FLORIDA SOLAR ENERGY CENTER®

Interim Report

Residential Attic Performance Comparison Research

DBPR Project #B3EB11
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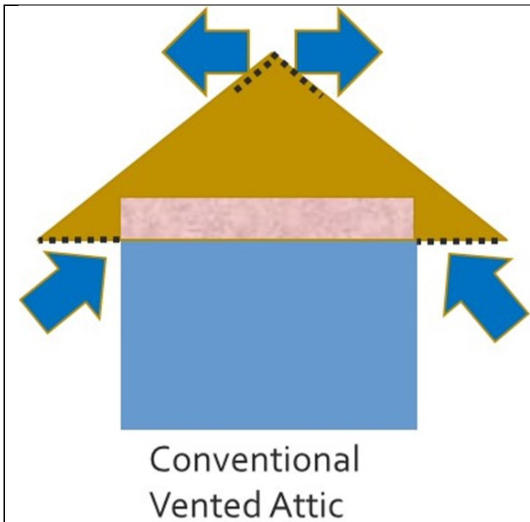
Introduction

The primary goal of this research is to determine if significant energy savings are possible from simply eliminating attic venting in a research lab home with insulation on the ceiling plane and having no insulation applied on the roof deck. This specific practice is not acceptable in the current Florida building code. Anecdotal claims from individual homeowners taking it upon themselves to seal attic vents have claimed significant energy savings and even lower indoor humidity. One such homeowner served on the Florida Building Code Mechanical Technical Advisory Committee for years.

Another goal of this research is to determine if there are any potential beneficial or detrimental moisture issues associated with eliminating attic venting when R30 insulation remains on the ceiling.

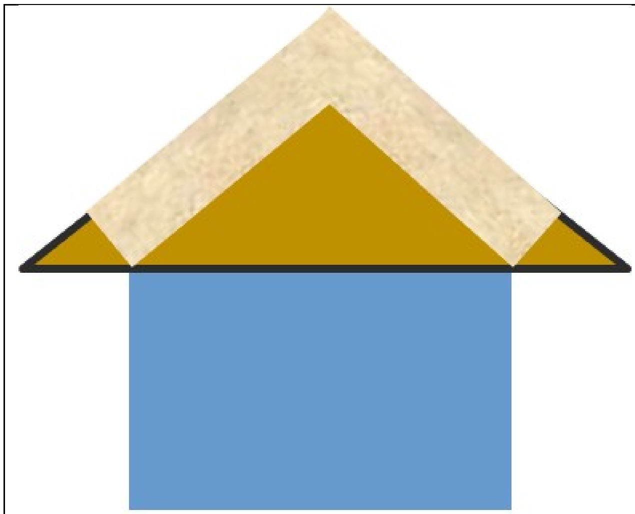
Most Florida homes have vented attics with insulation on the topside of ceiling and kneewalls. The attic is typically vented with soffit vents and ridge or off-ridge vents. Figure 1 illustrates this common attic.



Example of blown in insulation on ceiling of a home with a vented attic.

Figure 1. Illustration of vented attic concept with photo of inside attic with blown-in insulation on ceiling.

Residential Florida Building Code R806.5 currently only allows an unvented attic space that “is completely within the building thermal envelope.” A common method of unvented attic compliance in homes is use a spray foam applied over the underside of roof decks continuously downward to the upper top edge of ceiling at exterior walls. An example is shown in Figure 2. This method is preferred by some since it is more likely to result in a tighter home and it minimizes the energy penalties associated with having central ducts in an attic.



Example of an off-site home with spray foam insulation on the roof deck in an unvented attic.

Figure 2. Illustration of the unvented attic concept with photo of low density spray foam application in an attic.

The Florida Department of Business and Professional Regulation (DBPR) has established a contract with the Florida Solar Energy Center (FSEC) to perform a comparative study of attic performance between a lab home with a vented attic and same home with sealed attic vents.

The contracted scope of work is summarized below in the following items:

1. FSEC shall monitor attic and space conditions of four attic/duct configurations shown in Figure 3.
2. Testing shall be completed using the FSEC Manufactured Housing Lab (MHLab). The MHLab shall be tested with existing insulation on the ceiling, attic ducts and indoor ducts. Interior sensible and latent loads will be programmed on daily schedules. A central ducted SEER 13 heat pump will be used for space conditioning.
3. In the MHLab, data shall be collected by rotating the configuration of the sealing or venting of the attic and alternating the central duct location (see Figure 3). The four test configurations are:

   - Vented attic with central ducts in attic.
   - Unvented attic with central ducts in attic.
   - Vented attic with central ducts in conditioned space.
   - Unvented attic with central ducts in conditioned space.

4. Monitoring shall include:

   - Space conditioning energy use.
   - Interior, attic, and outdoor temperature and relative humidity.
   - Ceiling heat flux measurement by thermocouple.
   - Supply plenum and supply register air temperature to assess attic duct heat gain.
   - Moisture content measurement in roof deck and ceiling.

