INTERNAL MICROCLIMATE RESULTING FROM VENTILATED ATTICS IN HOT HUMID REGIONS

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ABSTRACT

Ventilated spaces in the built environment create unique and beneficial microclimates. While the current trends in building physics suggest sealing attics and crawlspaces, comprehensive research still supports the benefits of the ventilated microclimate. Data collected at the University of Florida Energy Park show the attic environment of asphalt shingled roofs to be typically hotter than the outdoor conditions, but when properly ventilated sustains a much lower relative humidity. The hot, humid regions of the United States can utilize this internally convective, exchanging air mass to provide stable moisture levels within attic spaces. Positioning the buildings primary boundary at the ceiling deck allows for utilization of this buffer climate to minimize moisture trapping in insulation and maximize the insulation's thermal benefits. This investigation concludes the conditions in a ventilated attic are stable through seasonal changes and promotes cost effective, energy efficient climate control of unconditioned spaces in hot, humid regions.

INTRODUCTION

The microclimatic conditions surrounding a building have a direct impact on the energy consumption necessary to provide indoor comfort. The hot, humid climate of Florida provides unique challenges for energy efficient building design. It has been shown by Silberstein and Hens that insulation of the building envelope is greatly hindered by the intrusion and stagnation of absorbed moisture. With correctly ventilated spaces and properly positioned insulation, excessive moisture should not accumulate. (Silberstein and Hens 1996) The study's results illustrate the benefits of removing moisture continuously through ventilation. The ventilated attic structure serves the purpose of creating a climatic barrier enhancing the performance of the insulation. A high rate of moisture removal with ventilated attics in colder regions has been reported, when the attic does not cool significantly over night. (Samuelson 1998) This study revealed the benefits of ventilation in cooler climates and the results indicated a reduction of soffit ice dams and increased insulation efficiency of the ceiling space. Although the previous research does not discuss all aspects of attic microclimates, these conclusions support an investigation of the effectiveness of ventilated attics in warmer regions where nighttime temperatures often remain high.

Alternatively, moisture can be transported by pressure differences in the building moving vapor from the conditioned space to unconditioned spaces leading to potential moisture problems such as mold and mildew growth. Lstiburek, et. al. describes the necessity to properly seal building cavities between conditioned and unconditioned spaces to prevent condensation of water vapor that is communicated between the adjacent spaces. (Lstiburek, Pressnail and Timusk 2002) This research illustrates that ventilation can create pressure differences leading to the moisture transport between spaces. The previous research did not investigate a particular attic for a full twelve month period. During certain months pressure differences across adjacent spaces may fluctuate yielding a beneficial self regulating system of moisture movement. It is the position of this paper that the ventilation of an attic space in hot, humid regions serves to purge hot, moist air providing an air mass with a lower humidity ratio to sit directly above the indoor conditioned space. This is a necessary cycle that directly controls unwanted condensation and inhibits the growth of mold and mildew within attic insulation and on roof truss members.

Therefore, the ventilated attic should not represent the effective building envelope, but instead be defined as a primary boundary to control the impact of weather on the interior of a building and the mechanical support systems. The conditioned space below, a separated and insulated space, functions as the true building envelope where all other systems are operating to support the environmental conditions within that space. Humidity, temperature, and ventilation rates are important factors in the heat and moisture transport of both conditioned and unconditioned spaces that affects indoor comfort, energy efficiency, and air quality.

Quantifying the benefits of a ventilated attic microclimate requires yearlong investigation exploring each factor of the climate through all seasons taking into account varying outdoor conditions. However, previous research conducted concerning hot, humid regions has not presented a consistent yearlong data stream to evaluate the benefits of passive ventilation and it's affects on moisture transport.

The yearlong measurements for this study were taken during 2006 and the data of that year are presented in this paper. Collected data provide a complete illustration of the climate developing within the unconditioned attic spaces of residential and light commercial construction. Evaluation of the building envelope and seasonal microclimates is essential to achieving energy efficiency, and this data will aid in evaluating cost effective energy efficiency measures for the built environment.

