ASSEMBLIES

INTRODUCTION

Natural ventilation became part of a standard attic design in the late 1930s. In 1939, the Federal Housing Administration set a natural ventilation area ratio standard as a means of minimizing condensation on the underside of the roof sheathing. This requirement was the result of the research performed by Frank Rowley, professor at the University of Minnesota, and published in ASHRAE Transactions (Rowley, Algren, and Lund, 1939). Rowley concluded that natural ventilation openings are required for the circulation of air in the attic space to prevent surface condensation on the underlayment of the roof. Following Rowley's work, the National Housing Agency published "Property Standards and Minimum Construction Requirements for Dwellings" for the Federal Housing Administration (FHA) in 1942. This document contains the first record of the 1:300 specifications. (FHA, 1942).

Attics have dramatically changed since the days of Rowley. Cool roofs now represent a growing portion of the overall residential market. Underlayments with water vapor permeances ranging from near 0 to 100 perms are available in the marketplace. Radiant barriers are traditionally installed in attics located in cooling-dominated climates. Above-sheathing ventilation (ventilation space created between the roof sheathing and waterproofing layers) has shown promise in improving the energy efficiency of attic assemblies. Airtightness of building envelopes has increased. Finally, the introduction of sealed attics (moving the insulation layer from the attic floor to the roof sheathing and eliminating attic ventilation) has been proposed as an energy-efficient and durable solution related to the entry of moisture-rich air in hot and humid climates and the need to recapture energy losses from a leaky distribution system located in the attic space. The result of this experiment showed that sealed attics with an air and thermal barrier on the sloped roof deck can be built without associated energy penalty in hot climates, as compared to traditional ventilated constructions (Rudd and Lstiburek, 1998).

The purpose of this research project was to create attic assemblies that included all of the features that would impact the hygrothermal performance of an attic assembly. An existing test facility was modified to accept a family of different attic assemblies. These assemblies were instrumented and monitored for a period of more than one year. These test data are used to compare performance between the attic assemblies and to validate a computer simulation tool that can extend the comparisons to other assemblies and climates.

The Facility and the Experiments

A series of experiments was planned to be performed on the South Carolina Natural Exposure Test Facility (NET) located in Charleston, SC. A photo of the facility is shown in *Figure 1*. This facility was constructed in 2004 and was originally used to test wall systems. The footprint of the NET is 80 ft. long by 25 ft. wide with the long dimension facing south. The roof was a traditionally constructed rafter system with 2 by 6 rafters, 24 inches on center; oriented strand board sheathing; and a slope of approximately 4:12.

For these experiments, the attic of the NET was subdivided into seven separate attic modules, with divider walls constructed to create the individual attics. The divider walls were approximately R-15 and were air-sealed. The old roof and sheathing were completely removed and replaced during the construction. The interior of the NET is both temperature- and humidity-controlled. During the course of the experi-

ments, the interior conditions were maintained at 75°F and 45% relative humidity.

Descriptions of the test attics follow. The attics are described in the same order that they appear in the NET starting on the west side of the building (left side of *Figure 1*). A schematic of the attic assemblies is shown in *Figure 2*.

Attic 2: Sealed Attic (SLD)

This attic has 5.5 in. of open-cell foam installed on the roof sheathing. The sheathing is covered with 15-lb. felt paper (8 perms) and traditional, dark-colored shingles with a solar reflectance of 10%. This attic is unventilated and has no insulation in the attic floor. The attic assemblies were installed in May 2010.

Attic 3: Nonbreathable Underlayment (NB)

This attic has R38 fibrous-batt insulation installed on the attic floor. The sheathing is covered with a nonbreathable sheet underlayment (0.04 perms) and traditional dark-colored shingles with a solar reflectance of 10%. Appropriate lengths of soffit and ridge venting are added to obtain a 1:300 ventilation area.

Attic 4: Cool Shingles (CC)

This attic is identical to Attic 3 except the dark-colored shingles are replaced with cool shingles that have a solar reflectance of 28%.

Attic 5: Above-Sheathing Ventilated Roof (ASV)

This attic has R-38 fibrous-batt insulation installed on the attic floor. 2-by-4 wood nailers are installed on top of the roof



Figure 1 — The southern exposure of the NET facility in Charleston, SC.

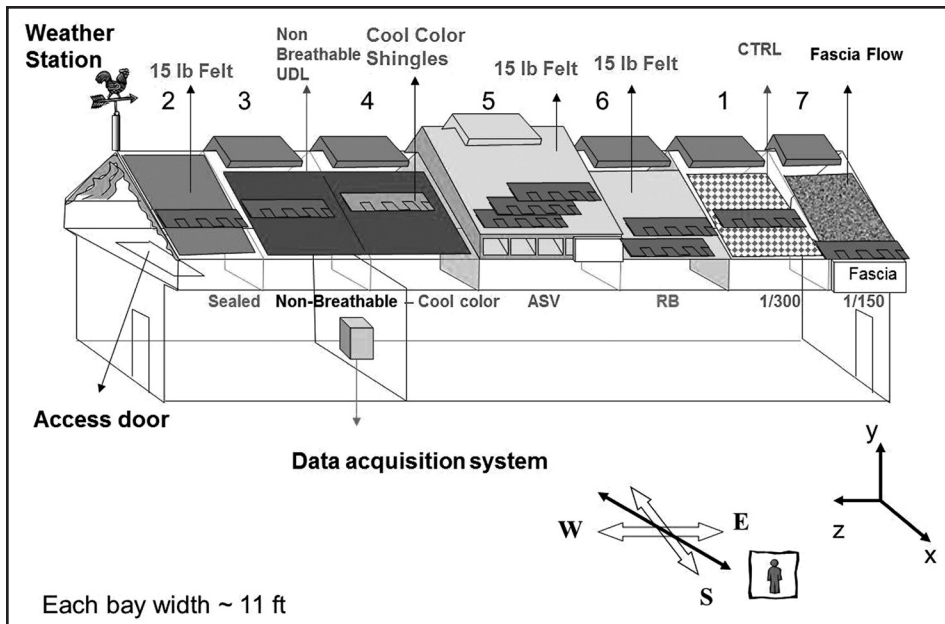


Figure 2 - Test attic assembly layout on NET facility in Charleston, SC.

