FLORIDA SOLAR ENERGY CENTER®

Interim Report

Further Investigation of Energy and Performance Impacts of Whole-House Dehumidifier Duct Configurations

DBPR Project #B3EB44
UCF/FSEC #2012-7112

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Introduction

As home energy efficiency increases, cooling loads decrease and the total hours of air conditioning also decrease. This raises the potential for elevated indoor RH during low cooling load periods without some form of supplemental dehumidification. Supplemental dehumidification can require a significant amount of energy use. In some low load homes with very efficient air conditioning, supplemental dehumidification may use as nearly as much annual energy as central cooling (Withers 2018).

There has been very little study of energy impacts of integrating dehumidifiers with central cooling. A review of a few ducted dehumidifier unit (DHU) manufacturer installation manuals found several different recommended ways to duct DHU. Installation manuals and a lack of third-party published research do not address any potential DHU duct configuration impacts upon central cooling or DHU energy performance. This project is a continuation of the ducted dehumidifier performance research (Withers et al. 2018) approved by the Florida Building Commission and sponsored by Florida Department of Business and Professional Regulation last year.

The primary research purpose is to determine which whole-house ducted DHU configurations provide the best performance and lowest energy use. The goal of this current research project is to build upon previous research and evaluate two additional dehumidifier unit (DHU) ducted configurations. The electric energy use of central air space conditioning and DHU as well as latent dehumidification performance will be evaluated and compared to last year's research results (Withers et al. 2018).

Previous DHU Duct Configuration Tests

Three primary DHU configuration experiments were conducted last year to evaluate the energy performance of each test configuration. Conceptual illustrations of these three lab DHU test configurations are shown in Figures 1-3. Lab test configurations evaluated were:

1) DHU air ducted from/to the central main body of building.
2) DHU air from/to return side of central cooling (AC).
3) DHU air from/to supply side of AC.

It was found that Test 1, DHU air from/to return of central cooling system used about 12% more annual space cooling and dehumidification energy compared to when DHU is ducted to and from indoors. Test 1 also resulted in up to 28% poorer central cooling dehumidification performance. As a result it was recommended that this specific configuration not be allowed in Florida Building Code.

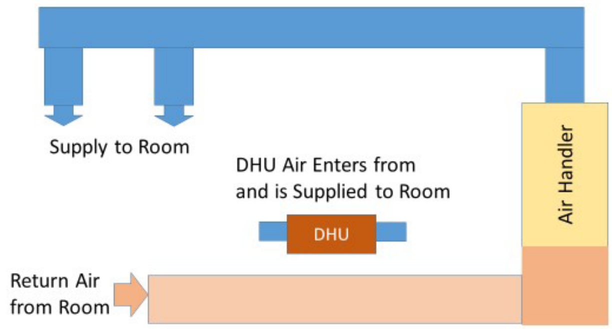

Figure 1. Illustration with DHU not ducted to central cooling ducts. DHU air directly from and back into conditioned space. (Test 1)

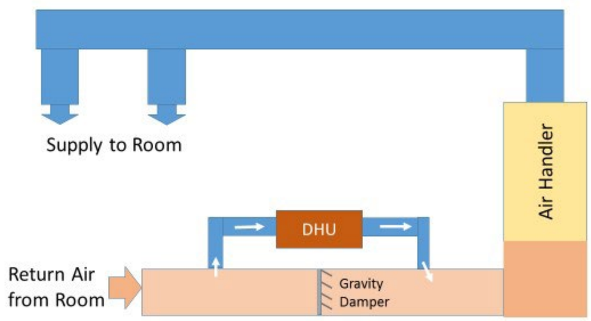

Figure 2. Illustration of DHU ducted to the main central return duct. Gravity damper only opens when central system on. When closed, it blocks short-circuiting of DHU supply air straight back into DHU return. (Test 2)

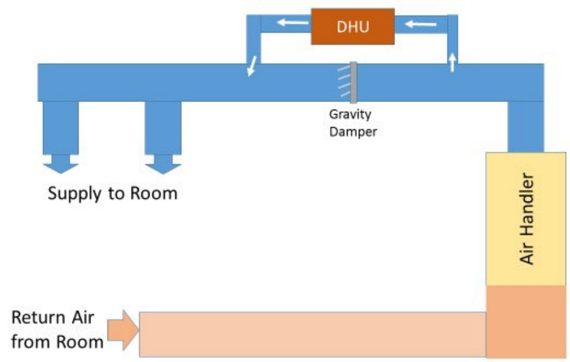

Figure 3. Illustration of DHU ducted to the main central supply duct. Gravity damper only opens when central system is on. When closed, it blocks short-circuiting of DHU supply air straight back into DHU return. (Test 3)

New DHU Test Configuration Tests

Two more DHU test configurations are being tested in this current project. For purposes of comparing to the previous Tests 1-3 from last year, these new tests will be referred to Test 4 and Test 5.