PROCEDURE

The research took place at the Building Products Test Facility on the University of Florida campus in Gainesville, FL. The building was completed in 1998 and was wired to provide data related to the internal microclimate of structures, both ventilated and sealed, in hot humid regions. Data has been collected at that facility since 2001.

The building used had 12 bays. Figure 1 illustrates the building floor plan. Bay 9, was chosen for this analysis due to the construction of a ventilated crawlspace and attic using wood framing members typical of Florida residential construction. The bay is also centrally located shielding the instruments from edge effects. The bays conditioned space has dimensions of 3.2 m (10.5 ft) wide and 6.1 m (20.0 ft) long with ceiling heights of 2.4 m (7.9 ft). Above is a standard attic with floor dimensions 3.0 m (9.8 ft) long and 3.2 m (10.5 ft) wide with a roof slope of 5:12, and a ventilation area of 0.18 m^2 (1.91 ft^2) for every 18.6 m^2 (200.2 ft^2) of attic floor space, or a ventilation ratio of 1:105.

The building is oriented with the long axis along the East-West line. The pitched roof deck surfaces face North and South, and are constructed with asphalt shingle roofing. The soffits and ridge were vented with materials from AirVent, Inc. The soffit vent provided a ventilation area of 190.5 cm^2/m and the ridge vent provided 381 cm^2/m. The attic was constructed with R-30 insulation in the ceiling deck. Two types were used: blown-in fiberglass and loose fill cellulose. The interior space was cooled with a single Packaged Through the wall Air Conditioner (PTAC).

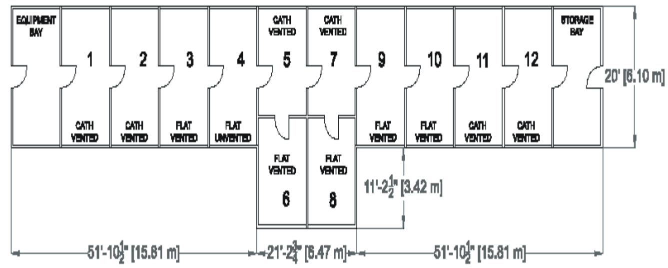
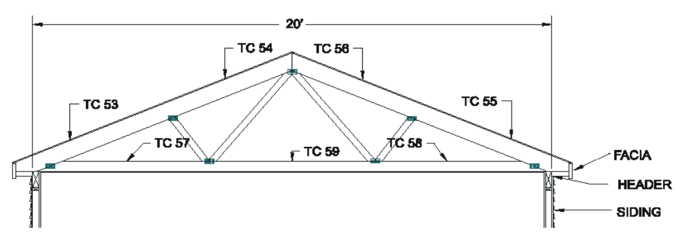


Figure 1. Plan-view of test facility

In addition to the building, a weather monitoring station from Campbell Scientific, Inc. positioned 7.6 m (24.9 ft) northwest of the building at a height of 3.0 m (9.8 ft), was used. This monitoring station measures the external conditions of temperature, relative humidity, barometric pressure, wind speed, and wind direction. Weather conditions were compared to measurements taken inside the building, constructing a relationship between the external conditions and the resulting internal attic climate.

Sensors were placed throughout the attic in order to understand the movement of air, temperature, and moisture. Combined temperature and relative humidity sensors are located in the center of the attic, ridge vent, and soffit vents. In addition to these sensors thermocouples were attached to various roof joists, at the lower and middle positions on both roof deck surfaces, and between the plywood sheathing and the shingles. Air flow was measured by bidirectional anemometers. They were positioned in both soffits, in multiple positions at the ridge vent, and three other locations along the roof decking of the attic. The placement of some of the various sensors can be seen in Figure 2.

Data were recorded every 15 minutes for the entire year. During the collection period, the system consistently collected data for 34,891 data points out of a possible 35,040 points for an accurate description of 99.6% of the year. The collected data rendered an accurate conclusion of both the average and instantaneous microclimatic conditions of ventilated attics.