sheathing, and a second layer of oriented strand board is nailed on top, creating a continuous $\frac{3}{4}$ -in. airspace between the two layers of oriented strand board that can communicate with the soffit and ridge vents. The sheathing is covered with 15-lb. felt paper (8 perms) and traditional, dark-colored shingles with a solar reflectance of 10%. Appropriate lengths of soffit and ridge venting are added to obtain a 1:300 ventilation area. A fascia vent (2 times the net-free area versus standard soffit vents) was installed on the ASV section as well as the ridge vent, while a traditional soffit vent was used for intake in the attic portion of the roof. A ridge slot cut into the roof exhausted for both ASV and attic. Hence, this bay had a higher ventilation rate than any of the other attics.

Attic 6: Radiant Barrier (RB)

This attic has R-38 fibrous-batt insulation installed on the attic floor. A radiant barrier that was factory-applied to the underside of the oriented strand board sheathing was installed in this attic. The sheathing is covered with 15-lb. felt paper (8 perms) and traditional dark-colored shingles with a solar reflectance of 10%. Appropriate lengths of soffit and ridge venting are added to obtain a 1:300 ventilation area.

Attic 1: Control Attic (CTRL)

This attic has R-38 fibrous-batt insulation installed on the attic floor. The sheathing is covered with permeable membrane underlayment (16 perms) and traditional dark-colored shingles with a solar reflectance of 10%. Appropriate lengths of

soffit and ridge venting are added to obtain a 1:300 ventilation area.

Attic 7: Increased Ventilation (FF)

This attic has R-38 fibrous-batt insulation installed on the attic floor. The sheathing is covered with an impermeable peel-and-stick underlayment (0.1 perms) and traditional dark-colored shingles with a solar reflectance of 10%. A fascia vent system is installed in this attic to increase the ventilation area to 1:150.

The Instrumentation

During the construction of the NET facility attics, sensors were attached at pertinent locations to analyze the *in-situ* performance of the individual attic bays. The sensors were placed in an identical pattern for each attic cavity to facilitate the comparison of results.

Thermistor temperature sensors were combined with relative humidity sensors by placing the two sensors in a permeable sack made of spun-bonded polyolefin to protect the sensors from contact with water. Thermistor temperature sensors are also used for the sensing shingle underside temperature, as well as the temperature across the fiberglass insulation. Figure 3 depicts the location of these sensors within the attic assembly.

Heat flux transducers (HFTs) were attached to the underside of the roof decks, as well as on the surface of the gypsum board on the attic floor, as shown in Figure 3. These precalibrated devices generate an electrical signal proportional to the total heat rate applied to the surface of contact and allow collection of conductive heat flux data through the inclined roof decks and the attic floor. The HFTs must be calibrated in the configuration that they will be operating. Therefore, the roof deck HFTs were calibrated in a surface-applied configuration, and the attic floor HFTs were calibrated in between gypsum board and fiberglass insulation using a heat-flow-meter apparatus.

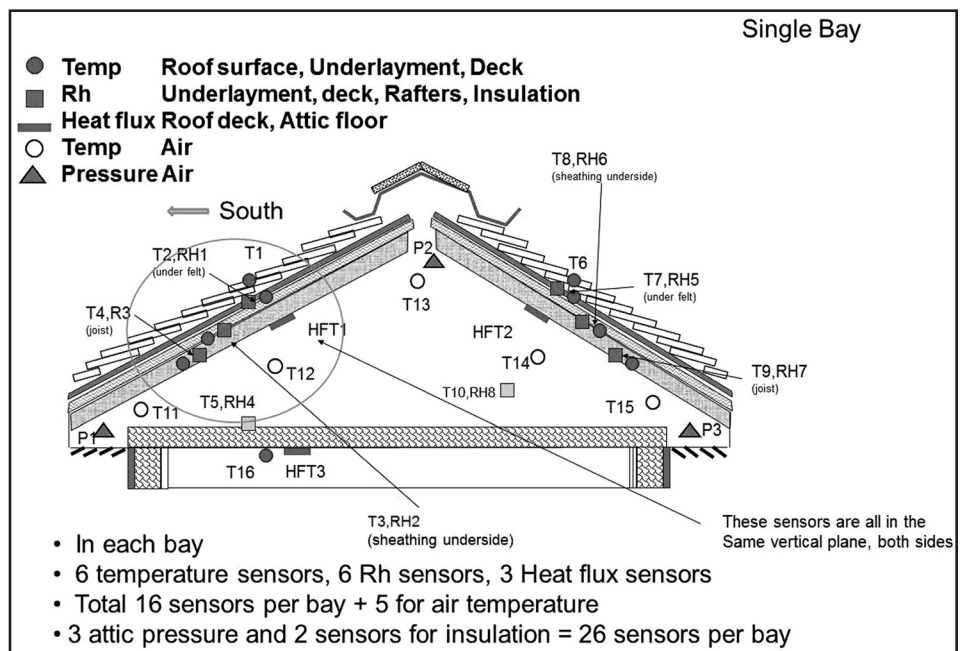


Figure 3 - Instrumentation layout for each attic assembly.

