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Residential Performance Code Methodology for Crediting Dehumidification and Smart Vent Applications Interim Report

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Rationale

As energy efficiency reduces the hours where air conditioning is called for, and as codes require outdoor air to be brought into homes, humidity levels in homes may rise to the point where dehumidification is required. However, there are currently no standards in Florida's Energy Conservation Code for dehumidification. Thus, a mechanical contractor that invests in an expense such as variable speed heat pumps or heat pipe technology in order to dehumidify and save energy receives little benefit relative to another home that installs an inefficient dehumidifier. A reference home dehumidification strategy needs to be established.

Another strategy to reduce interior moisture loads is to allow flexible hours of mechanical ventilation. Research being conducted by LBNL, FSEC and others are showing potential to save some energy by controlling when ventilation occurs, or "smart ventilation." However, the energy conservation code will need to have a strategy for providing an appropriate baseline for a code reference home.

Overview

The performance method (R405) is the most popular compliance method in Florida. The method requires a software vendor to virtually create a baseline reference home the same size as the home to be permitted and insulate and equip it to a set of parameters spelled out in Table R405.5.2.1. This table includes the temperature that both the to-be-permitted home and the baseline must be maintained to simulate heating and cooling. It also has rules on energy use of the ventilation system for the baseline home. What needs to be added are the following parameters:

1. The interior humidity set point required to be maintained, and whether this applies all year or only at certain times of year. Also, is this set point constant or does it start dehumidifying at one set point and shut off at another like many portable dehumidifiers?
2. The energy use of the dehumidifier in the baseline home. Is using a constant Liter of moisture removed per kWh a sufficient methodology and what should the baseline value be?
3. For simulations that allow smart ventilation, what level of ventilation must be maintained, and if that smart ventilation reduces ventilation during peak times, does the baseline stay constant in its ventilation rate?

Summary of Work Performed

The literature review has been performed. The review maybe expanded as new papers surface on these topics. This report contains the review as well as draft code recommendations. The impact of the draft code recommendations is work yet to be conducted.

Task 1 -4 Progress

Task 1: Literature review of dehumidification strategies, devices and controls.

Literature review will at a minimum include searching databases of NREL, LBNL, ASHRAE, DOE Building America and general search with key words of home or residential dehumidification.

A number of references have been reviewed and the relevant ones are included here as an annotated bibliography. Italics are used to indicate direct quotes from the referenced publication.

This report begins with earlier literature study work by FSEC, specifically:

Charles R. Withers, Jr., Jeff Sonne, "Assessment of Energy Efficient Methods of Indoor Humidity Control for Florida Building Commission Research," June, 2014 http://www.floridabuilding.org/fbc/commission/FBC_0614B/Energy/Energy_Efficient_RH_control_Draft_Final_06_15_14.pdf

This report conducted for the Florida Building Commission, had two parts: a literature review to determine the energy efficiency and cost-effectiveness of various residential latent load approaches; and an experiment measuring the humidity and energy performance of four latent load management approaches at various levels of mechanical ventilation. Key parts of that literature review are copied here so as to avoid repetitive work.

Approximately 30 articles, research reports, presentations and code documents were reviewed by Withers and Sonne. Information sources included the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Building Science Corporation (BSC), CDH Energy Corp., Florida Solar Energy Center (FSEC), International Code Council (ICC) and Oak Ridge National Laboratory (ORNL).

Indoor Humidity Level Limits

An important first step in determining appropriate latent control approaches is determining what constitutes appropriate indoor humidity levels. In a 2002 publication, Joe Lstiburek (Lstiburek 2002) notes the variety of factors that go into determining proper RH levels:

> *…determining the correct range depends on where the home is located (climate), how the home is constructed (the thermal resistance of surfaces determines surface temperatures), the time of year (the month or season determines surface temperatures), and the sensitivity of the occupants.*

A recent Building America Expert Meeting report (Rudd 2013a) that included input from BSC, CDH Energy Corp., FSEC and IBACOS summarized several publications.

A number of references (ASHRAE Standard 55-2010, Balaras and Balaras 2007, Wolkoff and Kjaergaard 2007) refer to indoor RH between 30% and 60% as comfortable, healthy, and recommended for human occupancy. In its Answers to Research Questions section, the same publication further addresses this topic.

It was generally agreed that, a dehumidification control setpoint of 55%, in order to keep indoor RH from exceeding a 60% RH limit, was the correct strategy for high performance, low-energy homes. While it is clear that everything will not fail at once if the indoor RH goes over 60%, a 60% RH limit provides the best practice coverage for providing comfort and durability over a reasonable range of varying factors, such as internal moisture generation rate, and occupant comfort perception and susceptibility to illness stemming from elevated indoor humidity. Included in the variability of internal moisture generation rate is construction moisture drying. It has been BSC's experience that limiting indoor RH to 60% via supplemental dehumidification is a generic enough limit to remove moisture concerns related to the seasonal timing of building closure and occupancy in warm-humid climates. …

It was generally agreed that annual hours above 60% RH is the single most appropriate humidity control performance metric to use to compare system performance and to compare required supplemental dehumidification energy. That metric does give generally the same result as looking at 4-hour and 8-hour events above 60% RH.

The EPA Indoor airPLUS program is designed for *improved indoor air quality compared to homes built to minimum code*. This program specifies using equipment that will keep the indoor RH <60% (EPA 2013). The authors consider 60% RH as a reasonable recommended indoor control point for supplemental dehumidification in Florida homes. It is low enough to protect building degradation and a fair balance between energy conservation and comfort. Furthermore, it is an easy setting to find on controllers lacking set point markings on the control knob. While we recognize 60% as reasonable, individual comfort should be allowed to be accommodated. What constitutes comfort varies by individual and even varies in specific individuals over time. Occupants with health issues may have more specific requirements that must be considered.

Rising Indoor Humidity Levels

While, there are some factors that tend to increase indoor RH in new construction and other factors that tend to decrease RH, a 2014 ASHRAE publication (Henderson and Rudd 2014) indicates that overall RH levels are increasing.