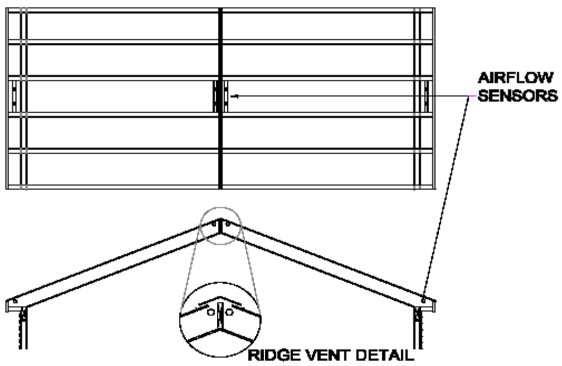


Figure 2. Illustration of sensor positions in test facility attic space

DATA

Monthly averages define an operating and consistent climate for the building envelope within the attic. On the exterior the shingles heat up and store heat, which is conducted through to the roof decking and reradiated to attic space. During the month of August, the shingle surface temperature peaks at 80.6°C (177°F) and 72.8°C (163°F), for the southern and northern facing roofs respectively. These extreme temperatures are the primary driving forces that provide the energy to create the attic microclimate. While the extreme data points are important to consider, it is the duration of these extreme temperatures that is significant. During the months May through August the shingles spend over 250 hours a month above 37.8°C (100°F), and in July through August spend over 80 hours a month above 65.6°C (150°F). Figure 3 displays the time spent above 65.6°C (150°F) for the shingles on both the northern and southern roof faces.

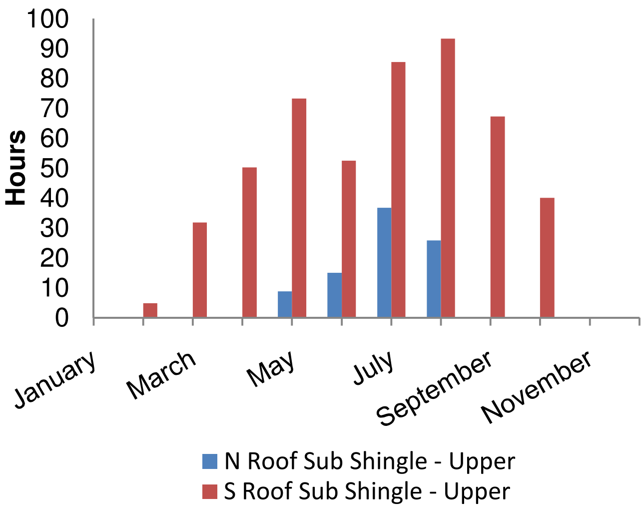


Figure 3. Time spent above 65.6°C (150°F) for upper shingles

The sustained high temperatures of the asphalt shingles contribute to a very hot attic environment. Temperature differences between north and south facing roof decks create convective currents of air inside the attic. The internal temperature of the attic space can peak as high as 49.4°C (121°F) during the month of July, and spend over 200 hours above 37.8°C (100°F) for the month of August. Figure 4 illustrates the temporal range for extended periods of high temperatures.

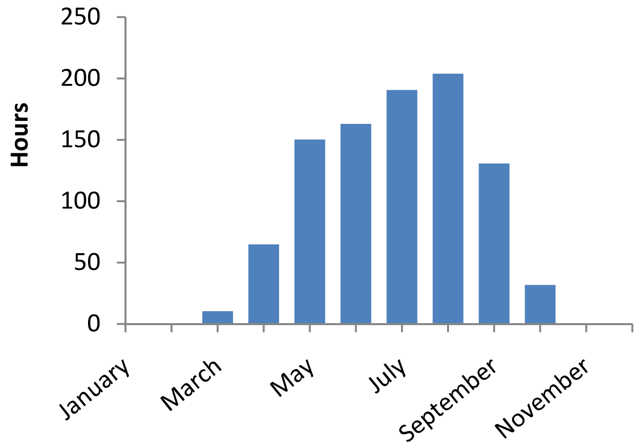


Figure 4. Time spent above 37.8°C (100°F) for attic space

Relative humidity measurements were taken throughout the attic and coupled with air flow measurements to calculate the moisture transport through the attic vents. In addition wooden roof members were wired with thermocouples to assess the likelihood of condensation on attic members, and absorption by the wood framing. Figure 5 displays the relative humidity at inlets and outlets for air flow with respect to the attic interior and outdoor conditions.