Test 4

Test 4 is similar to the previous Test 3 from last year with the DHU supply air ducted into the central supply, except the return air to the DHU comes directly from the indoor central room. An illustration of this test concept is shown in Figure 4. This test configuration has been reported as a preferred option used by some Florida contractors.

Test 5

Test 5 in this project is different from all other tests since part of the DHU entering air comes from outdoors and mixes with indoor air before entering the DHU. The DHU supply air was ducted to the central air duct in the same manner as Test4. This test mode was chosen since some builders in Florida are using this method as a means to provide adequate whole-house mechanical ventilation in tight homes and maintain acceptable indoor humidity.

Test 5 implementing the ventilating dehumidifier concept was operated in a way that would comply with ASHRAE 62.2-2016. ASHRAE62.2-2016 accounts for the number of occupants a home is designed for and allows the estimated natural infiltration (Qinf) to be applied towards the total required ventilation. The balance of the requirement must then be provided mechanically (Qfan). Test 5 was run assuming a design occupancy of 4 persons and the laboratory home had a measured airtightness of 2.4 ACH50. Based upon this, Qinf was calculated as 20 cfm and the required continuous fan flowrate for ventilation (Qfan) was 70 cubic feet per minute (cfm). The dehumidifier total airflow rate when ducted was about 155-160 cfm. The remaining 85-90 cfm of dehumidifier air came directly from the central indoor room.

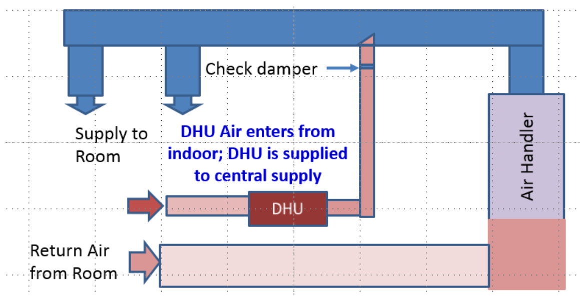

Figure 4. Illustration of DHU supply ducted to the main central supply duct. Gravity damper only opens when DHU is on. DHU air enters directly from indoor central room. (Test 4)

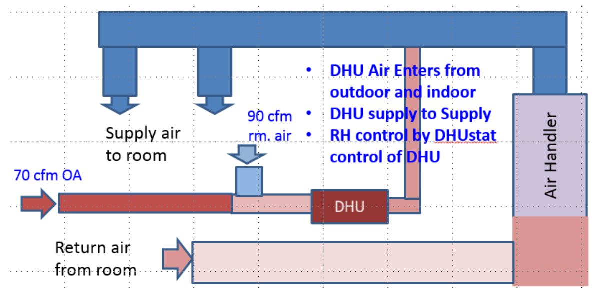

Figure 5. Illustration of a ventilating DHU design. DHU supply ducted to the main central supply duct. A portion of DHU air enters from indoor central room and the rest from outdoors. (Test 5)

Contracted Scope of Work

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 alternate the method of DHU duct configurations identified in Scope of Work item (2 a.) and (2 b.). Testing will be completed using the Building Science Lab building on the FSEC campus. A wall-hung dehumidistat control will be used to control the DHU at the indoor RH setpoint.
2. In a laboratory, alternate method of dehumidifier air distribution for specified test cases. DHU ducts will be configured in the following ways:
    a) DHU entering air (DHU return) from conditioned space and DHU supply air ducted into central heat/cool supply duct (Referred to as Test 4 in this report Figure 4)
    b) DHU entering air mixed at about 45% airflow rate from outdoors and 55% from indoors. DHU supply air ducted into central heat/cool supply duct (Test 5, Figure 5).

3. Write a final report (to be delivered by June 15) with results, combine with previous Withers et al. 2018 study results, and offer additional recommendations if warranted.
    a) Results will include a predicted annual DHU and space cooling energy use based on energy monitoring that can be compared to previous Withers et al. 2018 results.
    b) Results will include an evaluation of duct configuration upon DHU performance.
    c) Update Withers et al. 2018 report summary with new findings in final report.

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 Building Science Lab building located on the Florida Solar Energy Center campus.

Lab Building

This lab has a conditioned floor area of 2000 ft^2 with concrete masonry block walls having R-5 unfaced foam board insulation located on the interior side of the wall. Windows were single pane clear glass set in metal frame. Ceiling insulation was R-19 batt. Building airtightness was tested using a blower door and measured a normalized air leakage rate of 2.4 ACH50. There was no measurable duct leakage to outdoors (CFM25out=0). A manual J8 load calculation on the tested building calculated a summer 99% design total cooling load of 2.3 tons. The floor plan is shown in Figure 6.