Conventional air conditioners have traditionally been deemed adequate for controlling space humidity levels in residential applications. However, as homes in humid climates have become more energy efficient, there is evidence that relative humidity levels in homes have been increasing (Rudd and Henderson 2007). This implies that sensible heat gains to the building have been reduced more than moisture loads, leaving a mix of latent and sensible loads that is poorly matched to the sensible heat ratio of conventional air-conditioning systems.

The 2013 Building America Expert Meeting report noted above (Rudd 2013a) lists the influences modeling has shown to most effect indoor RH in high performance, warm-humid climate homes:

- Internal moisture generation
- Internal sensible heat generation

- Heating setpoint temperature
- Air distribution system duct location.

Regarding air distribution system duct location, the 2014 ASHRAE publication (Henderson and Rudd 2014) explains that moving ducts from the attic to the conditioned space reduces sensible heat gains more than it reduces latent loads, resulting in higher relative humidity levels.

Mechanical ventilation also has a significant impact on indoor RH. A recent monitored FSEC study (Parker et. al. 2014) found mechanical ventilation added to a tight (ACH50 2.2) central Florida lab home to raise summertime moisture levels by 2% - 5%.

Modeling results summarized in the 2013 Building America Expert Meeting report (Rudd 2013a) show this need.

The warm-humid climates of Miami, Orlando, Houston, and Charleston show a clear need for supplemental dehumidification for high performance homes. Without supplemental dehumidification, hours above 60% RH were in the range of 800 to 1800, with hours above 65% being about half of that. Most of the hours of elevated indoor humidity occur in the mild temperature but humid outdoor conditions of fall and spring, but also occur in winter in Orlando and Miami. A smaller number of hours occur during some summer nights and days-long rainy periods. Few hours above 60% RH occur during heating hours. Most hours between 60%-65% RH occur during either cooling or floating hours, and most hours above 65% RH occur during floating hours."

The paper discussed methods of dehumidifying in some detail. Table 1 from that work is included here:

Table 1. Supplemental Dehumidification Options (cost sources: Rudd 2013b and FSEC research). [from Charles R. Withers, Jr., Jeff Sonne," Assessment of Energy Efficient Methods of Indoor Humidity Control for Florida Building Commission Research," June, 2014]

Supplemental Dehumidification System	First-Cost Estimate Including Labor	Pros	Cons
Overcooling	**$0**	Low first cost. User control.	Results in cold clammy comfort. No help in swing season. Energy inefficient
Lowering fan speed	$0-$75	Improved dehumidification. Owner may be able to do this.	Some loss in cooling efficiency. No help in swing season.
Heat pipes	$3000	Long life, low maintenance	May not have room to install. No help in swing season.
Enthalpy recovery ventilation	$700-$1400	Can reduce load from ventilation. Balanced house pressure possible.	Extra energy to run the two fans needed. No help in swing season.
Dual capacity air conditioner	$1800*	Low speed can result in lower energy use while saving energy	Higher first cost. Better than single cap., but still some hours swing season it will not operate.
Variable capacity air conditioner ventilation	$3700*	Excellent efficiency. Longer run times. Good RH control. Good ventilation mixing.	High first cost. New on residential market, so more to learn.
Dedicated outdoor air system	$7000	Good RH control. Excellent ventilation effectiveness potential.	High first cost.

Mini-split Dedicated outdoor air system	$3200	Good RH control. High-efficiency.	Hard to size solely for low flows. Some localized overcooling may occur at times. Good mixing depends upon central fan cycling.
Stand-alone Dehumidifier with Remote Dehumidistat	$500-$2000**	Works with or without AC. Good RH control.	Energy -inefficient. Adds heat, some RH dead bands can be excessive. Noise may be issue.
Integrated Ducted Dehumidifier	$1,000-2000**	Works with or without AC. Good RH control. Air is distributed better than stand-alone. Noise issue less likely than stand-alone	Energy inefficient. Adds heat, some RH dead bands have been found excessive
Sub-cooling Reheat	$1,600	Good RH Control. More efficient than dehumidifiers.	Overcools and then heats, using energy for both. High first cost.
Full-condensing Reheat	$1,750	Good RH Control. More efficient than dehumidifiers.	Overcools and then heats, using energy for both. High first cost.
Desiccant Dehumidifier	$2,000	Good RH control. Has potential to be recharged by solar or gas	Higher first cost,

The experimental work consisted of using a mini-split to bring in outside air with a high efficiency central cooling system and comparing it to just bringing in the outside air to the return area of the central system. Each configuration included a dehumidifier set to 60%RH. Outside air was introduced at 60 cfm, and later repeated at 130 cfm. The 60 cfm was what the IMC2012 would require for a three bedroom home. The 130 cfm represents what ASHRAE 62.2 would require for an extremely tight home of 0.5 ACH50 with 3025 ft^{2} and 5 bedrooms. The mini-split configurations were set to use the mini-split to cool to 74F and only when it could not meet demand did the central unit kick on at 77°F. This strategy has since been shown effective in most existing homes to save energy, however our lab had a SEER 21 central system and the mini-splits used more energy as they cooled and dehumidified more than just the central system due to the lower set point. All four configurations maintained the relative humidity below 60% during our tests so the dehumidifier did not turn on.

Lstiburek, J. (2002). “Relative Humidity.” Presented 2002 Healthy Indoor Environments, Austin TX. Building Science Corporation, Inc. Accessed June 2014: http://www.buildingscience.com/documents/reports/rr-0203-relative-humidity

Rudd, A. (2013a). *Expert Meeting: Recommended Approaches to Humidity Control in High Performance Homes.* Somerville, MA: Building Science Corporation. Accessed June 2014: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/expt_mtg_humidity_control.pdf.

Balaras, C.; Dascalaki, E.; Gaglia, A. (2007). "HVAC and Indoor Thermal Conditions in Hospital Operating Rooms." *Energy and Buildings* (39:4); p. 454. Accessed June 2014: http://www.sciencedirect.com/science/article/pii/S0378778806002209.