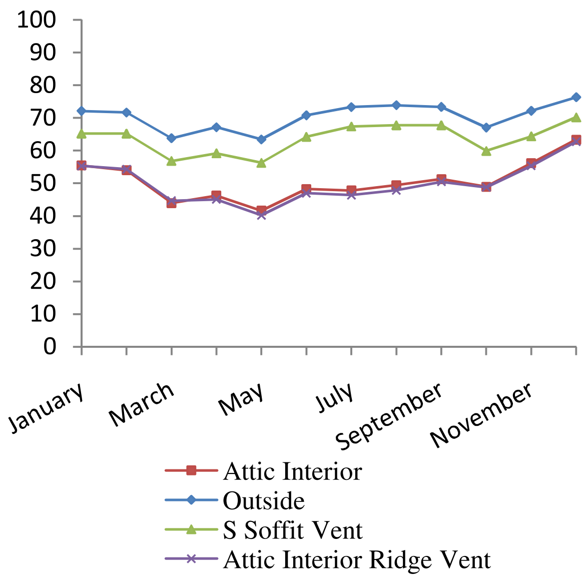


Figure 5. Monthly averages of relative humidity at various points

The data collected in this study offer a complete view of the average microclimatic conditions forming within a ventilated attic under a variety of external conditions representing all seasons.

RESULTS

A ventilated attic possesses many advantages for a hot humid climate. While peak attic temperatures are high during summers, the relative humidity remains well below that of the external environment. Relative humidity is of specific interest in this study because the overall health of the attic depends on the temperature and moisture gradient around the wood framing members. The exchange of moisture between the porous wood surfaces and the attic air is a function of relative humidity.

As shown in Figure 5 the monthly average relative humidity for the attic is consistently lower than the exterior. This relationship holds true for the daily instantaneous data recorded at 15 minute intervals. Figure 6 and 7 illustrate the temporally averaged daily conditions for February and July.

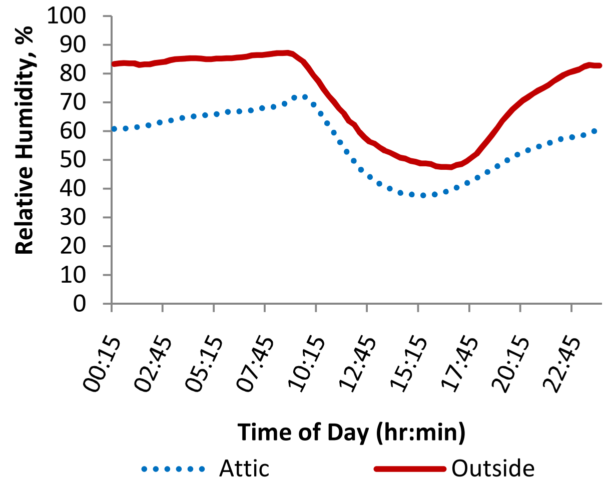


Figure 6. Time averaged daily relative humidity conditions for the average day in January

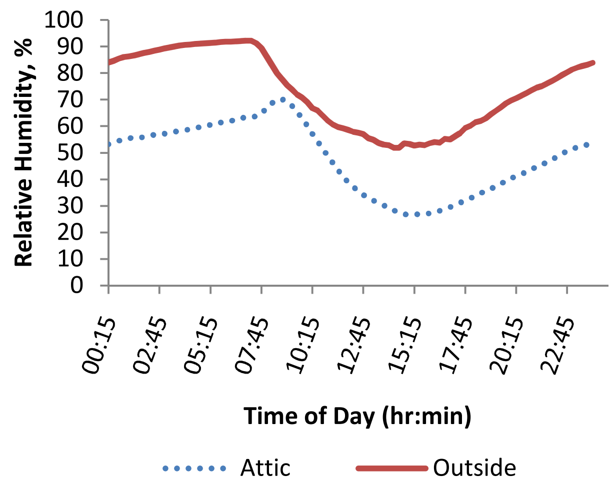


Figure 7. Time averaged daily relative humidity conditions for the average day in July