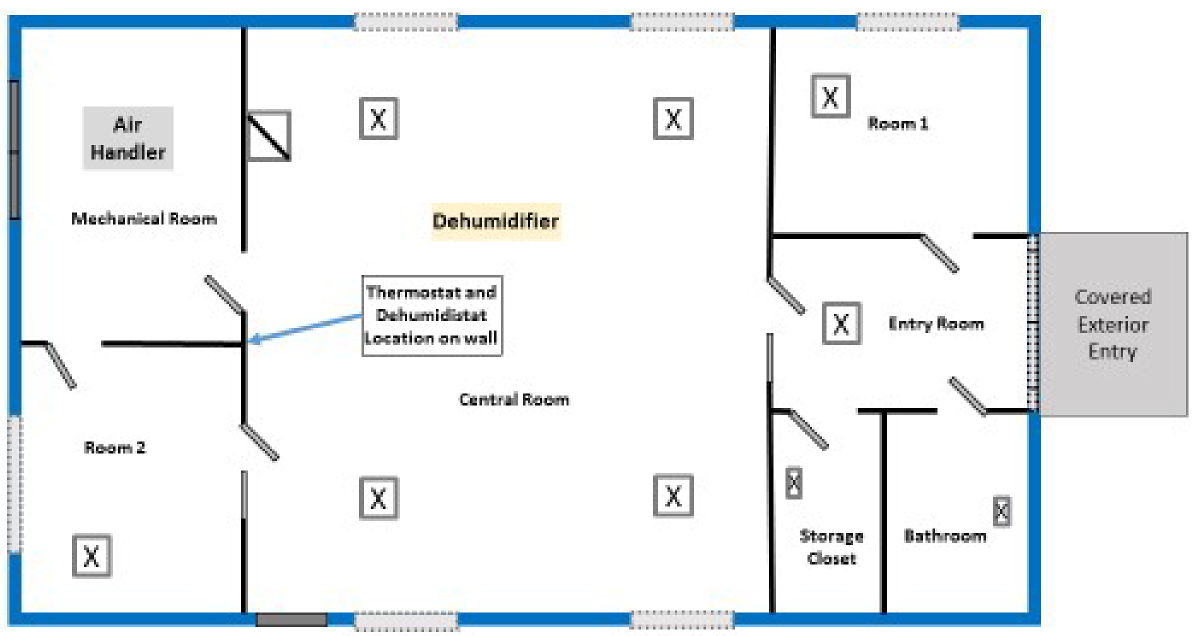

Figure 6. Building Science Lab floorplan.

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 lighting, space heater and mechanical fans. The interior sensible loads were monitored using power meters during the entire project to ensure consistency was maintained for each experiment. The average interior sensible load delivered per day was at a rate of about 4,200 Btu/h. Based upon a Manual J8 sizing calculation, this is an amount appropriate for the installed central air conditioner during the testing configurations on a design day.

Interior latent loads were delivered at three different target rates using a humidifier or hot plate. Target rates of 15, 30 and 60 pounds of water each day were evaporated into the building and distributed within the central area of building by a small circulation fan. Latent delivery was monitored using water meters or tipping buckets on water supply lines.

Lab Equipment

The central heat pump and ducted dehumidifier used in this project are the same units used in the first 3 tests from last year's project (Withers et al. 2018). The central ducted system was a SEER13 heat pump with a nominal rated cooling output of 2.7 tons, however fan operation at low flow setting and addition of gravity dampers within supply ducts resulted in measured delivered cooling at about 2.3 tons. The capacity is appropriate for the design building load. The heat pump system was controlled by a thermostat located on an interior wall in the large open central room. The thermostat was set to maintain an indoor average of 76F.

The whole-house ducted DHU used was an Ultra-Aire 70H model with rated efficiency of 2.4 liters/kWh and rated moisture removal of 70 pints per day at 80°F and 60% RH. This qualified as an ENERGY STAR® dehumidifier. Supplemental dehumidification was controlled by a dehumidistat located on a central interior wall near the central thermostat. The RH setpoint was at 50% RH.

Average daily indoor as well as outdoor conditions from September 2018 through February 20, 2019 are shown in Figure 7. It can be seen that the central heat pump system is maintaining setpoint. The supplemental dehumidifier is also able to maintain indoor RH below 50%. There is one two-day period where indoor RH exceeded 50% about 65 days into testing. This particular period had occurred due to isolated condensate line leaks that wetted the floor around the leak area for two days. Extra air circulation and some local heat was used to dry the area. The latent load humidifier was turned off for about one day. Days impacted from this event were eliminated from any analysis.