Wolkoff, P.; Kjaergaard, S. (2007). "The dichotomy of relative humidity on indoor air Quality." *Environment International* (33:6); p. 850. Accessed June 2014: http://www.sciencedirect.com/science/article/pii/S0160412007000773.

EPA Indoor airPLUS Version 1 (Rev.02) Verification Checklist. 2013. United States Environmental Protection Agency November 2013. Accessed 2014: http://www.epa.gov/iaplus01/pdfs/verification_checklist.pdf.

Henderson H.; Rudd, A. (2014). “Energy Efficiency and Cost Assessment of Humidity Control Options for Residential Buildings.” *ASHRAE Transactions*, (120) Part 1. NY-14-013 (RP-1449).

Rudd, A.; Henderson, H. (2007). “Monitored Indoor Moisture and Temperature Conditions in Hot-Humid US Residences.” *ASHRAE Transactions* (113) Part 1. Accessed June 2014: http://www.buildingscience.com/documents/confpapers/cp-0702-monitored-indoor-moisture-and-temperature-conditions-in-hot-humid-us-residences.

Parker, D.; Sherwin, J.; Raustad, R; Shirey, D. (1997). "Impact of Evaporator Coil Air Flow in Residential Air Conditioning Systems." Presented at the 1997 ASHRAE Annual Meeting, June 28-July 2. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-321-97/index.htm.

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ASHRAE

Charles R. Withers, Jr., “Measured Space-Conditioning Energy and Humidity in a Mechanically-Ventilated House Lab with Fixed and Variable-Capacity Cooling Systems Located in a Hot and Humid Climate,” ASHRAE IAQ Conference, 2016.

This paper presents results of lab research on three methods of cooling and dehumidifying a home mechanically ventilated in accordance with ASHRAE 62.2-2013 (ASHRAE 2013a). The first method *was a minimum efficiency fixed capacity central ducted system, the second was a very high efficiency variable capacity central ducted system, and the third was a single ductless minisplit system.*

The author describes some of the challenges of controlling humidity. Maintaining good indoor relative humidity (RH) and simultaneously providing adequate mechanical ventilation can be challenging during warm and humid weather, particularly during low cooling load periods. During warm and humid weather, mechanical ventilation introduces moisture into a home that must be removed; otherwise the indoor RH may increase beyond acceptable levels during certain hours of the year. The fundamental problem with relying solely on central cooling systems to manage moisture during low sensible load periods is they are oversized for cooler periods of the year despite being “properly sized” for a hot design cooling day. Operation of air conditioning relies on set points that are lower than the room temperature. Lowering the cooling set point during cooler weather increases runtime, but during very low cooling load periods, the space can become overcooled and runtime is not adequate to remove much moisture from the air. This can result in cool, humid (cave-like) uncomfortable conditions.

Withers points out the importance of dehumidistat location: Dehumidifiers can effectively control indoor RH but at lower efficiency than air conditioners. Dehumidifiers that short-cycle or operate with fan run-on at the end of cycles operate very inefficiently (Winkler et al. 2014).

Furthermore, dehumidifier operation may occur more than is necessary if the dehumidistat is located in a confined space where mechanical ventilation air is delivered, such as a closet. A dehumidifier with dehumidistat control contained within an isolated mechanical ventilation closet or other location where untreated outdoor air comes in direct contact with dehumidistat control could use 10 times more energy than necessary to maintain acceptable indoor RH (Withers 2015). This stems from the fact that outside air in places like Florida (climate zones 1a and 2a) have RH greater than 60% RH for about 80%-85% of the hours in a year based on TMY3 data. Allowing mechanical ventilation air to mix with dry indoor air before it comes in contact with dehumidistats will decrease the RH and help optimize good RH control and energy conservation. Therefore locating dehumidistat controls and mechanical ventilation delivery should be carefully considered.

The experimental configuration compared a SEER 13 central ducted single speed unit with a backup dehumidifier, a SEER 22 variable capacity central ducted unit with a dehumidifier, and a ductless mini-split heat pump with a SEER 13 central ducted single speed unit as backup. During summer the mini-split and SEER 22 units averaged 52% relative humidity while the base SEER 13 averaged 50% RH. The dehumidifier did not need to run for the SEER 13 unit and only ran 2% of the time for the SEER 22 test. The mini-split ran 95% of the time only requiring the central unit to run 9% of the time. The RH went slightly above 60% RH in this configuration some of the time, between 3am and 8am when sensible loads were low.

During low cooling load periods (Some fall and winter days) tests were limited to one system. The mini-split system maintained 58% to 64% RH in normal mode. Using the manufacturer’s dry mode improved performance slightly.

Energy savings for the high efficiency central unit were evaluated at 23.5% and the mini-split at 27%. Each system handled summertime conditions with mechanical ventilation without a great need for additional dehumidification.

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Don B. Shirey III, Hugh I Henderson Jr., “Dehumidification at Part Load,” ASHRAE Journal, April 2004.

The paper quantifies the latent removal degradation of vapor compression air conditioning systems under part load. Vapor compression air conditioning systems will re-evaporate moisture on the coil once the system is off as shown in their Figure 2 reproduced here.