The moist air entering the attic through the soffits gains heat, and rises a vertical distance of 1.6 m (5.2 ft) exiting the ridge vent. Figure 8 illustrates the temperature rise as air travels from soffit to ridge averaged over the course of each month. As the temperature rises, the air can hold more moisture lowering the relative humidity, decreasing the chance of condensation, and reabsorbing any moisture that precipitated out onto the insulation or attic members.

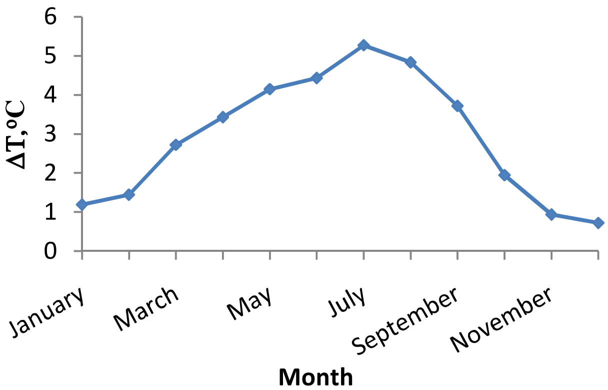


Figure 8. Average temperature difference of air travelling from soffit to ridge

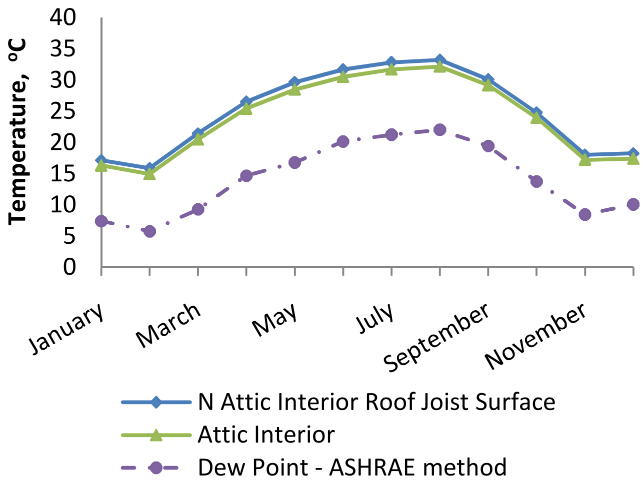


Figure 9. Monthly average temperature comparison for attic materials

This moist air is maintained at high temperatures well above the dew point limiting the instances where condensation can occur. Figure 9 displays the monthly average temperatures for the attic interior, roof joist surface and dew point. The roof joist member is at a slightly higher temperature than the attic interior air measurement as a result of absorbed energy from re-radiated heat emanating from the roof deck. From this figure it can be concluded, condensation onto roofing members is rare and adequate ventilation quickly removes accumulated moisture. Additionally, the reradiation of heat from the roof decking is an important element in the heat balance of the attic space.

Figure 10 shows the excessive temperature of roofing materials and the attic temperatures as compared to the outdoor conditions.

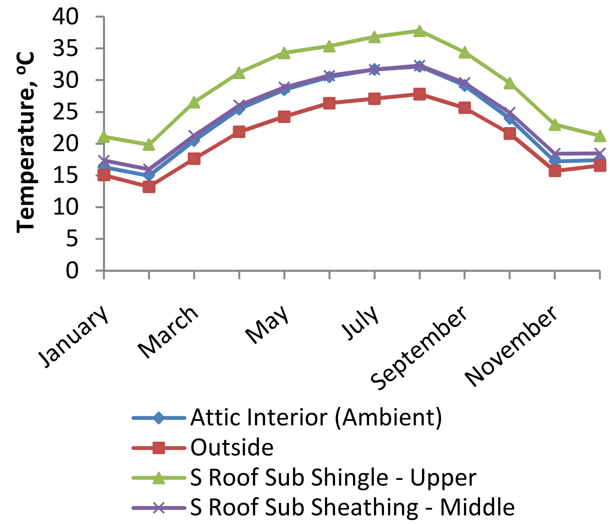


Figure 10. Temperature comparison of attic elements to environmental conditions

Heat flux due to solar radiation drives the internal microclimate, and Figure 5 and 10 together illustrate this hotter, drier microclimate with respect to outdoor conditions.