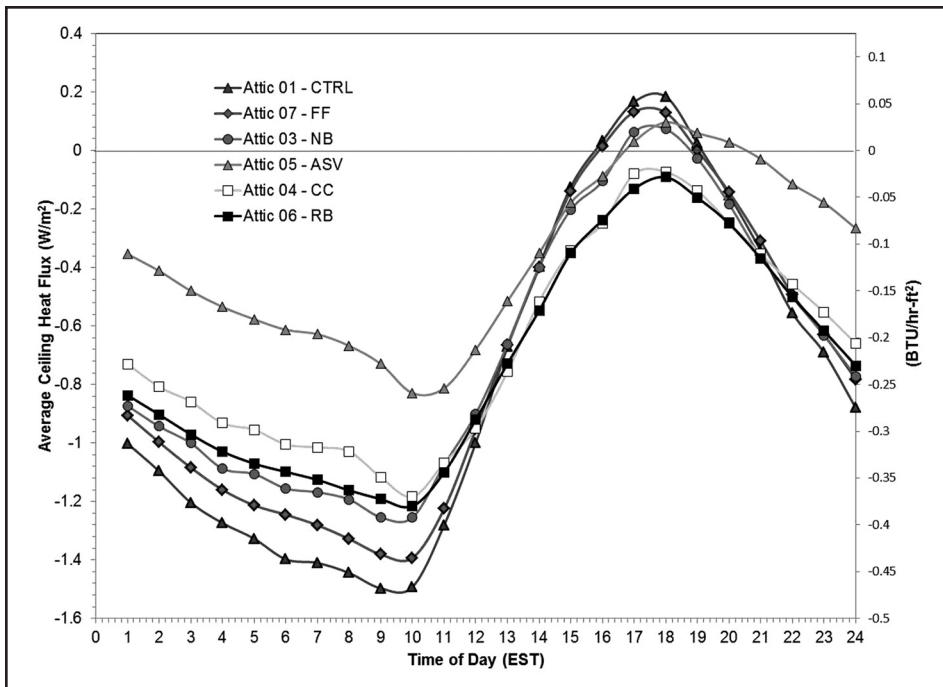


Figure 4 – Average winter comparative heat flux.

Pressure taps were installed near the ridge and each soffit to estimate the ventilation flow rate. Taps were also installed on the south and north façades of the building and in the building interior. Weather data are collected on the roof of the NET facility and include wind speed and direction, solar irradiance, rainfall, ambient temperature, relative humidity, and pressure.

Data from all of the sensors are recorded continuously several times a minute into the data acquisition system inside the NET facility. Weekly, these data are downloaded to the ORNL campus for processing. Data collection started in August 2010 and, as of this writing, is ongoing.

To simulate moisture generation from occupied home conditions, moisture was added to these attic spaces by installing a humidifier in each attic (except in the sealed attic). The relative humidity level was determined using an earlier ORNL study of relative humidity in several attics from hot/humid climates and was varied on a monthly schedule.

The Experimental Results

There are numerous comparisons that can be made with the data gathered in this research project, and only some of these comparisons have been concluded to date. A sampling of the data and some of the initial conclusions will be discussed in this section of the paper.

Winter Ceiling Heat Flux Comparison

Heat flux through the attic floor into the conditioned space has been determined to be a primary indicator of an attic's comparative load on the HVAC system of a building. Each attic in the facility was outfitted with a heat flux transducer to measure the amount of heat entering (or leaving) the conditioned space. During the summer and winter months of 2011, these data were analyzed in BIN averages as well as on the

basis of an overall integrated value for comparison. Winter ceiling heat flux is shown in Figure 4 on the basis of a time-step BIN average.

The sign convention of the ceiling HFTs is positive for heat flowing from the attic into the conditioned space. As expected, in winter, the heat flow is mainly in the negative direction, indicating an attic space that is cooler than the conditioned space. The data suggest that the CC and RB attics remain cold enough that, on average, the direction of heat flow never reverses.

Attic 5, outfitted with above-sheathing ventilation, has the least average diurnal variation (amplitude of oscillation across the zero line). It also shows the least amount of heat lost from the conditioned space during the early morning.

Open-cell spray foam was applied to the roof deck and gable ends of Attic 2 to form a sealed (SLD) attic. Once cured, the foam fully covered the 2-by-6 rafters, and its R-value was computed at about R-22. Sealed attics recommend no insulation in the attic floor; hence, its heat flux values are much higher and vary more than other attics.

Figure 5 illustrates the large difference in ceiling flux for the SLD compared with the CTRL and ASV attics.

The primary reason for sealing the attic is to capture lost energy from a leaky distribution system and use it to make the attic part of the conditioned space. If the attic air is relatively close to the conditioned temper-