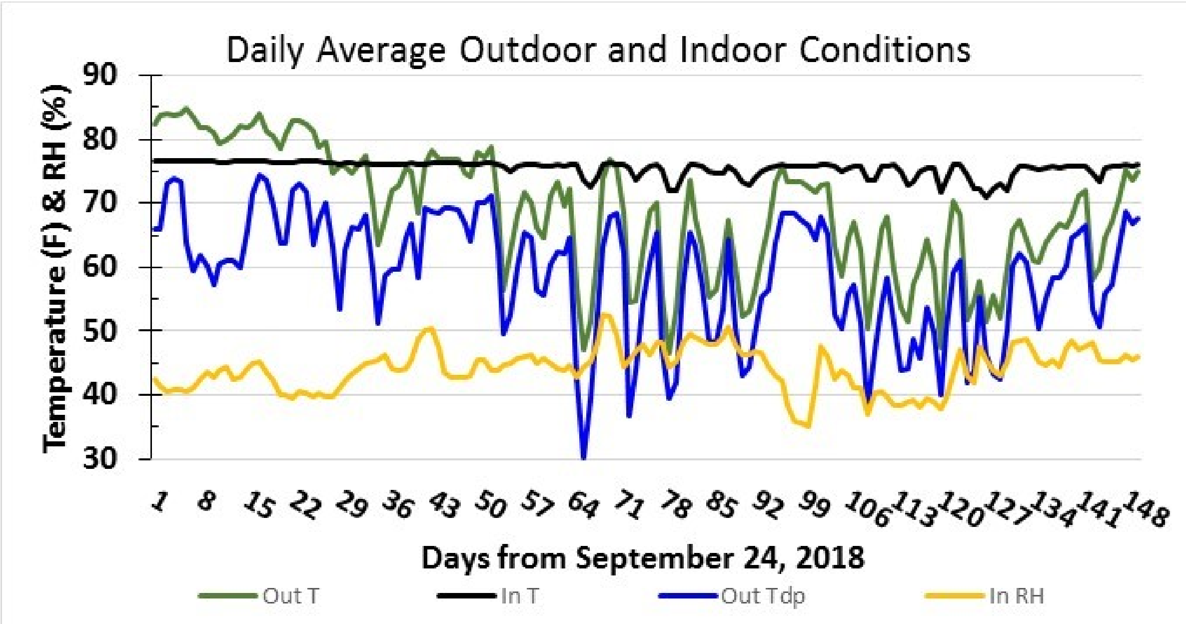

Figure 7. Daily average outdoor temperatures and indoor temperature and relative humidity.

Lab Sensors

All sensors for this project were installed and verified to be in good working order. Temperature and relative humidity (RH) sensors measured indoor, attic, and outdoor conditions. Power meters measured internal loads and space conditioning energy.

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 thermocouple and Vaisala sensors.

In all, 37 channels of data from sensors were collected using a Campbell Scientific, Inc. CR10 datalogger. 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. Days during transition between test configurations or other interruptions to testing were also screened out from analysis.

Lab Test Method

Two 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 4 and 5. Duct modifications suitable for both tests began in September 2018 and then provisional testing of Test 5 (ventilating DHU) was begun. Some modifications were made during the provisional testing period to assure the correct airflows from outdoors and indoors were acquired. Each test configuration has been implemented over time in an effort to acquire as much variation in weather conditions for each test as possible. Rotation through the two test configurations are planned to continue well into May to enable as much weather variation as possible for each test.

Interim Lab Test Results

Energy

Preliminary analysis has begun to investigate space conditioning energy use impacts of the two 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. Data collection began September 2018 and will continue through May 2019.

Figure 8 shows data from Test 4 having 100% of the DHU return air come from indoor central room. The DHU supply air was directed into the central supply main duct before any supply branches. The data are separated into three groups having different interior latent loads. This is consistent with the testing method during Tests 1-3 last year. The first group is with indoor latent load of 15 lb/day. The 15 lb/day latent load is reserved for weather that varies from cold up to mild cooling load. The second group is with a latent load of 30 lb/day. This group is only showing 6 days of data so far, but will continue to increase over the next few months. The last group is with indoor latent of 60 lb/day. The 60 lb/day latent delivery is reserved for days with warm to hot weather. This group has a substantial amount of data, but it is expected to be expanded a little more towards May.

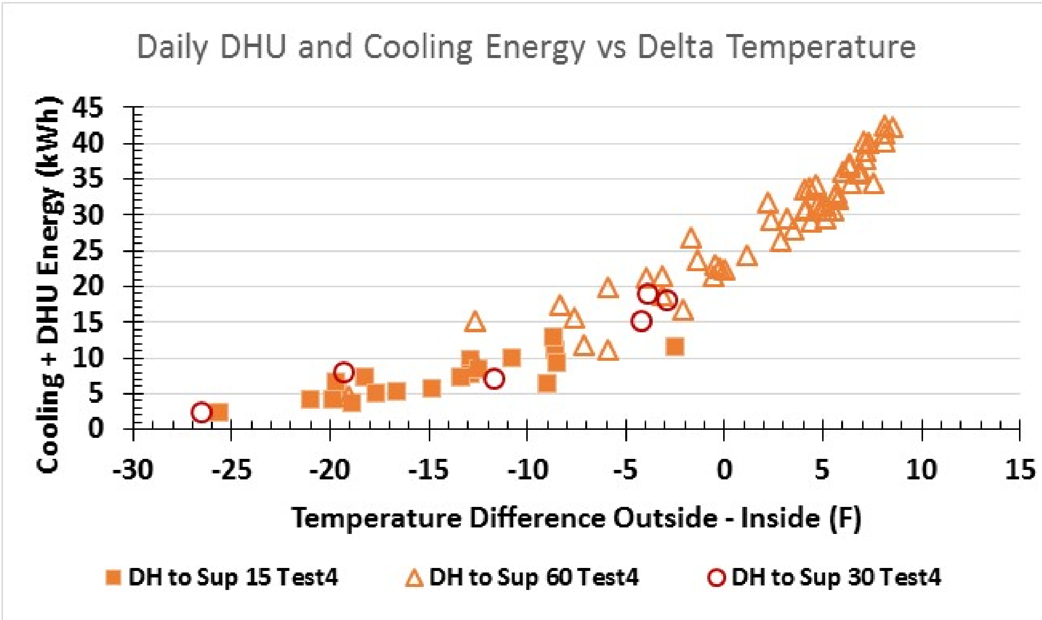

Figure 8. Test 4 data with DHU air entering from indoor central room and supplied into the central cooling system main supply. Data is differentiated at three different indoor latent loads.