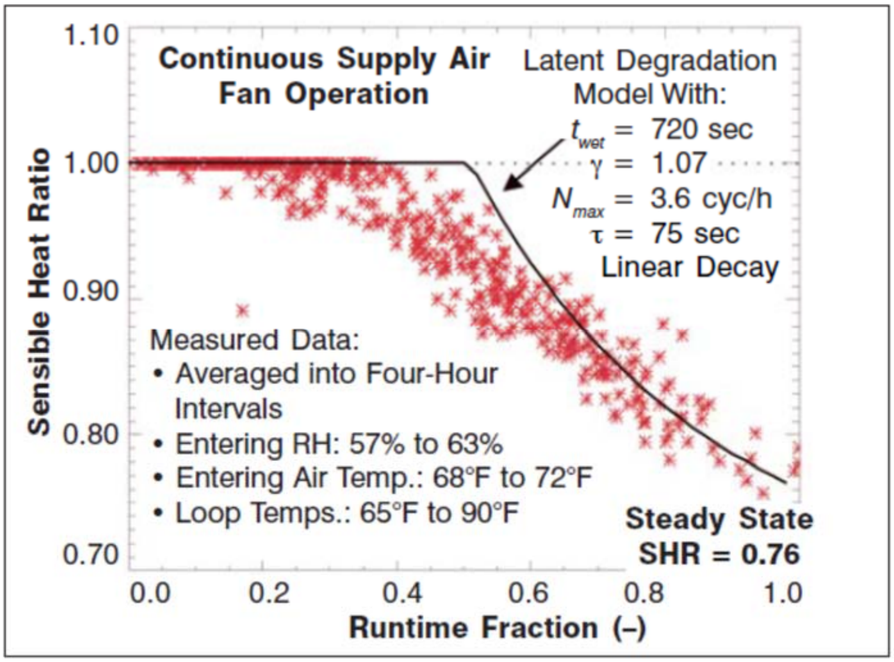

Figure 1. From ASHRAE Journal, 2004, Shirey and Henderson's Figure 2.

Thus the moisture removal capacity is related to the run cycle. Part load latent performance is severely degrade for continuous running fans and still present in auto fan mode. Performance will be closer to steady state if multistage systems are used so at the smaller size the system will have longer runtime fractions.

The amount of time the fan runs after the coil cooling has stopped will only assure that more of the water on the coil will evaporate.

Tested four different coils one of them at two airspeeds determining that the time for condensate to first fall from the coil varied from 12 minutes to 33 minutes for the lab test coils at nominal conditions. The authors provide an equation for.

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Lewis G. Harriman III, Dean Plager, and Douglas Kosar, "Dehumidification and Cooling Loads From Ventilation Air," ASHRAE Journal, November, 1997

The authors introduce a method of characterizing latent and sensible loads from 1 cfm of ventilation air. The proposed "ventilation load index" (VLI) is the total load generated by one cubic foot per minute of fresh air brought from the weather to space-neutral conditions over the course of one year. It consists of two numbers, separating the load into its dehumidification and cooling components: latent ton-hours per cfm per year and sensible ton-hours per cfm per year. For example, a ventilation air load index of 6.7 + 1.1 means that the total annual latent load is 6.7 ton-hours per cfm, and the annual sensible load is 1.1 ton-hours per cfm.

They avoid counting hours where the humidity or sensible loads would be beneficial. They use 75°F and 50% relative humidity for their indoor conditions at which to base the VLI. As can be seen below, Miami has the higher annual loads from 1 cfm of ventilation than those from other states that they analyzed using TMY2 weather data.

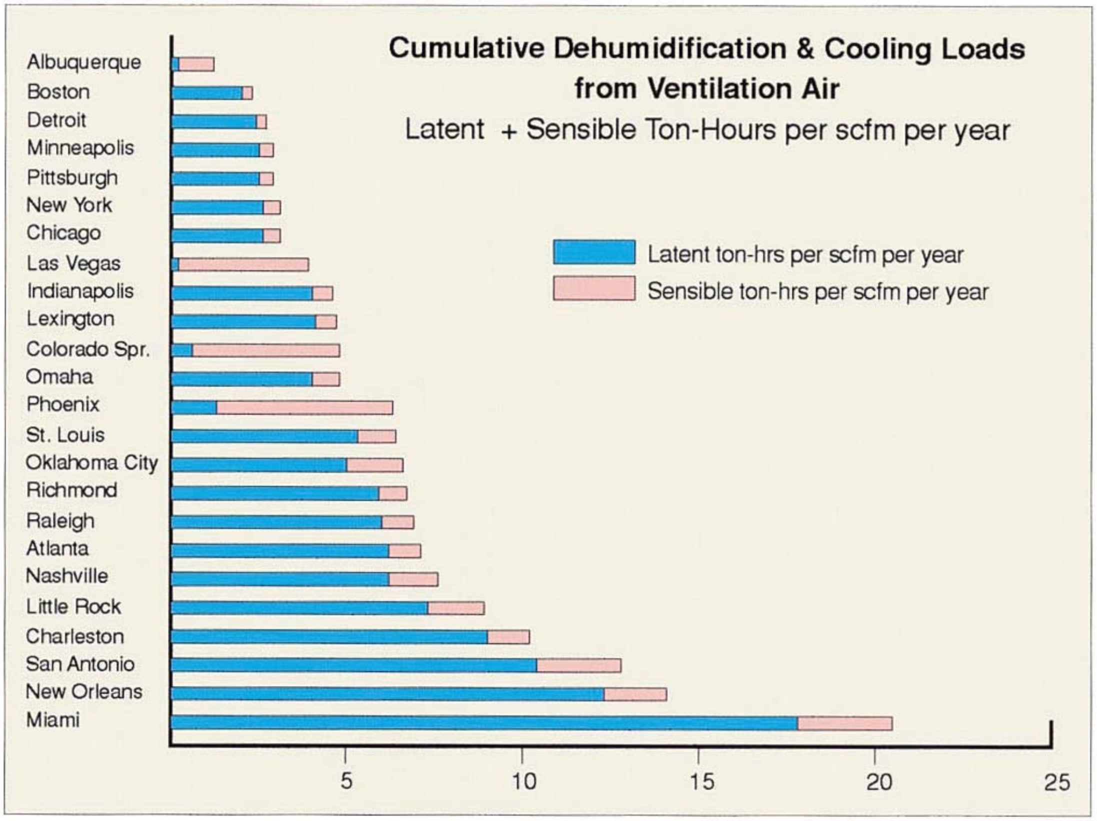

Figure 2 From ASHRAE Journal, November 1997, Harriman, et. al. Figure 2

Other Florida cities (Excepted form their Table 2 showing latent ton-hrs per scfm and sensible ton-hrs per scfm, respectively)

- Daytona Beach 12.3 1.7
- Jacksonville 12.2 1.8
- Key West 21.6 3.5
- Miami 17.8 2.7
- Tallahassee 11.6 1.7
- Tampa 14.2 2.3
- West Palm Beach 17.0 2.3

Their analysis is helpful in viewing the amount of annual latent load due to each cfm of ventilation.