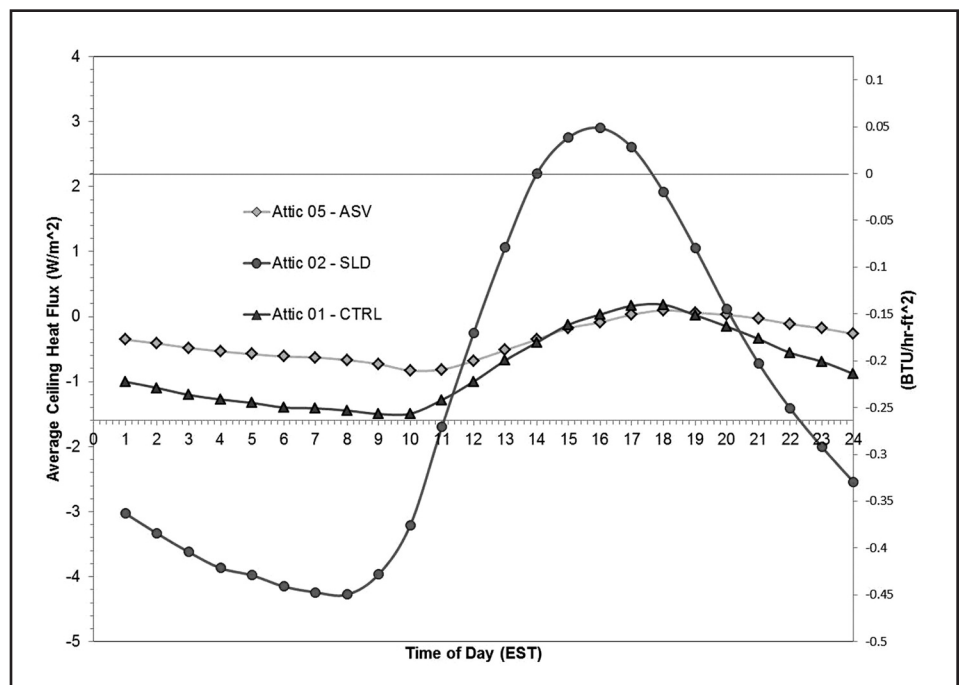


Figure 5 – Sealed attic ceiling winter heat flux.

$$\text{Total Integrated Flux} \left[\text{hr} * \frac{\text{W}}{\text{m}^2} \right] = \sum_{n=0}^m .5 * \Delta X_n * (Y_n + Y_{n+1})$$

Equation 1

ature, then the ceiling flux will be negligible. A concern with the sealed attic is that the retrofit increases the volume of the conditioned space, and the heat system must run longer to satisfy the increased load.

The collected winter data were reduced into the total integrated flux, and results are provided in *Table 1*. This integration was performed by a simple application of the trapezoidal rule. See *Equation 1*.

Where Y_n and Y_{n+1} correspond to the current and future time step, ΔX_n is the time step (one hour in this case), and the subscript “m” denotes the final point in the series, which varies depending on the summer or winter data sets. Keep in mind that this integration represents a summation of the area under the curve of the heat flux, which also takes into consideration negative values; therefore, the total integrated heat flux should be considered an overall value.

Overall, the ASV attic reduces the total heat flux through the attic floor by 53% as compared to the control (CTRL) attic. CC and RB show comparable reduction of 14.8% and 11.2%, respectively, which agrees with the graphical results of BIN-averaging the data in *Figure 4*. Another important observation is that 1:150 accounts for a 7% reduction in ceiling heat flow over a 1:300 attic.

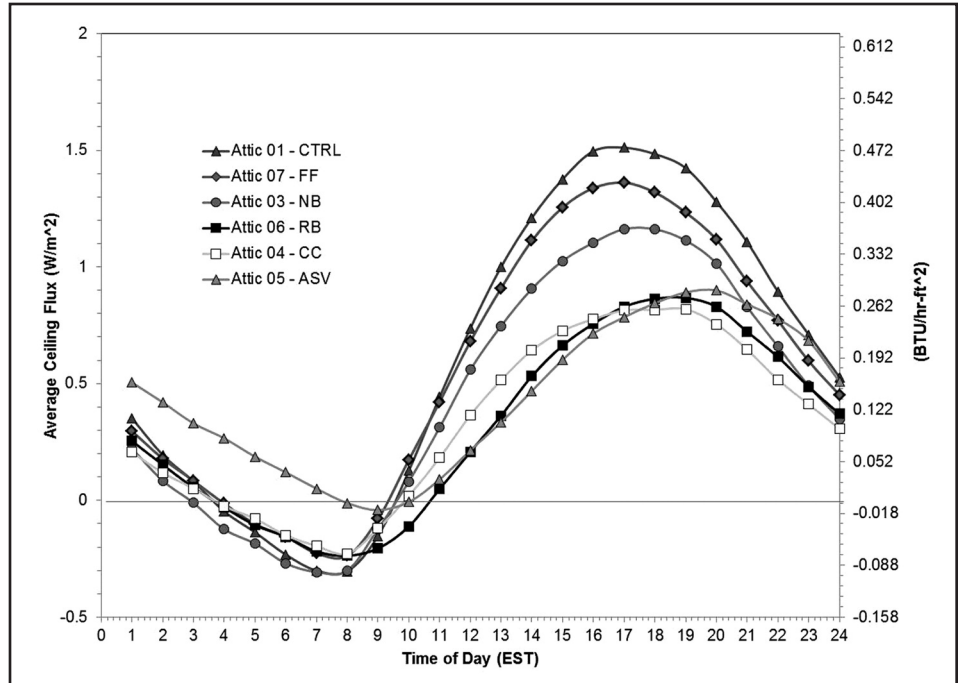


Figure 6 – Summer ceiling heat flux.

Summer Ceiling Heat Flux Comparison

Observing heat flux through the attic floor is especially important during the summer months, because the temperature of the attic can reach upwards of 50°C (122°F), and that temperature difference drives the heat from the attic into the conditioned space at a generally larger magnitude than in the winter. The BIN average heat flux through the attic floor is shown in *Figure 6*. All attics, with the exception of the ASV case, have a window of time from 3:00 AM to 9:00 AM where the heat flux is negative. For this period, the temperature in the attic cavities is, on average, less than the conditioned space.

Attics ASV, CC, and RB demonstrate

relatively the same level of ceiling flux, with an average peak flux value of 0.86 W/m². Adding the low-permeance membrane appears to increase the heat flux by 0.35 W/m². Increasing the ventilation area from the NB at 1:300 to the FF at 1:150 increases the heat flux from the NB peak of 1.16 W/m² to the FF peak of 1.36 W/m², which is an increase of 0.2 W/m².

In the summer season, the radiant barrier and cool color shingles show the greatest benefit in minimizing the heat flow through the attic floor. As compared to the CTRL, the RB and the CC show a similar 43% reduction in total integrated ceiling heat flow. This pattern is logical because the increased reflectivity of the cool color shingles and the long-wave radiation shielding of the radiant barrier offer protection against incident solar radiation, the dominant mode of summer heat transfer in an attic cavity. See *Table 2*.