Figure 9 shows data from Test 5 having about 70 cfm air from outdoors mix with about 90 cfm of indoor room before entering the DHU. The DHU supply air was directed into the central supply main duct. Indoor latent was maintained at a constant 15 lb/day for this test configuration. Fifteen lb/day interior generated latent is within the range of what is currently known about homes. The data show a reasonable representation from very cool to warm days. It is expected that more data will be collected at warm to hot days (dT= 0 to 5) as we get into May weather.

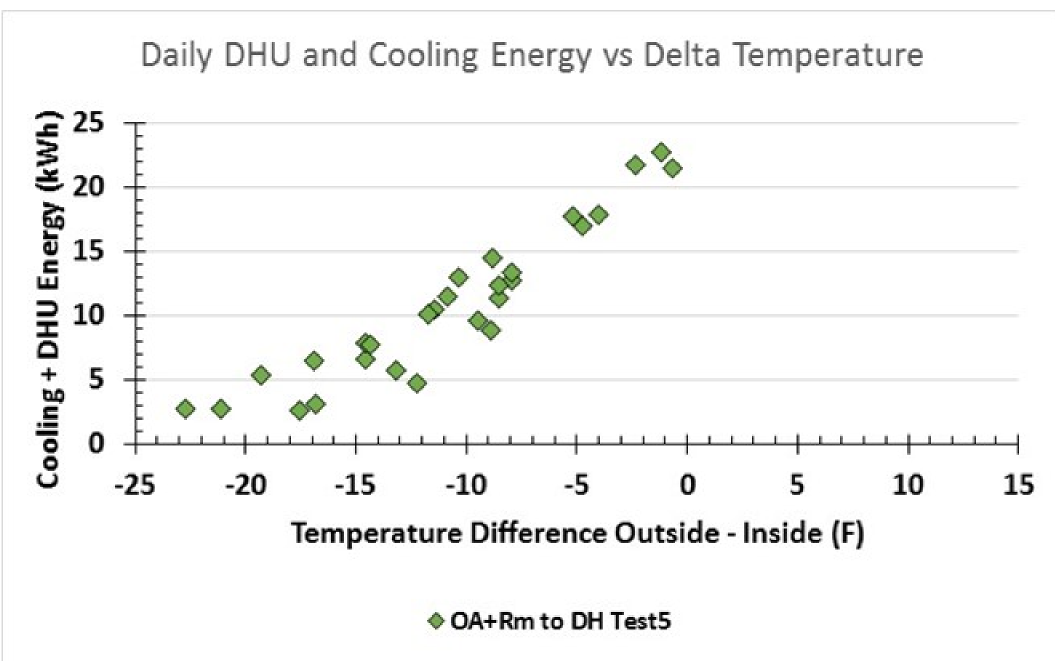

Figure 9. Test 5 data with DHU air entering from outdoors and mixing with indoor air. The DHU supply air is delivered to the central cooling main supply. Indoor latent was maintained at a constant 15 lb/day.

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 10 shows an example of a least-squares polynomial best-fit line plotted for Test 5 for data collected to date. It is expected that the fit lines will change as more data is collected.

There have been very limited sustained periods of cold weather for the tests. Given that the Building Science lab has high mass and reasonably well insulated, it takes several cold days in a row before there is enough heating load with an interior heating setpoint at 70F. Therefore there has been no space heating during any tests to date.