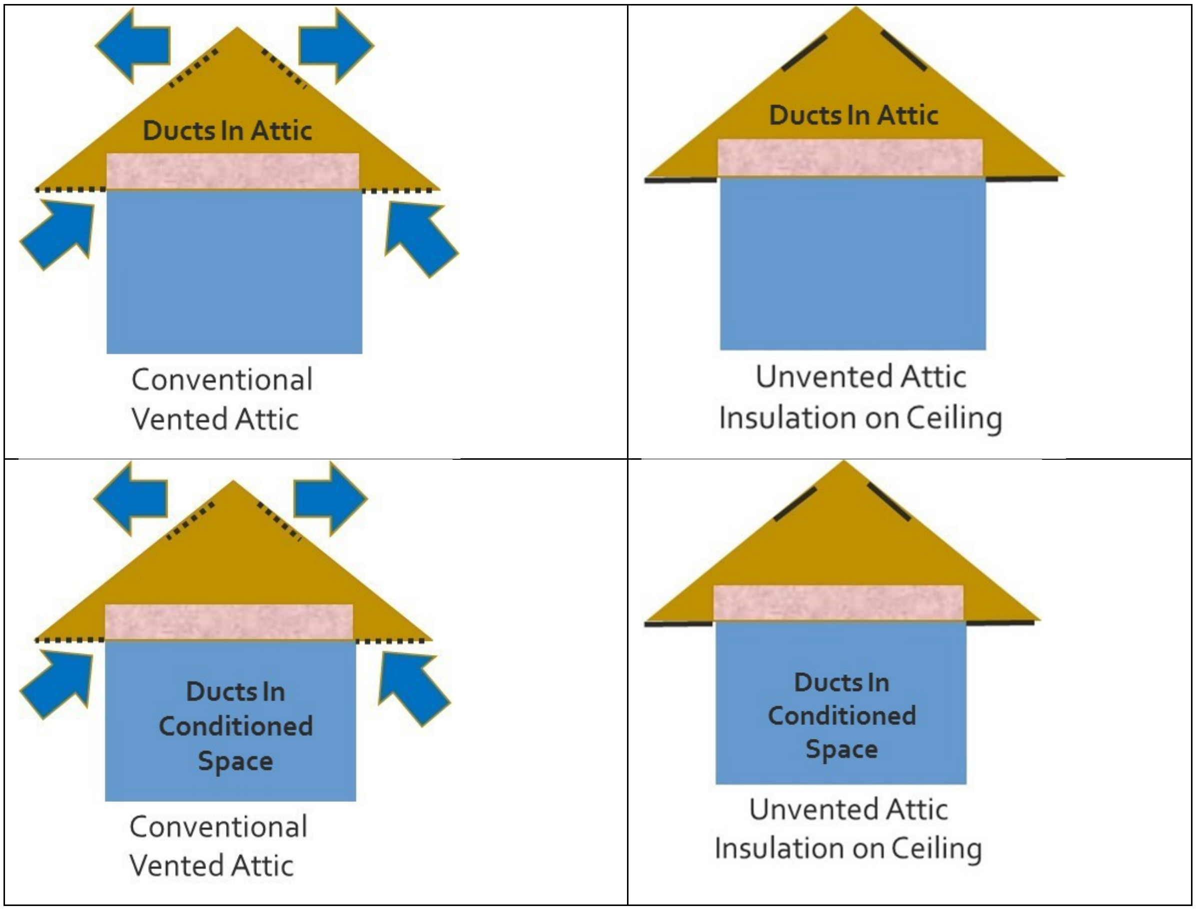


Figure 3. Illustrations showing the four test configurations to be tested in the MHLab.

This interim report discusses the experimental method and preliminary results of this research project to date.

Experimental Method

Lab and Equipment Description

This section discusses details about the test building, equipment details and data collection procedures. All test configurations were conducted within the MHLab building located on the Florida Solar Energy Center campus. The MHLab is a 1620-ft^2 double-wide manufactured home with an unvented crawl space, R-19 floor insulation, vented attic with R-30 insulation on the ceiling, wood frame wall construction with R-19 insulation, double pane windows, three bedrooms, and two bathrooms. The floor plan is shown in Figure 4.

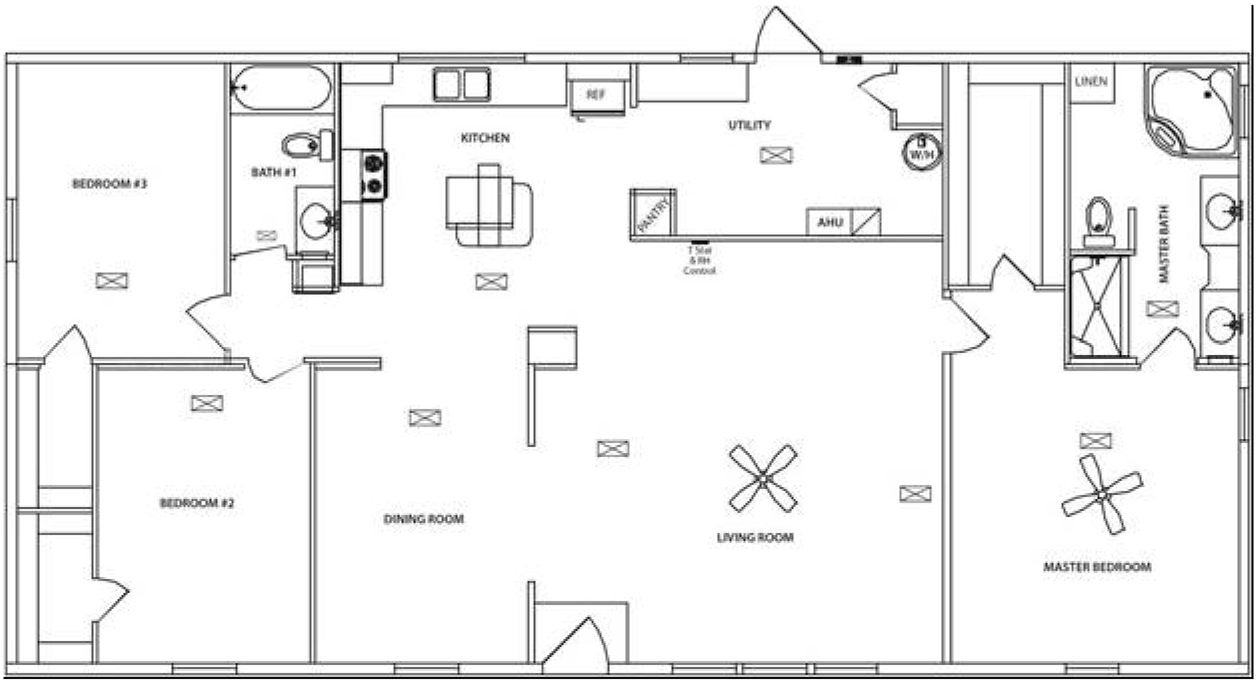


Figure 4 MHLab floorplan.

Building airtightness was tested using a blower door with the Delta Q method and measured a normalized air leakage rate of 5.4 ACH50. House tightness testing with attic venting was repeated after the attic vents were sealed and yielded no significant change. This helped verify that the ceiling plane of the lab home was reasonably tight having no significant air pathways from the conditioned space into the attic.

There was no return duct leakage. The attic supply duct leakage to outdoors was indicated to be 26 cfm with duct at 25 pascals of pressurization (CFM25out= 26). This indicates a normalized leakage (Qn) of only 0.016 cfm25 / ft^2 conditioned space, which is reasonably tight.

A manual J8 load calculation on the tested building calculated a summer 99% design total cooling load of 1.8 tons with supply ducts in the attic. The central ducted system was a SEER13 heat pump with a nominal rated cooling output of 2.0 tons. The heat pump system was controlled by a thermostat located on an interior wall in the large open central living room area. The centrally ducted system located in the attic was primarily flex duct with an effective insulation R-value of 11.6 based upon previous testing and analysis. While this is greater than typical R-6 duct insulation, the impact of this increased R value was previously determined to result in about 6% decrease in typical summer cooling energy (Withers, Cummings, and Nigusse 2014). The central ducted system located within the conditioned space had R-6 insulation.