Addition of above-sheathing ventilation results in a 29% reduction against the standard, followed closely by the use of a low-permeability membrane at 24%. Similar to

WINTER			
Attic	Feature	Total Integrated Ceiling Heat Flux [$\frac{\text{kJ}}{\text{m}^2}$]	Reduction From CTRL (%)
05	ASV	-2700	53%
04	CC	-4896	15%
03	NB	-5100	11%
06	RB	-5287	8%
07	FF	-5325	7%
01	CTRL	-5746	Base
02	SLD	-9735	-69%

Table 1 – Total integrated ceiling heat flux (winter 2011).

SUMMER			
Attic	Feature	Total Integrated Ceiling Heat Flux [$\frac{kJ}{m^2}$]	Reduction From CTRL (%)
06	RB	4582	44%
04	CC	4666	43%
05	ASV	5779	29%
03	NB	6201	24%
07	FF	7288	10%
01	CTRL	8122	Base
02	SLD	37012	-356%

Table 2 – Total integrated heat flux (summer 2011).

the winter data, the 1:150 FF (as compared to the CTRL) attic results in a 10% reduction in total integrated ceiling flux.

The SLD attic is of keen interest because its integrated ceiling flux is 356% more than that of the CTRL attic. In other words, the sealed attic increases living space cooling load by 356% as compared to a conventional 1:300 attic.

Winter Moisture Control in Attics

A concern about attic construction is the accumulation of moisture in the moisture-sensitive components during that period of time when moisture would be driven from the conditioned space and inserted into the attic. For the NET facility, this period would be from December through March.

We investigated the temperatures of the OSB underlayment in each attic to determine if there was potential for surface condensation based on surface temperature depression below the dew point temperature of the air. Attic air dew point temperature was calculated using a standard ASHRAE routine and compared to the field data on an hour-by-hour basis. Condensate occurs when the dry-bulb temperature of a surface is depressed below the dew point temperature of the surrounding air, which, in this case, is the air inside the attic cavity. The method chosen to calculate the dew point temperature (T_{dp}) for this report is a simple estimation based on a psychrometric state point determined by a known air temperature and relative humidity. Note that Equation 3 is specifically for temperature units of Celsius. Coefficient “a” in Equation 3 is 17.27, and coefficient “b” is 237.7 (Simmons, 2008). See Equation 2.

The total number of times that the surface temperatures of the wood joist or the

data collection as a percentage, Table 3.

According to Table 3, the ASV attic has the best surface condensation moisture control, with the possibility of condensation at only 1% of the recorded time. The increased ventilation FF attic does provide better dew point control than the NB attic, with a 1.7% decrease for the sheathing and a 2.0% decrease for the joist. As expected, the breathable underlayment reduces condensate potential by 33% in the joist. Note that the SLD attic was not included in this table because the sheathing has no direct contact with the attic air.

Modeling the Attics

To be able to extend the experimental data gathered during this series of tests, a thermal model of the attic was used. AtticSim (Wilkes and Rucker, 1983; Wilkes, 1991a; Wilkes, 1991b) is a computer tool for predicting only the thermal performance of attics. It mathematically describes the conduction through the gables, eaves, roof deck, and ceiling; the convection at the exterior and interior surfaces; the radiosity heat exchange between surfaces within the

$$T_{dp} = \frac{b \left(\ln(RH) + \frac{aT_{db}}{b+T_{db}} \right)}{a - \ln(RH) - \frac{aT_{db}}{b+T_{db}}}$$

Equation 2

attic enclosure; the heat transfer to the ventilation air stream; and the latent heat effects due to sorption and desorption of moisture at the wood surfaces. Solar reflectance, thermal emittance, and water vapor permeance of the sundry surfaces are input. However, AtticSim is a heat transfer model, and it does not model moisture transport in roof systems.

The model can account for different insulation R-values and/or radiant barriers attached to the various attic surfaces. It also has an algorithm for predicting the effect of air-conditioning ducts placed in the attic. The code reads the roof pitch, length, and width and the ridge orientation (azimuth angle with respect to north) and calculates the solar irradiance incident on the roof. Conduction heat transfer through the two roof decks, two gables, and vertical eaves are modeled using the thermal response factor technique, which requires the thermal conductivity, specific heat, density, and thickness of each attic section for calculating conduction transfer functions. Heat balances at the interior surfaces (facing the attic space) include the conduction, the radiation exchange with other surfaces, the convection, and the latent load contributions. Heat balances at the exterior surfaces balance the heat conducted through the attic surface to the heat convected to the air, the heat radiated to the surroundings, and the

attic enclosure; the heat transfer to the ventilation air stream; and the latent heat effects due to sorption and desorption of moisture at the wood surfaces. Solar reflectance, thermal emittance, and water vapor permeance of the sundry surfaces are input. However, AtticSim is a heat transfer model, and it does not model moisture transport in roof systems.

WINTER					
Attic	Feature	Hours $T_{sheath} < T_{dp}$ (2,015 total)	% Time for Condensation on Sheathing	Hours $T_{joist} < T_{dp}$ (2,015 total)	% Time for Condensation on Joist
05	ASV	20	1.0%	10	0.5%
07	FF	75	3.7%	32	1.6%
06	RB	83	4.1%	26	1.3%
01	CTRL	102	5.1%	48	2.4%
04	CC	103	5.1%	62	3.1%
03	NB	110	5.5%	72	3.6%

Table 3 – Surface condensation potential.