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Environmental Health Committee (EHC) Emerging Issue Report: Note: Emerging Issue Reports are developed and approved by the ASHRAE Environmental Health Committee (EHC). The Energy Efficient Humidity Control in Hot-Humid Climates Emerging Issue Report was approved by EHC in June 2007.

Energy Efficient Humidity Control in Hot-Humid Climates

This committee provides a summary of issues, largely addressing commercial buildings in humid climates, but focusing on research that is needed on the topic of how to keep buildings dry without overcooling them.

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NREL/DOE/BUILDING AMERICA

Arlin Burdick, IBACOS, "Strategy Guideline: Accurate Heating and Cooling Load Calculations," prepared for DOE Building America, 2011. http://www.nrel.gov/docs/fy11osti/51603.pdf

The authors indicate the intent of the guide:

This guide presents the key criteria required to create accurate heating and cooling load calculations and offers examples of the implications when inaccurate adjustments are applied to the HVAC design process.

The guide addresses safety factors that are often applied to sizing residential HVAC equipment. By applying safety factors to a house in Orlando they were able to show an almost 3-ton increase in design load.

Combining several adjustments only compounds the inaccuracy of the calculation results. The results of the combined manipulations to outdoor/indoor design conditions, building components, ductwork conditions, and ventilation/infiltration conditions produce significantly oversized calculated loads. The Orlando House example showed a 33,300 Btu/h (161%) increase in the calculated total cooling load, which may increase the system size by 3 tons (from 2 tons to 5 tons) when the ACCA Manual S procedures are applied. Not only does this oversizing impact the heating and cooling equipment costs, but duct sizes and numbers of runs must also be increased to account for the significantly increased system airflow.

The authors summarize the moisture issues associated with oversizing.

In the cooling season in humid climates, cold clammy conditions can occur due to reduced dehumidification caused by the short cycling of the equipment. The cooling system removes moisture from the air by passing the air across a condensing coil. The system must run long enough for the coil to reach a temperature where condensation will occur and an oversized system that short cycles may not run long enough to sufficiently condense moisture from the air. Excess humidity in the conditioned air delivered to a space may lead to mold growth within the house.

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Jon Winkler and Chuck Booten, "Procedures for Calculating Residential Dehumidification Loads," National Renewable Energy Laboratory (NREL), NREL/TP-5500-66515, June 2016 http://www.nrel.gov/docs/fy16osti/66515.pdf

The authors modeled dehumidification requirements for code level, ENERGY STAR LEVEL and what they indicated as BUILDING AMERICA level characteristics. The level of efficiency for envelope and tightness increased for each of these goals –the researchers selected 7, 4 and 1 ACH50 for climate zones 1 and 2 air infiltration. Each home was modeled with continuous ventilation of 50 cfm (authors do not indicate the method of ventilation) and internal moisture gain of about 11 lbs/day. Although the authors do not indicate the meth of ventilation, based on the following it appears it would be exhaust or supply only.

Infiltration air flow rates were calculated using the Component Leakage Area Method included in Manual J where the assumed ACH50 value was converted into an aggregate 4-Pascal leakage area (ELA4) value using equations in Chapter 16 of ASHRAE 2013a. Stack and wind coefficients were selected from Table 5D of Manual J for a 2-story building and a shielding class of 4 for a typical suburban location. Mechanical ventilation rates, calculated based on ASHREA 62.2 (ASHRAE 2010), were added in quadrature to the calculated infiltration rate to determine the total ventilation rate (ASHRAE 2013a), which was used to calculate the sensible and latent ventilation loads at the given design condition.

The authors concentrated on how best to size the air conditioning systems and the dehumidifiers. They used two different sizing calculations, similar to ACCA Manual J but not exactly. Their Method 1 *uses the cooling load temperature difference (CLTD) calculation method to calculate the opaque panel cooling load which accounts for the panel solar load and thermal mass*. Their second method used a delta T for summer cooling load through opaque surfaces. They also differed in the treatment of adjoining spaces with a summer type (Solar loaded) procedure for method 1 and a non-solar loaded procedure for method 2. These differences led to larger cooling systems for method 1 than method 2.

The unmet latent load was determined from using steady state performance of the cooling system such that the unmet load was the total latent load minus the product of the cooling system run time fraction and the system latent capacity. Next the unmet moisture load was used to estimate the capacity of a whole-house dehumidifier necessary to meet the load. The dehumidification requirements were modeled three different ways for each of the three homes and two cooling system measures.

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Armin Rudd, Joseph Lstiburek, Kohta Ueno, "Residential Dehumidification Systems Research for Hot-Humid Climates," NREL/SR-550-36643, February 2005 http://www.nrel.gov/docs/fy05osti/36643.pdf also same title at https://buildingscience.com/documents/bareports/ba-0219-residential-dehumidifications-systems-research-hot-humid-climates/view as BA-0219

The authors present results of a Houston, Texas monitored study of twenty homes. Three code level homes had neither ventilation nor dehumidification. Three other homes were built to high efficiency level with controlled mechanical ventilation, but no dehumidification separate from cooling. The other fourteen homes were built to the high efficiency level and had both mechanical ventilation and dehumidification. Two houses had standard dehumidifiers placed in a hall closet, two other placed in the attic, three houses had an ultra-air system, three others an

ERV, another three had premixing of outside air with inside air along with a dehumidifier, and one house had a two-stage cooling system with variable fan motor and a "Thermidistat control was both a temperature and humidity controller." The authors indicate the fan cycling control was set to 33% duty cycle (on for 10 min if it had not been on for 20 min) to intermittently average air conditions throughout the house and distribute ventilation air. Running the fan may have helped the uniformity of air, but it also may have evaporated any moisture remaining on the coil.