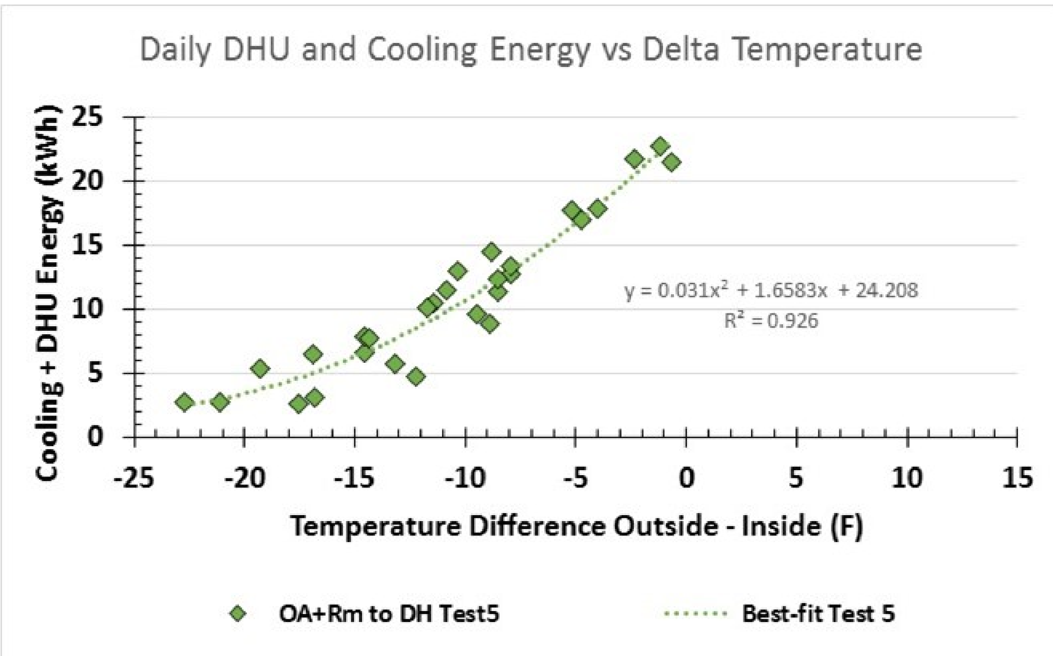

Figure 10. Example showing a preliminary least-squares best-fit line projected through Test 5 data.

Dehumidifier Performance

The DHU performance presented here in this interim report is only a preliminary sample of the type of data collected so far. Deeper analysis will be performed by the time the final report is produced.

The dehumidifier performance can be impacted by entering air conditions and other factors such as static pressure which can impact airflow rate. Monitoring to date has found that the DHU has been operating within manufacturer specifications under the primary test conditions presented to date. The DHU has a manufacturer stated efficiency of 2.4 L/kWh under rated test conditions of entering air at 80F and 60% RH using 580 watts of power. The actual entering air test conditions can be quite different from rated conditions, and the reader is reminded that the 15 minute interval data shown here are often not at steady state conditions.

Testing so far has found the efficiency during full 15 minute periods of dehumidification operation to be near proximity of the rated efficiency (2.4 L/kWh) although the test conditions are cooler and somewhat drier than rated conditions (80F, 60% RH). Figure 11 provides an example of the efficiency during three consecutive days of Test 5 (ventilating DHU). The entering conditions as well as the outdoor temperature are also shown in Figure 11.
The latent efficiency does not change by much when the entering conditions do not change much. Even though outdoor conditions may change, this air mixes with cool dry indoor air and only represents about 43% of the total entering air. An efficiency of 0.0 L/kWh simply means there was no mechanical dehumidification occurring. The longer gaps between dehumidification coincide with higher outdoor temperatures. This is as expected as there is more sensible load, the central air conditioning runs more and removes more moisture thereby decreasing indoor RH and the need for supplemental dehumidification.

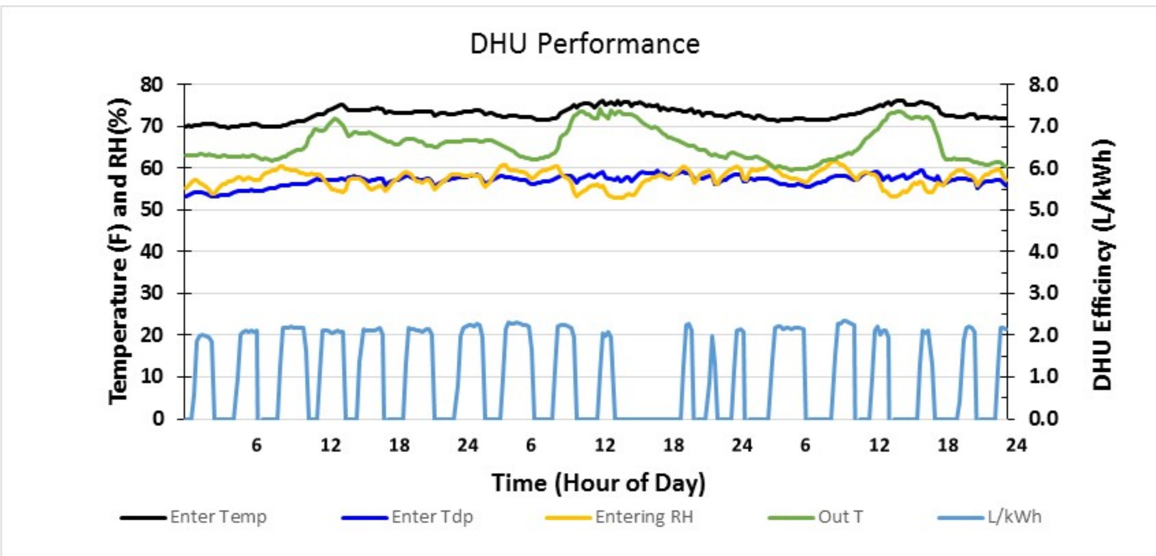

Figure 11. DHU efficiency shown with entering air conditions and outside temperature during February 1-3, 2019.