Internal loads were established using some guidance from a Building America report on internal residential loads (Hendron and Engebrecht 2010). Internal cooling loads were maintained consistently throughout all experiments by keeping the building unoccupied and providing internal sensible and latent heat through controlled measures. Sensible heat was added primarily through interior heat lamps, and an oven. The interior sensible loads were monitored using power meters to ensure consistency was maintained for each experiment. The average interior sensible load target delivered per day was at a rate of about 3,398 Btu/h.

Interior latent loads were scheduled throughout the day with a daily total target of about 9 pounds per day (average rate of 619 Btu/h). Most of the latent load was produced by evaporating water from a pan in the oven. The delivered latent load was monitored throughout the project by means of tipping bucket that provided a pulse output proportional to the volume of water passing through the latent delivery assembly. Three scheduled hot showers provided additional latent each day. Shower water volume and heating energy were measured to assure consistent shower operation.

All sensors for this project were installed and verified to be in good working order. Temperature sensors measured indoor, attic as well as the inner roof deck and outer roof deck surface conditions. Humidity sensors measured outdoor, indoor and attic conditions. Power meters measured internal loads and space conditioning energy. Omnisense loggers were used to measure roof deck and ceiling moisture content as well as temperatures and RH strata. A total of 6 vertical profile locations were measured from the attic roof deck downward to the conditioned space.

A summary of manufacturer stated accuracy of meters and sensors are below:

- Vaisala Temperature and relative humidity HMP60 sensors were installed. These sensors have a manufacturer stated accuracy of +/- 3% RH of RH reading and +/- 0.9 °F for temperature. Type T Thermocouples were also used to measure temperatures. These have accuracy of +/- 0.2°F.
- Continental Control Systems Wattnode power meters have a manufacturer stated accuracy of +/- 1% were installed to measure DHU energy, central AC system, and internal generated sensible loads.
- Condensate removal of AC system was measured by calibrated tipping bucket. Tipping buckets were calibrated by mass of water measurement collected along with the pulse output signal. Stated accuracy was 3% or better.
- Outdoor air temperature and humidity were measured by Vaisala sensors.
- Omnisense loggers had a stated accuracy of +/- 0.5 °F, +/- 2.0% RH.

In all, 117 channels of data from sensors were collected using Campbell Scientific, Inc. CR10 dataloggers. Data was gathered several times each day from FSEC's central computer terminal. Data from sensors were sampled at 10 second intervals, then processed and stored at 15 minute intervals. Upon collection by the central computing terminal, the raw data from the datalogger was screened for out of bound errors and then processed for terminal collection in the main project database account. Errors or missing scans were marked and noted within the main database. This is used to help avoid using any unsuitable data in analysis.

Lab Test Method

Four test configuration experiments were conducted to evaluate the energy performance of each test configuration. Conceptual illustrations of these lab test configurations were shown previously in Figures 3. Testing began September 24, 2018 with vented attic and attic ducts. Then different test configurations were implemented over time in an effort to acquire as much variation in weather conditions for each test as possible. Each test has been conducted at least once at this point in the project, however more test rotations are needed to acquire the desired weather variations for energy and materials impact evaluations.

Attic Vent Description

The MHLab attic has venting that meets 1ft^2 venting per 150 ft^2 of attic area (1:150). This venting is provided by continuous soffit vents that run around the entire roof perimeter. Four additional off-ridge vents are equally distributed on the roof deck. Polyisocyanurate board Foil-faced on both sides was used to seal soffit vents. The soffit seals were carefully installed to fit tightly against the vented surface and tightly between the exterior wall and fascia board. Vent seal boards were mechanically secured using screws and large fender washers. Each board was numbered so that they can be placed back in the exact location each time vents were sealed. Foil tape was also used to seal some vent areas as needed. Heavy mil plastic bags were used to seal the upper off-ridge vents.

Interim Lab Test Results

Energy

Preliminary analysis has begun to investigate space conditioning energy use impacts of the four different test configurations. The daily total energy use was plotted against the daily average temperature difference between outdoors and indoors. The temperature difference is noted as delta temperature (dT). Use of dT enables one to later predict energy use at specific indoor and outdoor temperatures.

The results for data collected from late September 2018 through February 10, 2019 are shown in Figure 5 and Figure 6. Figure 5 shows data with attic ducts in vented and sealed attic. Figure 6 shows data with indoor ducts with vented and sealed attic. Attic duct configurations use square markers, indoor ducts use circles. Vented attic configuration data is marked using open markers and unvented attic data uses filled in markers.