A key element to this shift in microclimate is the effect on stored moisture. For each fifteen minute time increment the mass flow rate of moisture through soffit and ridge was calculated using Equations 1 and 2.

$$\dot{m} = A * \vec{v} * \frac{1}{\vartheta(T,P)} * \left(1 + \frac{W_{ma}}{W_{da}}\right) \quad (1)$$

$$\vartheta(T,P) = R_{da} * T * \frac{\left(1+1.6078*\frac{W_{ma}}{W_{da}}\right)}{p} \quad (2)$$

Where $\dot{m}$ is the mass flow rate, A is the area of inlet or outlet, $\vec{v}$ is the velocity of air through the penetration, $\vartheta(T,P)$ is the specific volume of air, $\frac{W_{ma}}{W_{da}}$ is the moisture content in air corrected for partial pressure, T is the temperature of air, P is atmospheric Pressure, and R_{da} is the gas constant for dry air based on the carbon-12 scale.

The moisture flow rate data were time averaged for each month creating an average day. Figures 11-14 display 4 out of 12 months illustrating seasonal differences in attic moisture properties. Averages displayed below represent inflow at the soffits and outflow at the ridge.

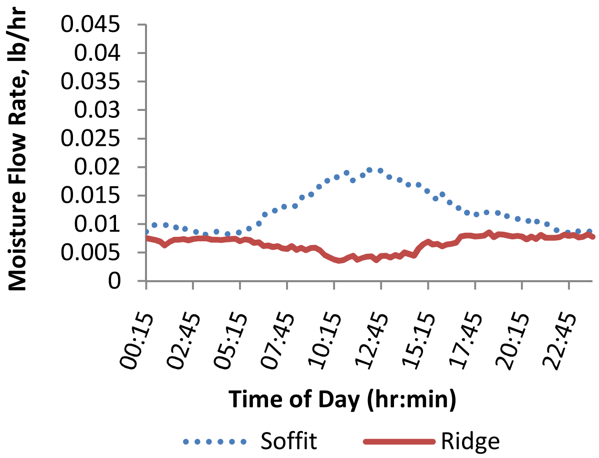


Figure 11. January moisture flux for the attic environment

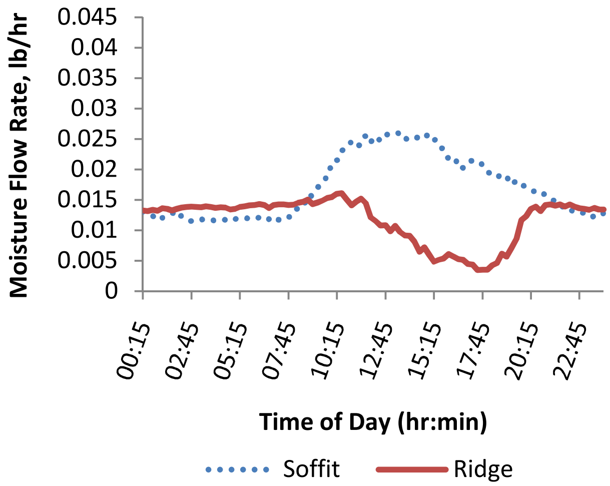


Figure 12. April moisture flux for the attic environment

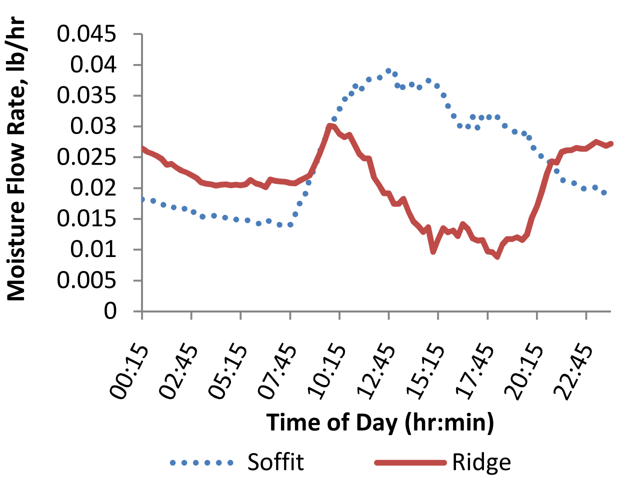


Figure 13. July moisture flux for the attic environment

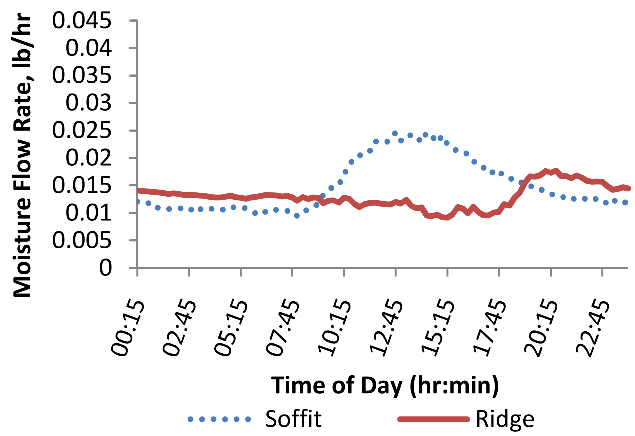


Figure 14. October moisture flux for the attic environment

Diurnal cycling creates an attic that "breathes" by taking in air and moisture at certain times then releasing it later. The system cannot negate the storage of moisture both within the attic space and the wooden attic members, so there is no observed equilibrium. A forward lagging of the system is evident of the slight rise of moisture in the attic as it responds to incoming humid air. The overall trend displayed in the graphs is a consistent system, which is the primary function attributed to a ventilated attic space.

Looking closely at the data it is clear that the air flow consistently enters the attic through the soffits. The ridge vent, with a higher volumetric flow rate than the soffit vents, consistently provides the bulk air flow out of the attic creating the only successful pathway to remove moisture. Therefore moisture flow is governed by the ridge vent.