A short period of five days was used to run 100% outside air through the DHU to be able to observe a wider variety of entering air conditions and the impact upon DHU performance. This also represents another ventilating DHU configuration that some contractors have used in larger homes when higher ventilation rates are needed. These 5 days are not represented in any Test 4 or Test 5 analysis.

As expected, a wider range of efficiency is observed in Figure 12 due to greater variability in entering conditions. It can be seen that generally DHU efficiency improved with more moist (higher dewpoint temperature) entering air and decreased as entering temperature increased during similar dewpoint temperature. The range of observed DHU efficiency was from 1.8 L/kWh up to 3.7 L/kWh. While the weather conditions in Figure 11 do not represent design cooling conditions, there are periods that represent weather that occurs much of the year in Florida.

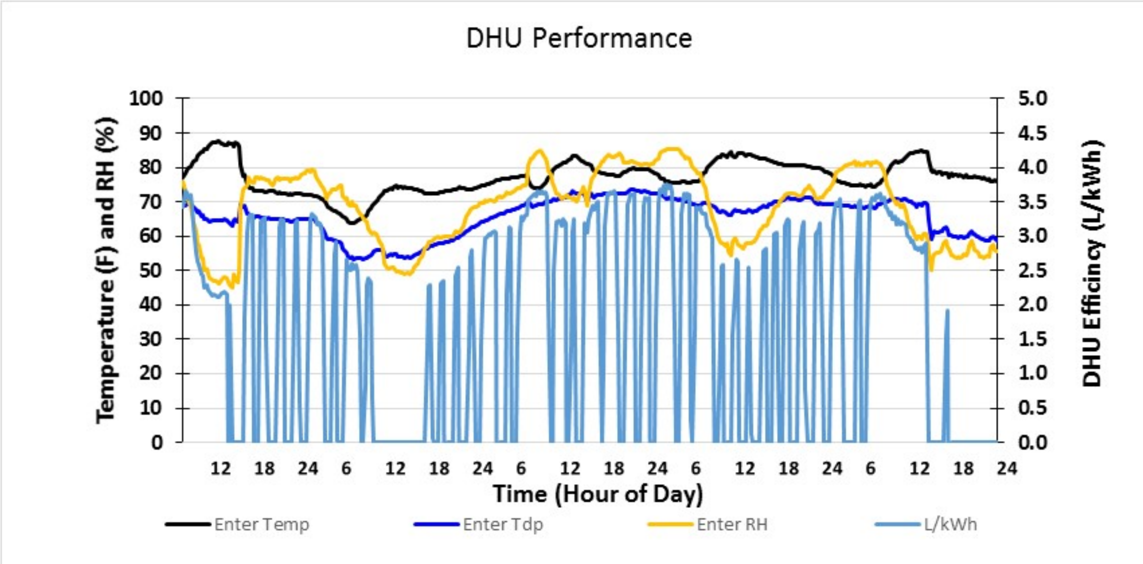

Figure 12. Five day period with wider variation in entering DHU conditions shown with DHU efficiency.

Dehumidifier power consumption was evaluated for a set of data with a wide range of entering conditions. The 15 minute data shown are when dehumidification operation occurred the entire period. Figure 13 shows the DHU power use plotted against two different series. It is plotted against the dewpoint temperature (blue) and also the drybulb temperature (black). Figure 13 shows that entering dewpoint temperature alone has a better correlation to energy use than drybulb temperature alone. This shows that DHU power can increase by about 27% depending upon entering temperatures. As more data is collected further analysis will be examined.

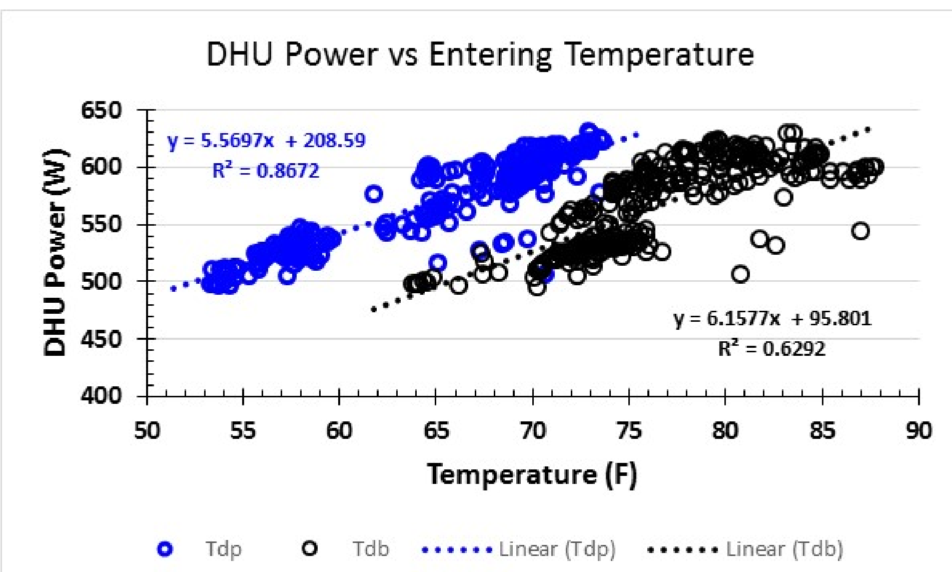

Figure 13. DHU power shown plotted against entering temperature.