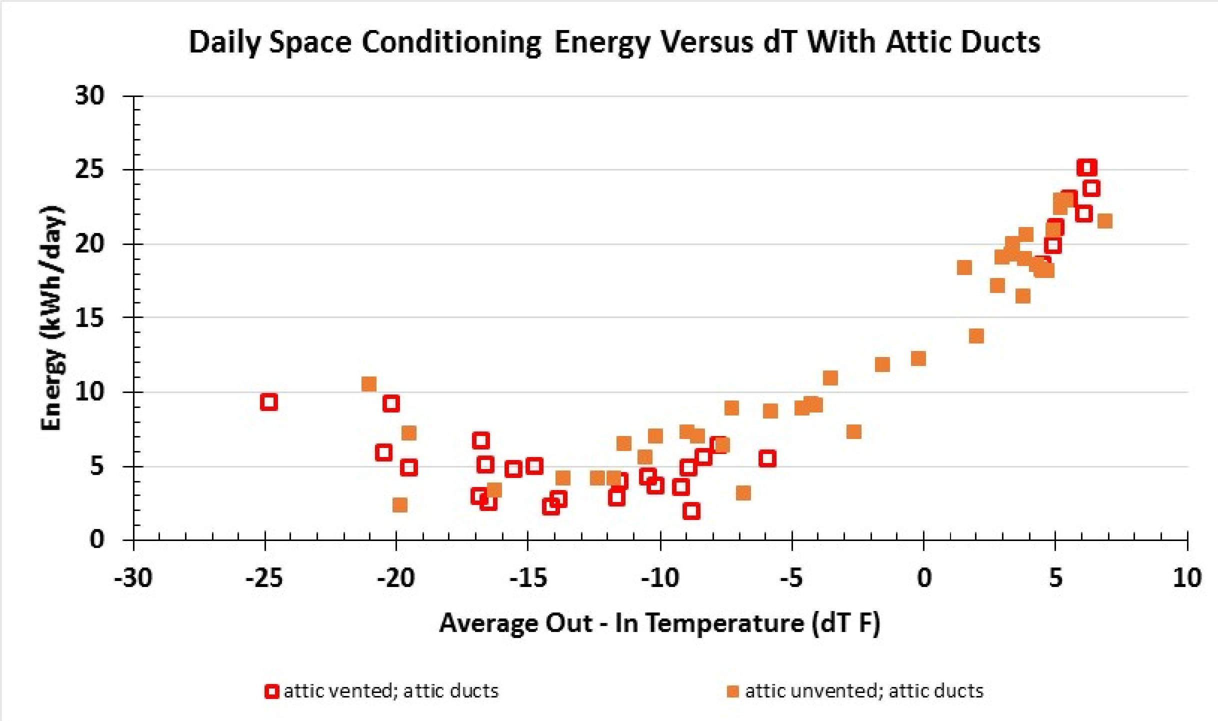


Figure 5 Space conditioning energy versus the temperature difference between outside and inside with ducts inside vented and unvented attic test configurations.

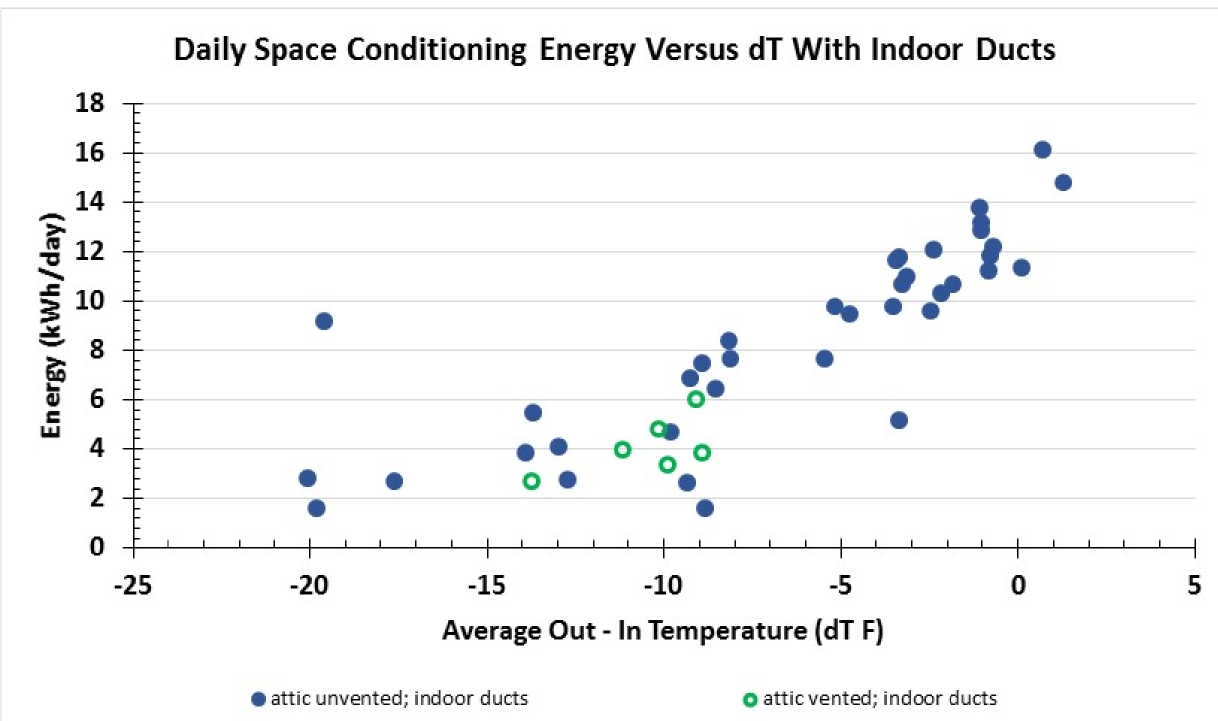


Figure 6. Space conditioning energy versus the temperature difference between outside and inside with ducts located indoors with vented and unvented attic test configurations.

The data show that a fair range in weather conditions has been acquired in three test configurations. The vented attic with indoor ducts (Figure 6 green open circles) has the least data to date. This test configuration began February 4, 2019 and is currently still underway. This test will continue and is expected to be able to also acquire a fair range in weather conditions by mid-May 2019.

The other test configurations will continue to be periodically rotated in an effort to gain better representation of various weather. For example, the vented attic with attic duct test (Figure 5 open red squares) has a wide range of data, but is missing representation at dT between -5 and 5. The unvented attic with indoor ducts has no data with dT greater than 2.

After more data is collected, a least-squares best-fit regression analysis will be completed for each test. This will produce an equation that will enable an annual energy use prediction for Florida cities such as Miami, Orlando and Jacksonville. Figure 7 shows data from all four test configurations collected through February 10, 2019. An example of a least-squares polynomial best-fit is shown for the three test configurations with the most data to this point in the project. It is expected that these fit lines will change as more data is collected at dT where it is currently sparse.

Data at dT greater than about -15 F represent cooling energy. Data at dT less than -15 F generally represents heat pump heating. There have been very limited sustained periods of cold weather for the tests.