The authors present analysis of runtime, energy use and relative humidity. Although the stand alone dehumidifier in a hall closet was not the least energy consuming (The two speed compressor with ECM motor and control was), the authors concluded it may be the best value.

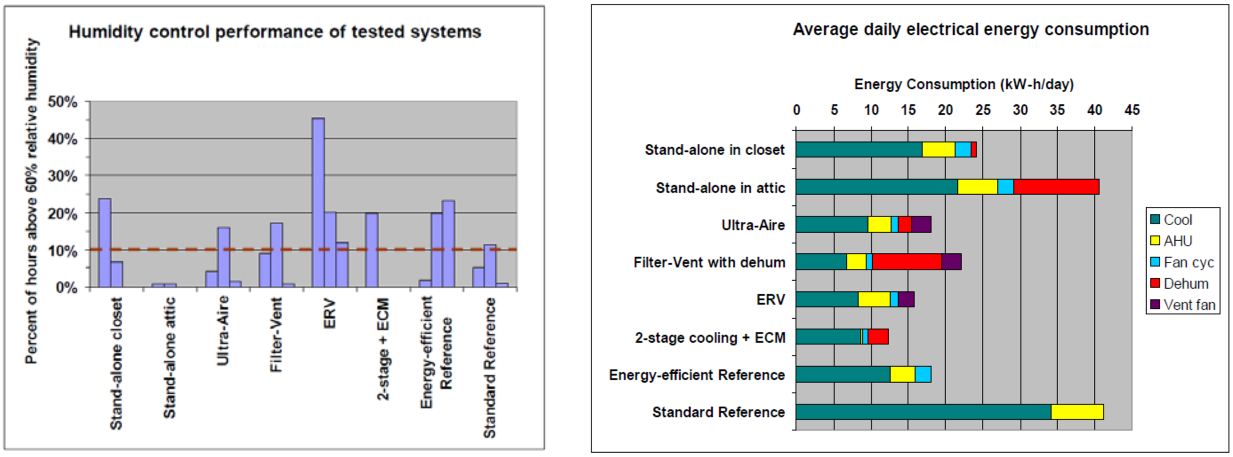

Figure 3. Humidity frequencies and electrical use in homes with six different dehumidification strategies (from Armin Rudd, Joseph Lstiburek, Kohta Ueno, "Residential Dehumidification Systems Research for Hot-Humid Climates," Figures 10 & 14).

The system providing the best overall value, including humidity control, first cost, and operating cost, involved a standard dehumidifier located in a hall closet with a louvered door and central-fan integrated supply ventilation with fan cycling.

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Dave Korn, John Walczyk, Cadmus "Exactly What Is a Full Load Cooling Hour and Does Size Really Matter?," *ACEEE Summer Study, 2016*

The authors showed different sizing factors but the most relevant part of their research of metered homes are repeated here form their paper.

To show the impact that system sizing has on humidity, we analyzed meter data of 60 air conditioners operating for an entire cooling season. This controlled sample includes only central air conditioners with single-speed compressors operating in the Midwest—a region with high temperatures and oftentimes high relative humidity.… Conventional wisdom suggests that oversized air conditioners lead to indoor humidity problems. Using a population of 60 directly metered air conditioners, we compared indoor humidity to the operating coincidence factors, directly testing if we could see a difference in humidity in oversized units that ran at low frequencies (short cycle times) at high temperatures. The authors did not see any clear trend in increasing humidity with decreasing run frequency.

Task 2: Literature review of dehumidification set point recommendations and studies of energy use associated with various set points.

Jeff Ihnen, “Keys to Efficient Dehumidification,” Engineered Systems Magazine, May, 2009, http://www.esmagazine.com/articles/93776-keys-to-efficient-dehumidification?v=preview

This is nicely organized guide to dehumidification, explaining some of the key terms and then listing strategies and systems for controlling moisture. Although it appears the article is geared more at commercial buildings, most of the suggestions apply to both even if all the systems don’t. The four strategies listed are to *only cool to the desired dew point when necessary, control cooling using variable volume as much as possible* [this refers to using low volume flow to remove more moisture], *keep the building positively pressured, shut down outside air when the building is unoccupied.*

The systems suggested by the author are:

- Dedicated outdoor air system (DOAS)
- Precool and reheat outdoor ventilation air with heat recovery.

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Joe Lstiburek, “What relative humidity should I have in my house?” RR-R203, Building Science Corporation, April, 2002

After an introduction to ASHRAE recommendations the author concludes:

Keeping relative humidity in the 25 percent to 60 percent range tends to minimize most health issues – although opinions vary greatly…The range of 40 percent to 60 percent relative humidity is commonly incorrectly recommended for health and comfort reasons. As we will see, there is a big difference between 25 percent as a lower limit rather than 40 percent – particularly in very cold and cold climates.

The author discusses heating climates and then following about mold growth in cooling climates.

In cooling climates, interior mold growth also occurs because interior surfaces are typically cold and then exposed to moisture levels that are too high. The cold surfaces in cooling climates arise from the air conditioning of enclosures. When exterior hot air is cooled, its relative humidity increases. If the exterior hot air is also humid, cooling this air will typically raise its relative humidity above the point at which mold growth can occur (70 percent).

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Philip Fairey, Danny Parker, Robin Vieira and Eric Martin, “Vent Right and Then? Mechanical Ventilation, Dehumidification and Energy Use in Humid Climates,” FSEC-PF-460-14, August, 2014 *http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-505-14.pdf*

This paper points out other Building America simulation work that used 60% relative humidity as a dehumidification set point. It also indicates that home ventilation in the southeast makes humidity control a challenge that otherwise would be minimized: ASHRAE 55-2013 on Thermal Environmental Conditions for Human Occupancy intends that indoor dew point temperatures be maintained below 62°F. The operating characteristic of typical air conditioning equipment is such that indoor dew point temperatures are normally near 55°F during the summer air conditioning season. In hot, humid southeastern and gulf coast climates where summertime outdoor average dew point temperatures reach 75°F, ventilation can introduce significant quantities of excess moisture into homes, presenting indoor comfort and moisture control issues that do not exist in other climates.