CONCLUSION

During the 2006 calendar year data at this building were collected to illustrate the microclimates developing in unconditioned spaces of residences built with a ventilated attic. The resulting data describes a climate that maintains a steady resistance to saturation providing a solid barrier to the elements. This climate serves to remove moisture at a rate consistent with the prevention of mold and mildew growth, and in the event of moisture intrusion can alleviate damage to insulation and prevent seepage into the conditioned space.

The resulting attic climate provides high temperature gradients between the attic and the conditioned spaces below. The attic will also hold a higher temperature than the outdoor environment, but maintain a lower relative humidity. Under these circumstances the building envelope boundary of hot, humid regions should be considered conditioned space and be insulated accordingly. Overall this data supports increased insulation and materials with high thermal resistances positioned at the ceiling deck to reduce the heat flux into conditioned space. It is possible that sealing the attic spaces entirely and insulating the structure would reduce the thermal heat transfer from an attic, but this would provide no outlet for moisture transported through porous roofing materials or past the ceiling plane.

Passively cooling the attic spaces in a hot, humid climate must be achieved in conjunction with ventilation rates that sustain moisture removal. The air movement in the attic serves to maintain a microclimate that is consistently dryer than the outdoor environment. Bulk air movement out of the ridge vent, contingent on radiated heat to the roof, is the result of natural thermal buoyancy and illustrates the necessity of ridge venting for proper microclimate development. Designing for a hot humid climate must balance undesirable heat storage while maintaining a moving air mass that can carry moisture through the ridge.

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