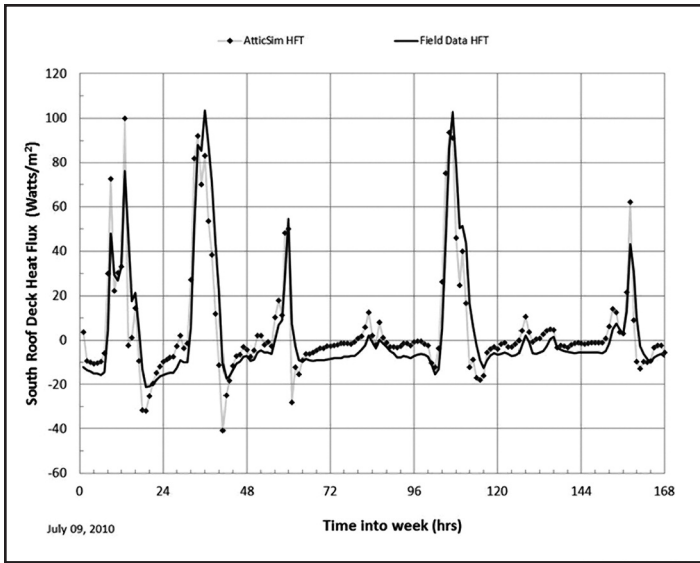


Figure 7 – Comparison of measured and modeled heat flux through the south roof deck.

heat stored by the surface. Iterative solution of the simultaneous equations describing the heat balances yields the interior and exterior surface temperatures and the attic air temperature at one-hour time steps. The heat flows at the attic's ceiling, roof sections, gables, and eaves are calculated using the conduction transfer function equations. The tool was validated against field experiments and is capable of predicting the ceiling heat flows integrated over time to within 10% of the field measurement. AtticSim has been developed into ASTM Standard C1340, *Standard Practice for Estimation of Heat Gain or Loss Through Ceilings Under Attics Containing Radiant Barriers by Use of a Computer Program* (ASTM, 2004) and is available for general use.

Validating the AtticSim Model

AtticSim was used to estimate the heat flux into the roof sheathing and through the ceiling for the CTRL test attic. Comparisons of these modeled heat fluxes for a week in the summer, with their corresponding measured heat fluxes, are shown in *Figures 7* and *8*. In *Figure 7*, the heat flux from the model (bold line) agrees very well with the measured data. The data in *Figure 8* does not show as good a comparison but does capture all of the trends created by the varying meteorological conditions imposed on the attic. The AtticSim model overpredicts heat flux in conventional attics. The small heat fluxes going through the ceiling make this a critical comparison. The greatest uncertainty in this analysis is the R-value of the fibrous insulation, which is typ-

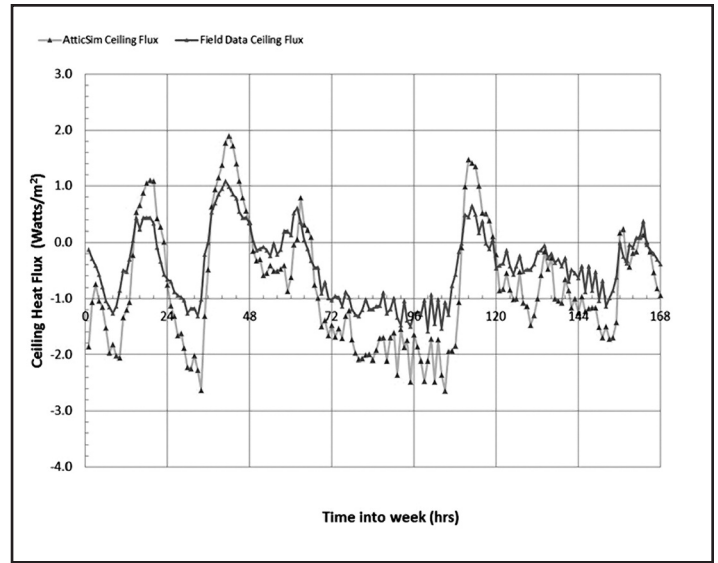


Figure 8 – Comparison of measured and modeled heat flux through ceiling.

ically within +/- 5% of the label value that was used for the analysis.

Using the AtticSim Model to Study Ventilation

Using a standard year of typical meteorological year (TMY2) data (ASHRAE, 2009), a yearlong performance of the NET facility was modeled, with a particular focus on the variation of ventilation. The effect of varying the ventilation area is observed by taking three of the attics (CTRL, RB, and ASV) and performing a parametric study on varying ventilation rates. Equal part soffit and ridge

ventilation areas were varied in each attic at footprint-to-ventilation area ratios of 1:25, 1:50, 1:150, 1:300, and 1:500 to show an overall effect of modifying the ventilation area heat transfer buffering to the conditioned space. (Note that we cannot control moisture in AtticSim.) Increasing the ventilation area ratios increases the actual orifice area through which wind-driven flow passes. AtticSim calculates the air-change-per-hour (ACH) values at each hour, based on an empirical routine developed for soffit and ridge vent systems (Burch and Treado, 1979). This ACH computation has been