Test 5 shows a big efficiency advantage over a traditional central system runtime ventilation design. A runtime ventilation system is one where the outdoor air is ducted into the central system return and air is pulled in using the central system supply air fan. Mechanical ventilation provided through the DHU only required 76 watts of power compared to 300 watts up to about 600 watts or more if a central air handler fan using a standard runtime vent design was used. Figure 14 shows the low end power used when only the DHU fan is operating without dehumidification. The red box highlights the power when only the DHU fan was operating at about 76 watts. The power increased to about 530 watts on average when dehumidification was called for during this period.

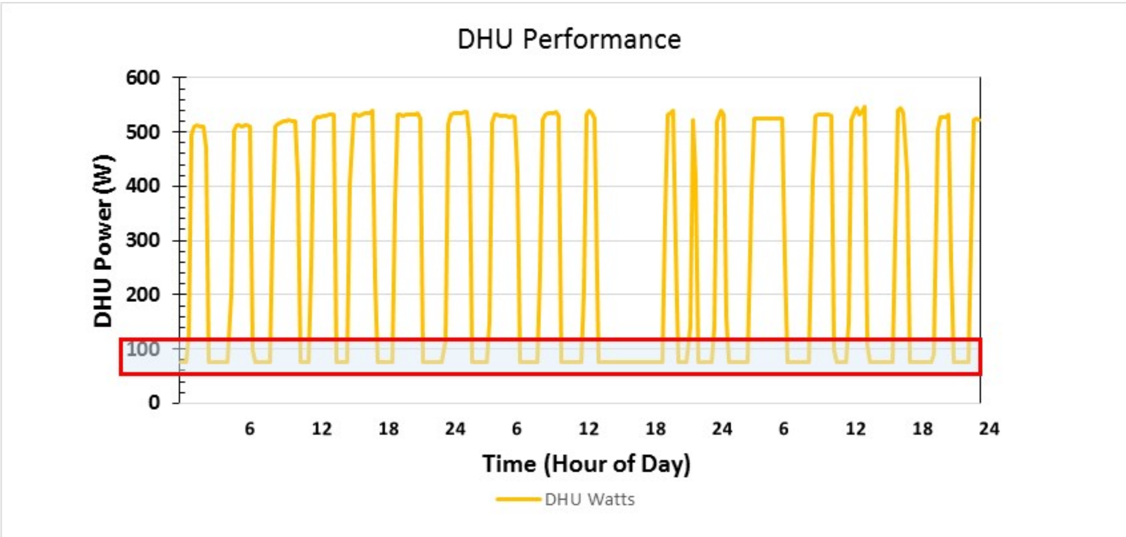

Figure 14. DHU power during three consecutive days.

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 and dehumidification performance analysis. Annual energy predictions of operating Test 4 and Test 5 will be completed after additional data collection. These will be compared to Tests 1-3 from last year with results reported in the final report this June.

In tight homes where whole-house mechanical ventilation is required, mixing the incoming outside air with indoor air before entering the DHU shows a promising alternative to running runtime ventilation using a central ducted system fan operated to meet ASHRAE 62.2 standards. This is because the fan of the DHU uses much less power if used to bring in outside air compared to a central ducted system fan used to do so in a runtime ventilation strategy. The DHU fan power was 75% less than the central fan used in this testing. The DHU fan power could be as much as 90% less or more if central systems larger than the nominal 3 ton system were used in this project. This is based on a straight-up comparison of the total power to operate each fan. Another way to look at this is in terms of efficiency measured as watts of power used per cfm air delivered (W/cfm).

While the case for using this DHU fan for mechanical ventilation looks good compared to a runtime ventilation method, other fans exists that may be just as efficient or better at moving ventilation air when evaluated on a W/cfm of ventilation airflow delivered. A runtime vent fan may be between 4-8W/cfm ventilation air delivered which is very high. The DHU tested in this project was only about 1 W/cfm ventilation air delivered. There are some ERV units that can ventilate with fans using less than 1 W/cfm.

Selecting the lowest operating cost ventilating system will come down to more than just the vent fan efficiency. An important thing to remember about using an ERV in Florida is that it will not be able to maintain indoor RH below 60% RH all hours of the year without supplemental dehumidification or expensive cooling equipment with special dehumidification modes that can operate at very low sensible heat ratios and at low cooling capacity. Some people may not mind indoor humidity hanging around 60%-65% and would not require supplemental dehumidification. In this case ERV alone may be a suitable mechanical ventilation method. For those requiring tighter control over indoor RH, and diminished moisture-related issues, total space conditioning and ventilation equipment first cost and operational costs must also be considered.

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