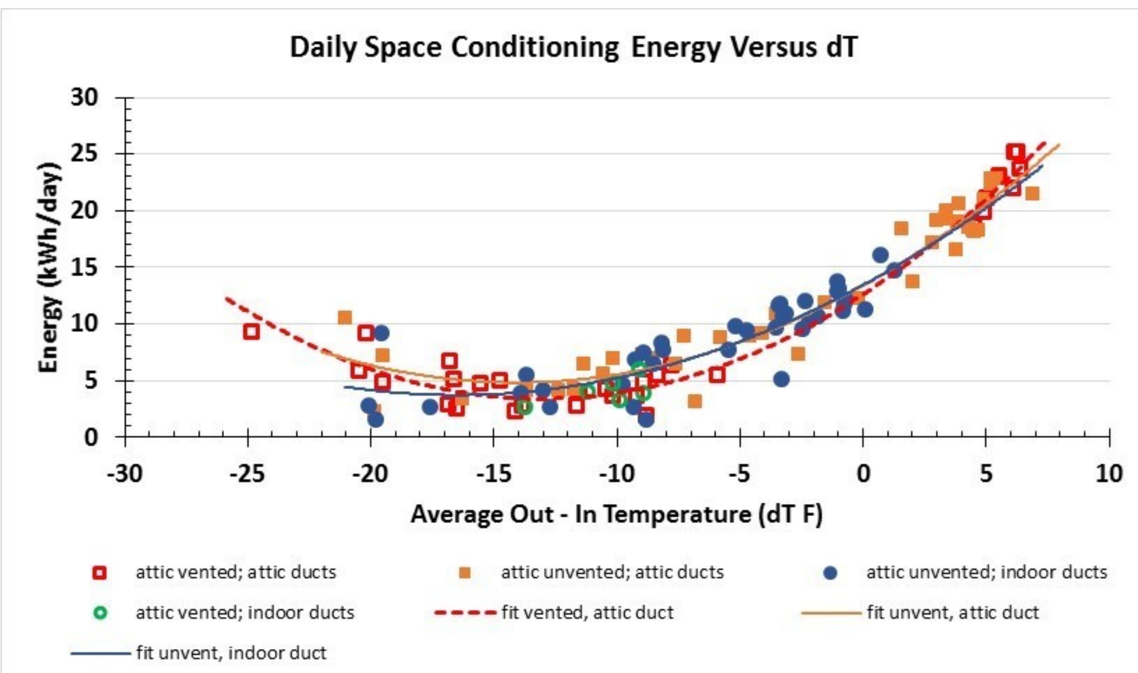


Figure 7. Energy versus the delta temperature shown with least-squares best-fit lines for three tests.

Space Conditions Comparison of Vented and Sealed Attic During Hot and Humid Weather

Currently the best available data for comparing vented and sealed attics is for two tests each with attic ducts during hot and humid weather. This is what will be covered within this interim report. The final report due by June 1, 2019 will contain a broader comparison among more test configurations at colder weather conditions. Colder conditions are expected to create more challenges for attic building materials moisture control.

Table 1 shows a comparison between the attic duct configuration with and without attic vents during similar hot and humid weather. Only two test configurations can be compared at this time due to limited data at these conditions. It can be seen that the weather conditions are very similar for the 4-5 days selected. The data shows that that the unvented attic became about 2.4 degrees F warmer on average. An increase in attic air temperature would be expected during the hottest time of day due to decreased ventilation when roof deck radiant temperatures are highest. The attic dewpoint decreased by 6.7 F. Some drop in attic dewpoint would be expected as the ventilation rate of moist outside air decreased after sealing vents.

Table 1. Comparison of Daily Average Interior Temperature and RH During Similar Hot Humid Outdoor Weather Conditions

Test Condition	Out T (°F)	Out T dp (°F)	Solar (kWh/m²)	In T 5 rm avg. (°F)	In RH (%)	In T dp (°F)	Attic T (°F)	Attic T dp (°F)	# days avg.
Vented Attic and Attic Duct	82.1	71.3	19.7	77.1	46.6	55.1	87.5	65.7	4
Sealed Attic and Attic Duct	82.2	72.1	19.7	77.1	45.3	54.3	89.9	59.0	5
Difference from Sealed Attic to Vented Attic	0.1	0.8	0.0	0.0	-1.2	-0.8	2.4	-6.7	1

The decrease in interior humidity and dewpoint are improvements in comfort-related metrics noticed with the sealed attic vents. However, it appears that this had occurred due to an increase in cooling energy. Table 2 shows the daily average cooling energy, runtime, and supply air temperature for the same set of days in Table 1. Cooling energy increased by 3.9% in this small sample of days. An increase in runtime would allow additional moisture to be removed by the air conditioning. The supply air temperature was practically the same during both tests and interior drybulb air also remained the same. No unexpected change in cooling system performance can explain the differences.

Table 2. Comparison of Daily Average Cooling Performance During Similar Hot Humid Outdoor Weather Conditions

Test Condition	Out T (°F)	Out T dp (°F)	Solar (kWh/m²)	Cool kWh/day	Runtime Hours	Supply Air T (°F)	# days avg.
Vented Attic and Attic Duct	82.1	71.3	19.7	20.6	12.5	56.5	4
Sealed Attic and Attic Duct	82.2	72.1	19.7	21.4	13.1	56.4	5
Difference from Sealed Attic to Vented Attic	0.1	0.8	0.0	0.8 (+3.9%)	0.6	-0.1	1

This limited data is not adequate to predict an annual energy impact, but indicates increased energy may be expected from sealing attic vents with insulation only on the ceiling plane and no insulation on the roof deck during hot weather.

Using the same hot and humid days from Table 1 and Table 2, a more detailed profile evaluation was made using data from the Omnisense sensors. Temperature, RH, Dewpoint and material moisture content sensors were placed in a vertical arrangement in one representative area of the attic over the master bedroom. These temperature and RH sensors were placed at 6 different heights. The locations from lowest to highest location are:

1) in room air mid-way between floor and ceiling
2) at the interior side of the gypsum board ceiling
3) on top of the gypsum board (and under insulation) in attic
4) on the top surface of insulation,
5) mid-way in attic air between insulation and roof deck,
6) at the underside of the wood roof deck.

Figure 8 shows an illustration of the Omnisense sensor layout arrangement at the red dots.

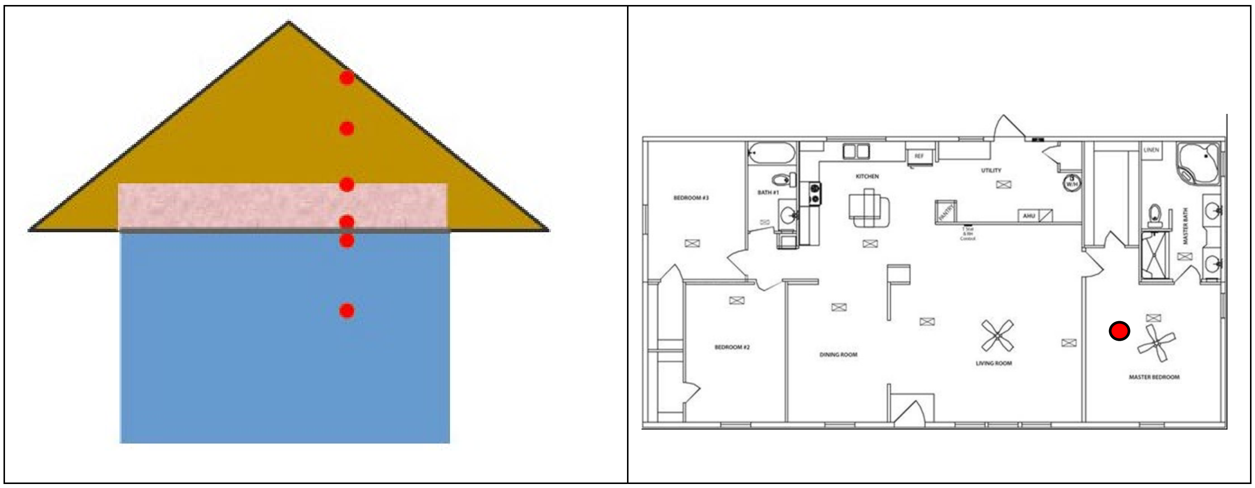


Figure 8. Illustration of the location of vertically arranged temperature, RH and moisture sensors.