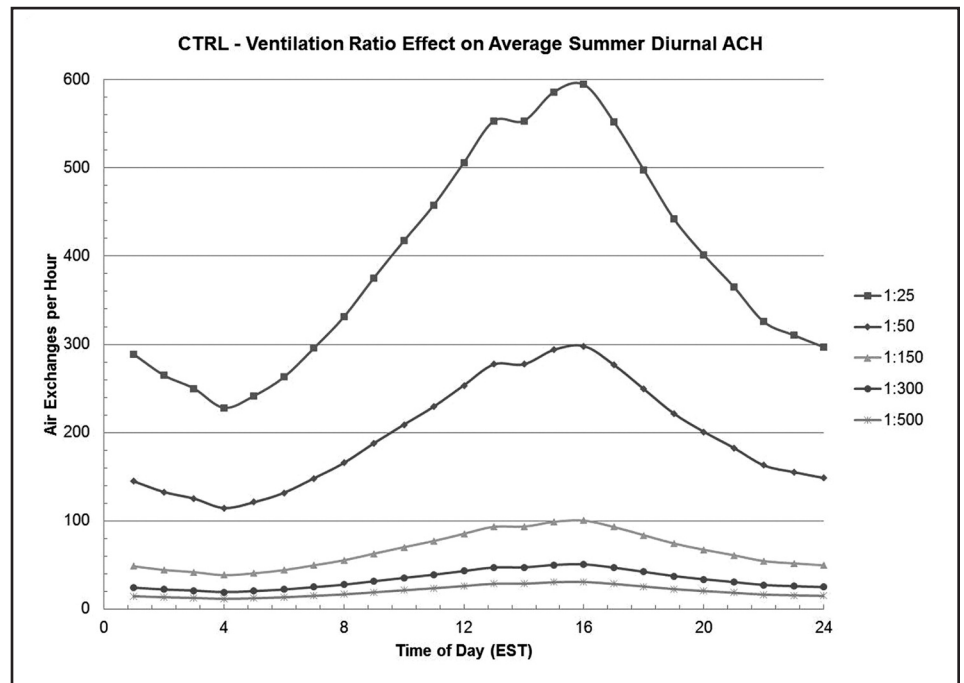


Figure 9 – Ventilation ratio effect during average summer day.

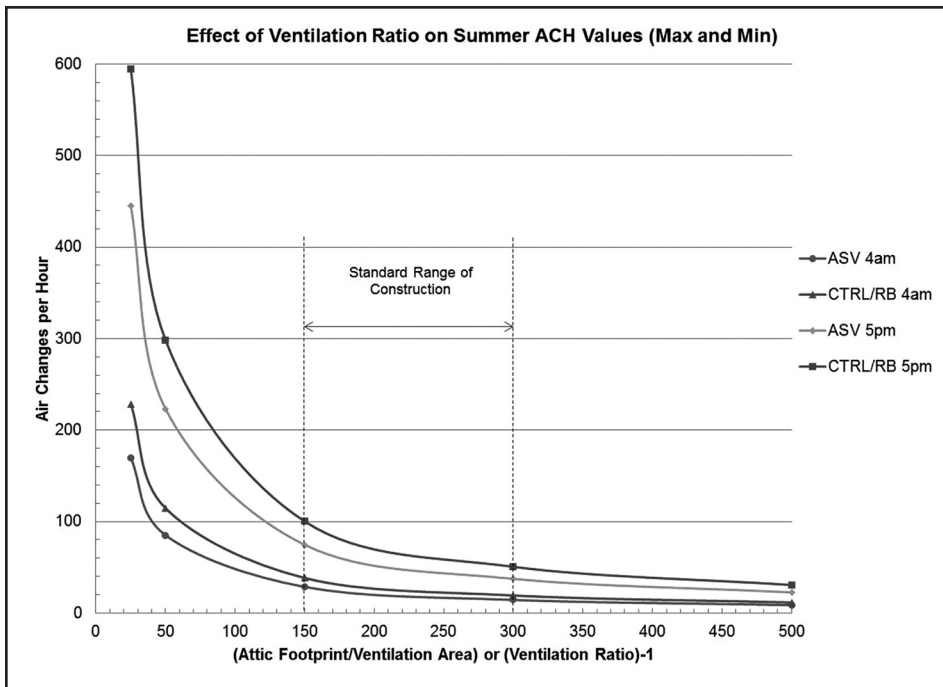


Figure 10 – Effect of ventilation ratio on maximum and minimum summer ACH values.

benchmarked to the NET facility via tracer gas analysis. Average diurnal ACH values in the CTRL attic are presented for the summer season in *Figure 9* to show the effect of increasing ventilation ratio on the flow rate during the course of a typical summer day.

The effect of increased ventilation ratio is an increase in flow rate over the entire diurnal cycle, but also in the amplitude of the maximum ventilation at the peak, from 30 ACH at 1:50 to 594 ACH at 1:25. Maximum ventilation takes place at approximately 5:00 PM, with minimum ventilation occurring at 4:00 AM.

Increasing the ventilation area for the attic cavity would logically increase the air-flow rate up to a certain point where the model would approach the situation of a system of flat plates suspended in an open airstream. Therefore, there is an obvious limit to how much airflow one can achieve by increasing the ventilation area. This limit is shown in *Figure 10*, where the effects of increasing the ventilation ratio are shown on the maximum and minimum ACH values during the summer season.

As seen in *Figure 10*, as the scale of data approaches 1:50, the ACH prediction increases exponentially. The reality, however, is that an attic will never be constructed with a ventilation ratio close to 1:50. At this point, the attic is no longer operating as an effective barrier against inclement weather. The range in ventilation ratio that most

effectively increases the attic’s ACH (without approaching the limit of reasonable ventilation area) is roughly 1:300 to 1:100.

Even more important than the effective increase of the ventilation rate is the prevention of condensation on the surfaces of the attic. Condensation potential on the OSB sheathing was calculated by simulating the dew point temperature of the attic air and comparing the predicted sheathing temperature against it. The percentage of total time for condensate potential is shown in *Table 4*, such that the results will emulate the results of the field data analysis previously shown.

The simulation results show that an increase in ventilation area consistently decreases the potential for condensation on the OSB sheathing. However, the magnitude of the effect is relatively small in comparison to the difference seen by changing the attic type. For example, the result of increasing the ventilation area in a CTRL attic from the standard 1:300 to 1:50 is a decrease of only 0.2%. If the CTRL attic with

a ventilation area of 1:300 is retrofitted with an ASV system, however, the percentage potential for sheathing condensation is 2.9%, a decrease of almost 10%.