The paper reports on side-by-side identical unoccupied labs that have internal heat and moisture generation. One has had an air leakage of 8 ACH50 and the other 2 ACH50. At one point a supply ventilation system was installed in the tight home delivering 63 CFM of air consistent with ASHRAE 62.2-2013 for a 3-bedroom home while the leakier home remained unventilated. The tight home ran in two week cycles of ventilation system on and off in order to examine indoor conditions and energy use under two different circumstances. The research included injecting CO2 into the unoccupied homes at a constant interval to measure the infiltration using the CO2 as a tracer gas.

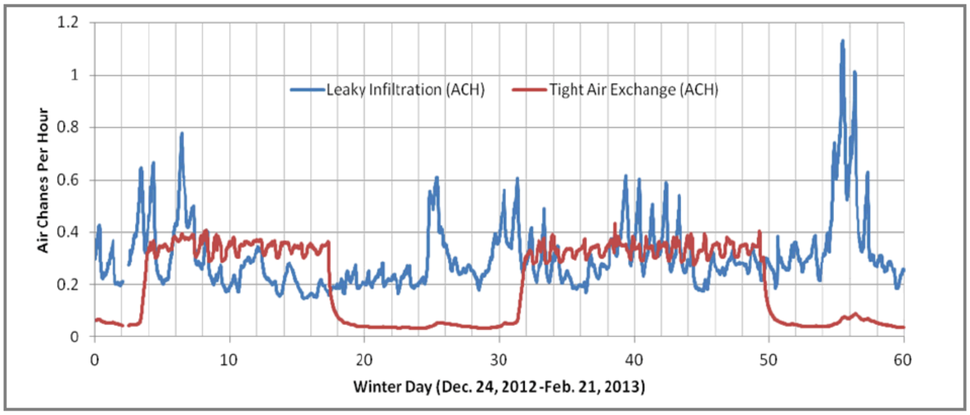

Figure 4. Winter measured air exchange between leaky 8ACH50 home (Blue line) and tight 2ACH50 home (Red line). Tight home ran for two weeks with 63 cfm of supply ventilation air and then was 0 ventilation for two weeks.

In summer there was little to no difference in energy use between the tight home and leakier home during periods where the tight home was not ventilated. However, the authors found that mechanical ventilation of the tight home increased *cooling energy use by 20-38% or about 4 kWh per day compared with the leaky home. Mechanical ventilation of the tight home increased indoor RH modestly by 2-5%. However, mechanical ventilation increased the comparative quantity of air conditioner moisture removal significantly by 27%.* This last result indicates that the air conditioning system was able to remove the majority of the ventilated moisture.

The authors also report on a total of 864 simulations were run for new home configurations using two building archetypes (1 story and 2 story), two building leakage rates (1.5 and 3 ACH50), two building orientations, three ventilation system types, three ventilation rates, and 12 climates. Results of the number of hours above threshold levels are shown below. At 60% relative humidity there are over 1500 hours for an exhaust or fan integrated ventilation system; most of these hours occur during milder weather where neither the heat or cooling systems are working and the number of hours that exceed 65% relative humidity fall to about 500 while only about 100 hours are greater than70% relative humidity.

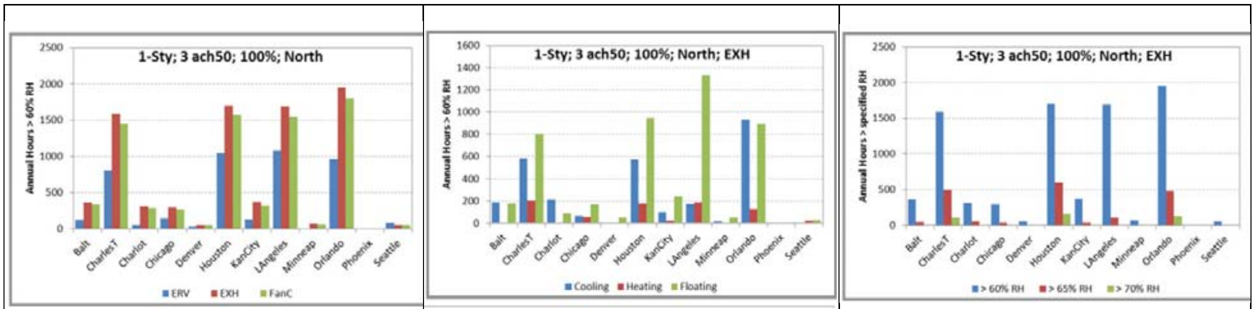

Figure 5. [Left]Simulation results of number of hours above 60% relative humidity in different climates for three types of ventilation systems, energy recovery (ERV), exhaust only (EXH) and fan integrated (FanC).[Center] Those hours occur primarily during floating periods where the sensible load is insufficient for air conditioner to run. [Right] Simulation resultsof hours above 60%, 65% and 70% relative humidity for exhaust only ventilation.

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Mattison, L. and D. Korn (2012). “Dehumidifiers: A Major Consumer of Residential Electricity.” ACEEE Summer Study on Energy Efficiency in Buildings, 2012. The Cadmus Group, Inc. http://www.aceee.org/files/proceedings/2012/data/papers/0193-000291.pdf.

The Cadmus Group metered 21 dehumidifiers operating in 19 homes in Massachusetts, New York, Maryland and Virginia. Metering of each unit began between mid September and early October 2011 and continued for one to 12 weeks. \

The authors found that the dehumidifiers used a considerable amount of energy, did not perform as efficiently as their rating under real time conditions and had difficulty with the accuracy of the humidity control. Here is a list of their conclusions:

- The average metered active power was 459 Watts.
- The average metered runtime was 8.9 hours/day. At 8 months/year, the average unit would operate 2,160 hours annually.
- Eleven of the units drew standby power between 0.4 and 1.9 Watts.
- The average metered electricity consumption was 4.2 kWh/day, or 1,000 kWh/year based on 8 months/year of operation. This is equal to 9% of the electricity consumption in an average home.
- For the 15 manually emptied units, the average water removal was 4.9 pints/day and the average EF was 0.8 L/kWh.
- The humidity controls on some units did not function properly, as some units did not operate when a separate meter showed ambient RH exceeding the setpoint.