Poor moisture control is the most serious concern as it can contribute to increased potential for occupant health and building degradation issues. Under hot and humid conditions, the house lab did not exhibit any conditions that warranted intervention of moisture related issues. Hourly data from several days was used to create a daily composite for each hour of the day for the vented attic and unvented attic when ducts were in the attic space.

The moisture content of a material is a relative measurement indicating the % of moisture mass in a material. Figure 9 shows the direct relationship between wood moisture content (WMC) and relative humidity. In general, prolonged WMC values exceeding 20% indicate a significantly elevated level of wood moisture, and can result in development of surface molds. WMC values exceeding 28%-30% indicate potential for decay fungi growth to occur that could damage the structural integrity of the wood deck if occurring over prolonged periods without adequate drying cycles. Figure 9 only applies to equilibrium conditions when the RH is unchanged. In reality, the RH swings drastically up and down in an attic resulting in moisture content changes that follow a diurnal pattern.

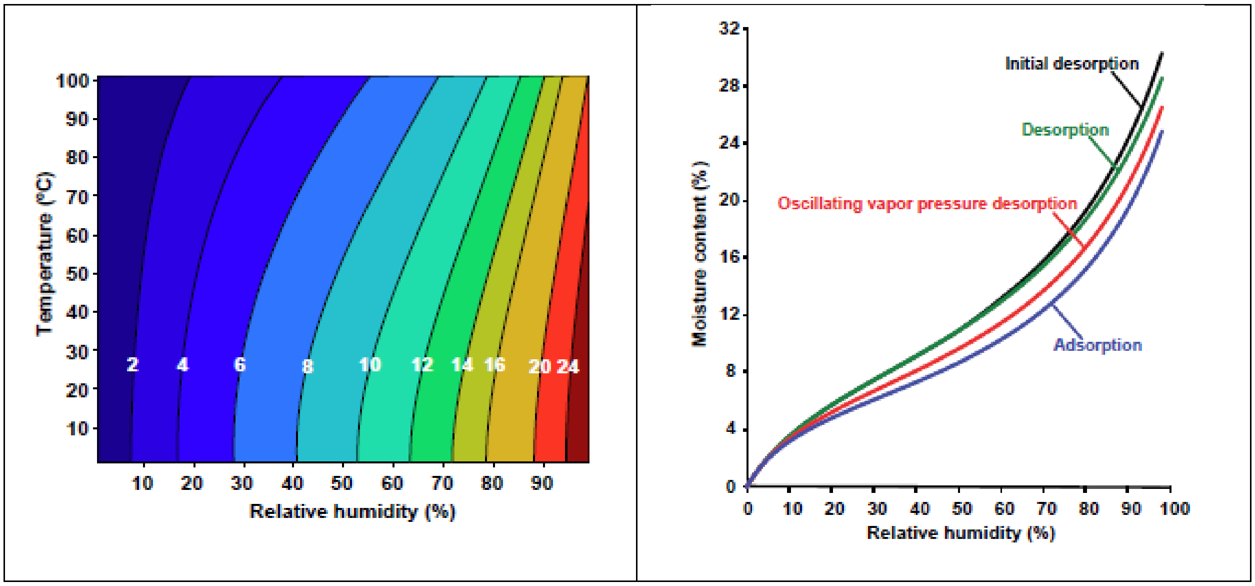


Figure 9. Relationship between equilibrium moisture content of wood and relative humidity (Forest Products Laboratory, 2010).

The term wood moisture equivalent (WME) % is used with the Omnisense sensors. It is indicative of % of moisture in wood. Although the gypsum board is not wood, the WME % can still be used to indicate if the gypsum ceiling board was becoming too moist using a value of 20% or greater. So while the reading in gypsum may not reflect the true % moisture content in gypsum, it is scalable and is adequate to determine if a material is becoming too moist. In reality, the gypsum would have an actual moisture content of about 0.7% when the WME% reads 20%. Periodic measurements were made using a hand-held Delmorst moisture meter with scales for wood and gypsum to independently verify that materials were not becoming too moist.

Figure 10 shows the moisture values at two different locations on the ceiling and at the roof deck. None of the hourly readings exceeded 15% during the hot period shown. The highest peaks of WME occurred in the vented attic roof deck after maximum wood absorption of moisture has occurred and indoor attic RH is at its highest levels. The vented attic deck WME actually goes below the WME of ceiling materials during the hottest time of day with RH at its lowest levels resulting in moisture desorption from the deck.

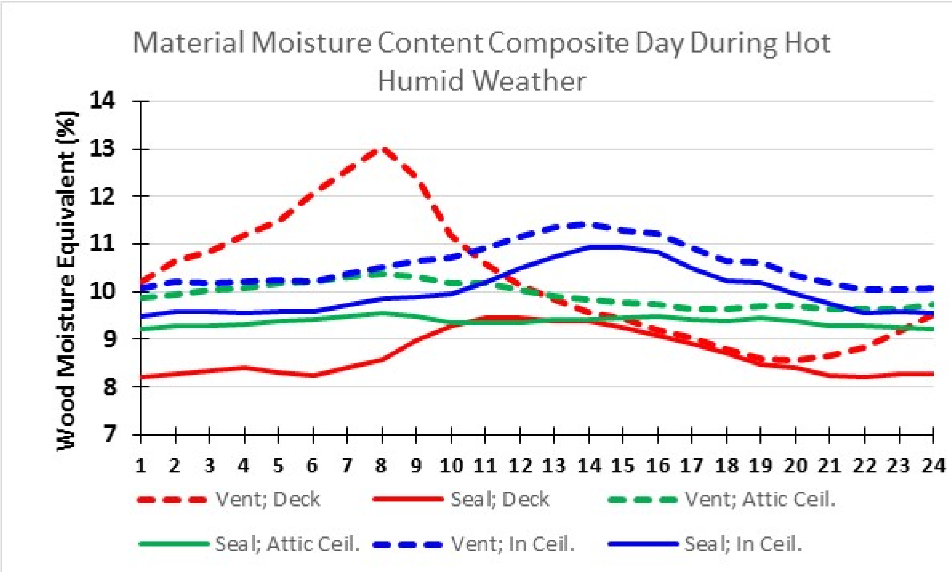


Figure 10. Daily composite of moisture content in ceiling and at roof deck.