The addition of the radiant barrier to the attic sheathing has the effect of keeping the surface cooler during the night during the winter months. This is explained by the simple fact that the radiant barrier halts the long-wave radiation down through the roof deck during the daylight hours and then performs the same way with the heat from the conditioned space during the night and early morning hours, which would depress the temperature of the OSB. Since the early morning hours are the most likely time for condensation potential, the cooler surface of the OSB would lead to a higher likelihood that condensation would occur.

These results are higher than the measured results presented in *Table 3*. Several reasons for the differences include the fact that the measured data were acquired during a very mild winter and that the leakage rate from the conditioned space to the attic may not have been comparable between the testing and simulation.

Simulations were run to compare the effect of ventilation on the ceiling heat flux, which is a best indicator of the influence the attic cavity has on the HVAC system of a residence. The data presented for these simulations are shown on time-of-day BIN averages to mirror the presentation style of the field data. Summer simulation shows that the average peak ceiling heat flux in the CTRL attic occurs at approximately 5:00 PM, at which point the maximum stratification of ventilation effect is observed in *Figure 11*. The results of the ASV and RB simulations are similar. As observed in experimental data, the model predicts that using a 1:150 attic lowers the heat in the living space by 7% as compared to a 1:300 attic.

CONCLUSIONS

A series of field experiments was performed on seven attics exposed to meteorological conditions in Charleston, SC. These data were used to validate AtticSim, a tran-

Percent of total time in which $T_{\text{sheathing}} < T_{\text{dp}}$					
Attic Type	1:25	1:50	1:150	1:300	1:500
RB	15.4%	15.9%	16.4%	17.0%	17.2%
CTRL	11.4%	11.8%	12.5%	12.7%	12.6%
ASV	2.8%	2.8%	2.8%	2.9%	2.7%

Table 4 – TMY2 results of sheathing condensation potential.

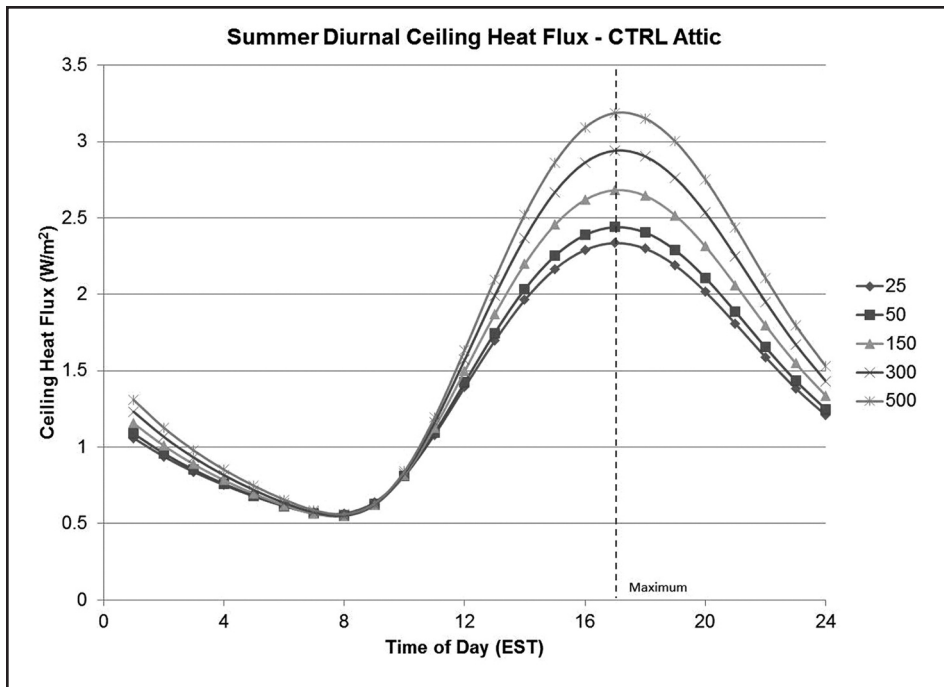


Figure 11 – Average result of summer diurnal ceiling heat flux simulations.

sient hourly attic simulation model.

Increasing ventilation to 1:150 from 1:300 reduces heat load by 10% in summer and reduces heating load by 7% in winter. Increased ventilation to 1:150 also reduces the condensation potential by 33% as compared to the 1:300 attic.

Sealed attics put the highest heat load on the living space compared to any other attic strategy. A sealed attic increases heat by 356% in the summer over the 1:300 attic and takes away 69% more heat in the winter as compared to the 1:300 attic. Hence, both in summer and winter, there is a very large energy penalty.

Field data on the ceiling flux heat transfer showed that the ASV attic had the least average diurnal variation over the winter 2011 season, with the least amount of heat lost from the conditioned space during the early morning (1:00 – 6:00 AM). Integration of the total heat flux over the winter season shows that the ASV attic reduces the total heat flux through the attic floor by 53% as compared to the CTRL attic.


Integration of the summer data showed that, when compared to the CTRL attic, the RB demonstrates a 44% reduction, and the CC shows a similar 43% reduction in total integrated ceiling heat flow. Addition of above-sheathing ventilation results in a 29% reduction against the standard.

As expected, cool-colored shingles reduce the heat load by 43% in summer. However, the shingles also help in reducing heating load by 15% during winter. Cool-colored shingles with a low-perm underlayment work as effectively as RB systems and work better than ASV in reducing heat load in summer.

Low-perm underlayments show some benefit in reducing heat load and need further investigation.

Measurements indicate that increasing the ventilation ratio decreases the condensation potential from 5.1% to 3.7% during the winter months, whereas the ASV attic reduces the potential to a mere 1.0% throughout the year.

Modeling the impact of ventilation on ceiling energy performance suggests that only modest improvements are made by increasing the ventilation rate. Doubling the ventilation area, for example, yields a reduction in peak heat flux of 7%. This is only based on the heat transfer model without taking moisture into consideration.

As expected, breathable underlayments reduce potential for condensation by almost 33% as compared with nonbreathable systems. 

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