The following summary of WME during hot humid weather shown in Figure 10 is offered here:

- All materials had acceptable moisture levels.
- Vented attic roof deck showed greatest amplitude of variance as expected.
- The sealed attic roof deck had the lowest WME of all.
- There is a trend for the indoor ceiling WME to increase during the hottest time of day for both vented and sealed attics, but vented attic had higher WME at top and bottom side of ceiling.
- Vented attic side of ceiling had a daily average WME that was 0.5% WME higher than sealed attic.
- Vented indoor side of ceiling had a daily average WME that was 0.6% WME higher than sealed attic.
- These results do not indicate that moisture issues would not occur during other weather conditions.

Figure 11 shows the composite profile of attic drybulb temperatures during hot and humid weather conditions. The sealed attic showed small increases in temperatures.

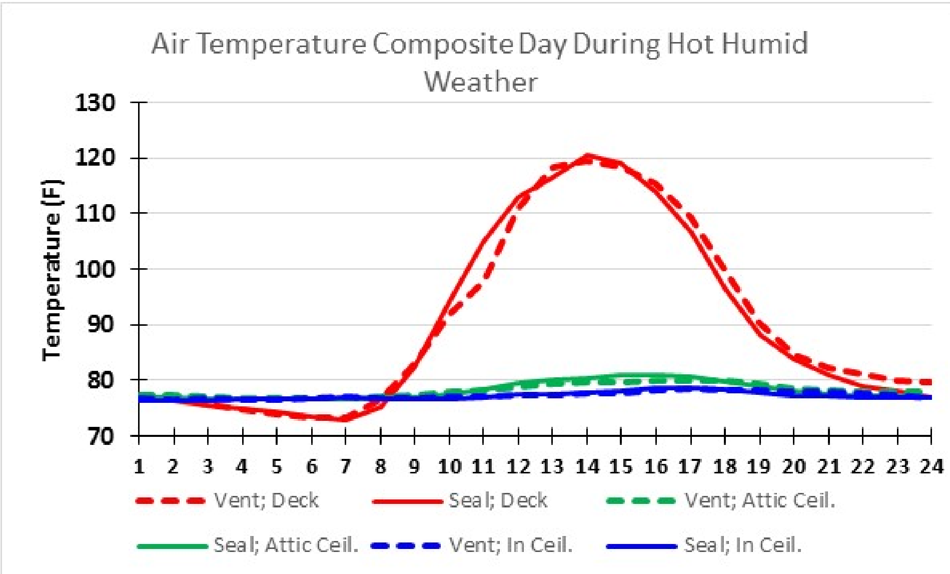


Figure 11. Daily composite of air temperature at different attic locations and on both sides of ceiling.

Figure 12 shows the composite profile of attic dewpoint temperatures during hot and humid weather conditions. Dewpoint temperature can be used to show a relative change in absolute moisture in air. It can also be compared to outdoor dewpoint temperature during this time which averaged about 72F. All measurements shown in Figure 12 demonstrate an increase coincident with solar energy to some extent. The indoor ceiling shows dry air as expected. The very small increase during midday appears to be due to increased vapor drive from attic toward conditioned space.

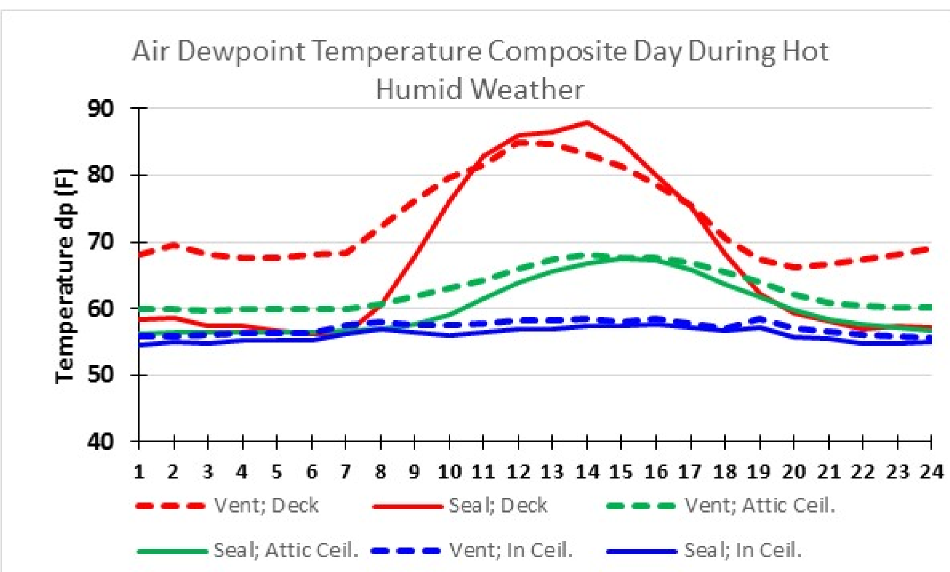


Figure 12. Daily composite of dewpoint air temperature at different attic locations and on both sides of ceiling.

Figure 13 shows better resolution of the dewpoint temperatures on each side of the ceiling that were also shown in Figure 12. The vented attic indoor ceiling dewpoint increased about 2F from the lowest point to the highest midday point. The sealed attic indoor ceiling dewpoint increased about 2.5 F.

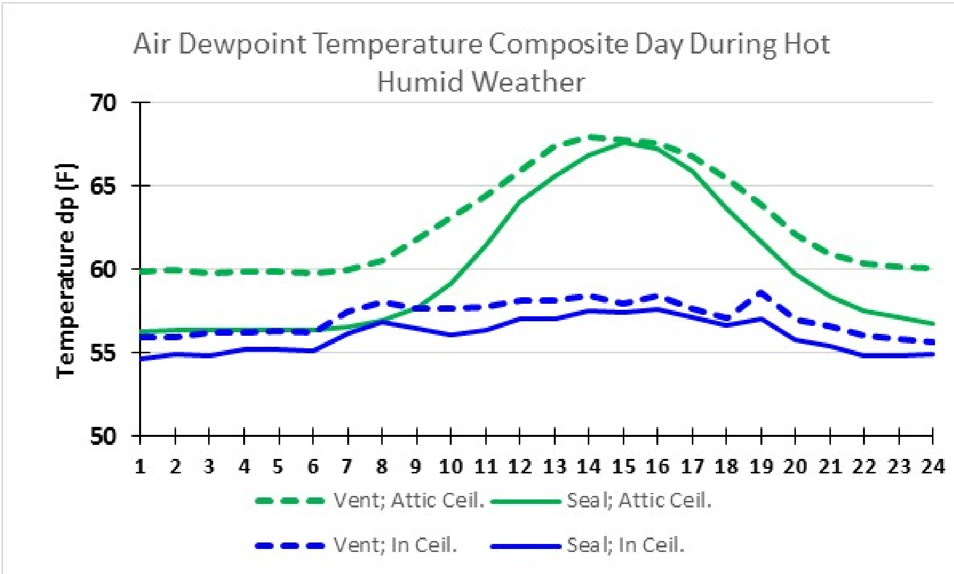


Figure 13. Daily composite of dewpoint temperature on both sides of ceiling.

The data shown here is a small fraction of data collected to date. More analysis is expected to be performed in the next few months. On the next page, Figures 14, 15 and 16 can be found as an example of the span of data and need to further investigate attic conditions, particularly under colder weather conditions. The points shown represent daily average values.

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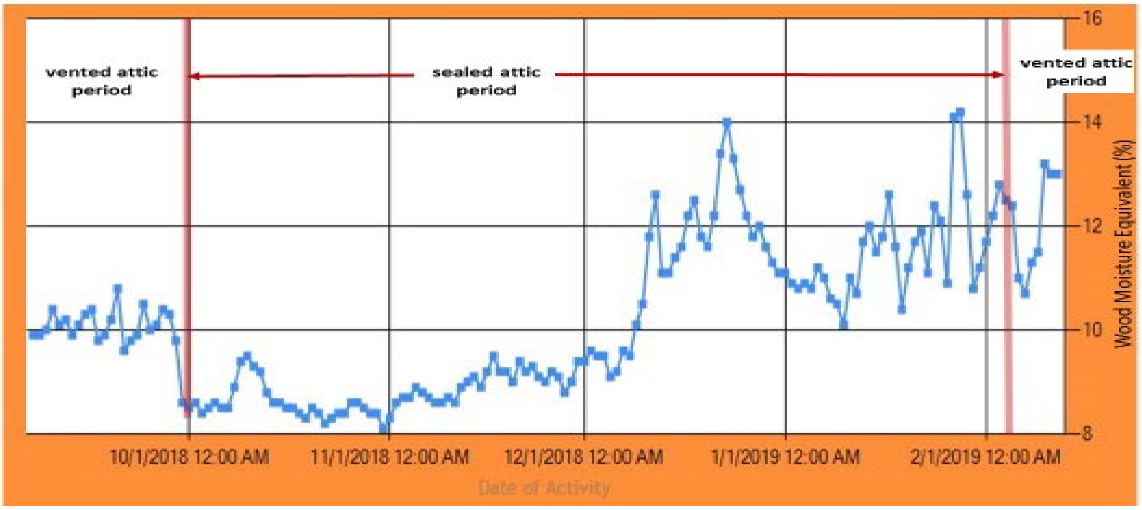

Figure 14. Wood Moisture Equivalent (WME) % at roof deck shows higher moisture during colder weather.

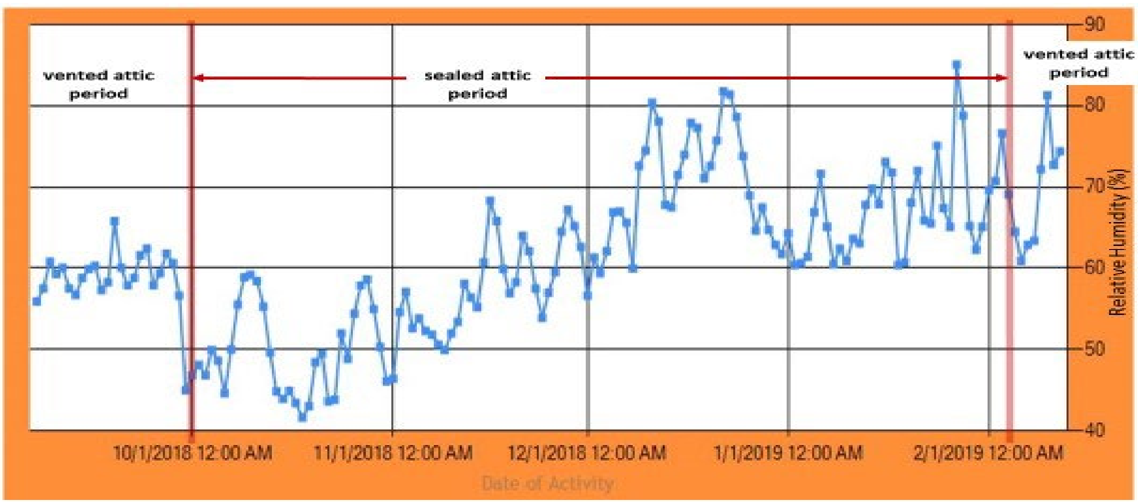

Figure 15. An increase in RH % at roof deck trends shows an expected direct relationship to WME% in Figure 14.

Figure 16. Colder attic deck temperatures trends coincide with higher WME % in Figure 14.

Interim Summary

All necessary equipment and materials have been installed in a timely manner and are operating effectively. Data continues to be collected and test configurations will continue to be rotated in the next remaining months of the project. This will further improve confidence in the energy analysis and offer more opportunity to investigate building materials moisture impacts.

Data available to date do not indicate significant energy savings from simply sealing attic vents with R30 insulation on the ceiling and having no insulation on the roof deck in the lab home with dark composite shingles. Simple comparison between a few similar hot and humid days indicate the sealed vent attic with ducts in the attic became hotter and drier than the vented attic with ducts in the attic as expected. The daily total air conditioning energy use increased by 3.9%. The sealed attic did have drier indoor air (lower interior RH and lower interior dewpoint temperature) with indoor air temperatures maintained at the same level. This drier air appears to be simply due to the extra air conditioning runtime that occurred with the sealed attic vent.

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