- The measured EF was lower than the rated EF for all but two units. This lower operating efficiency is believed to be in part because most units in this study were operating in spaces with lower temperature and RH than the standard test conditions.
- User operation is a key factor in effectiveness and energy consumption of dehumidifiers, including frequency of emptying tubs for units that don't drain directly.

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Lawrence Berkeley National Laboratory (LBNL)

Henry Willem, Camilla Dunham Whitehead, Chun Chun Ni, Venessa Tavares, Thomas Alan Burke, Moya Melody, and Sarah Price, 2013. Field-Monitoring of Whole-Home Dehumidifiers: Initial Results of a Pilot Study; November 2013

LBNL Monitored three Wisconsin homes with whole house dehumidifiers located in the basement. One system dehumidified the basement, another house and the third basement and house. The units used 8 to 9kWh/day on average with set points ranging from 40% RH to 50% RH. RH varied some during standby mode with each system. Two of the systems took air form the basement causing negative pressure which might mean more air was infiltrating to the basement form either the main house or the outside. *A decrease of RH in the range of 18-34% (mean, daily) was recorded among the study sites. However, the effect was associated with elevated air temperature in the range of 11°F to18°F (mean, daily).*

Danny S. Parker, FSEC for LBNL, "Determining Appropriate Heating and Cooling Thermostat Set Points for Building Energy Simulations for Residential Buildings in North America," May, 2013, http://fsec.ucf.edu/en/publications/pdf/fsec-cr-2010-13.pdf

This document relates as it has a good literature review of studies in which residential temperatures were measured. Higher temperatures in houses can handle more absolute moisture before the relative humidity exceeds a certain level. The report showed that in heating climates the measured temperatures during heating periods were often 68°F or less; and for Florida the measured temperature during cooling was 78°F with a nighttime set lower at 77°F.

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Task 3: Literature review of smart ventilation strategies and recent developments at ASHRAE and LBNL regarding allowances.

This will include reviewing papers from the most recent ASHRAE conferences and searches for resources with keywords of smart ventilation, temperature controlled ventilation, and humidity controlled ventilation.

ASHRAE's annual 2016 Conference was held in St. Louis MO from June 25 to June 29. Review of the conference guide revealed no pertinent papers. Searches of LBNL and NREL/FSEC websites found thirteen applicable papers written from 2014 to 2016 summarized in the following annotated bibliography. No references were found that dealt directly with code modifications or allowances.

The following conclusions can be generalized from these papers

- *Smart ventilation controls were effective at reducing indoor humidity levels, and they maintained air quality equivalent to or better than a continuous fan sized to 62.2-2013.*
- The majority of information regarding the energy and moisture impacts of mechanical ventilation is based on simulations using one of two software packages, LBNL's REGCAP or FSEC's EnergyGauge USA.
- Low-load efficient houses in Florida will have significant periods of interior humidity above 60%RH regardless of ventilation systems due to interior generated moisture load at times of minimal or no cooling system operation.
- Health impacts of ventilation are not studied in any significant detail.
- Mechanical ventilation in Florida will increase interior humidity and require more HVAC energy.
- Natural infiltration in a Florida home built to 8 ACH50 will not provide the necessary ventilation rate to comply with 62.2-2013 due to Florida's mild climate and the resulting reduced infiltration drivers.
- *High indoor humidity generally does not occur during cooling system operation and most problems occur during winter and shoulder season transitions or during late evening and early morning hours.*
- *Sensible cooling load drives cooling system moisture removal.*
- *Ventilation has non-negligible but secondary impacts on indoor humidity levels.*
- Very tight construction risks excessive and potentially damaging indoor moisture levels.
- FSEC's simulation work indicates that application of an Enthalpy Recovery Ventilator in lieu of the exhaust ventilation will significantly reduce indoor humidity.
- Simulation results in all California climates using LBNL's RIVAC controller show that smart ventilation control systems can reduce the energy penalty from ventilation by more than 40% without compromising long-term and short-term exposure to indoor pollutants, however this includes the impact of California's time-of-use electrical charges.
- Several studies, including a recent FSEC study, show significant failures of ventilation systems in the field, ranging from dirty, clogged filters to fan failure.

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ASHRAE Standing Standard Project Committee 62.2, ASHRAE Standard 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. American Society of Heating Refrigeration and Air-Conditioning Engineers.

62.2-2010-Among much else this standard defines minimum cubic feet per minute (CFM) requirements for ventilation systems. CFM requirements are based on the number of bedrooms and the area (NOT volume) of the conditioned space. Continuous ventilation rate (CFM) = (conditioned floor area (CFA)*0.01)+(7.5*number of bedrooms (Nbr)+1) A default natural infiltration level of 2 CFM per 100 ft2 of floor space is used. The only implied requirement for Smart Ventilation Control is an effective ventilation rate of intermittent systems that provides a flow equal to the HOURLY requirement of a continuously operating fan

62.2-2013-This standard updates Standard 62.2-2010. A major change is a replacement of the default natural infiltration credit with the actual, measured annual average infiltration rate. The calculation is now Required CFM=(CFA*0.03)+(7.5*Nbr+1), required mechanical ventilation is equal to the Required CFM minus the calculated infiltration CFM. This results in a significant increase in the mechanical ventilation rate for more air tight buildings. The updated standard further defines intermittent mechanical ventilation systems, requiring ventilation operation at a minimum of every 3-hours, or a daily equivalent flow. A further enhancement to the standard is a definition of equivalent ventilation, allowing a smart ventilation controller to provide an ANNUAL exposure rate (level or amount of indoor pollutants) less than or equal to that provided by continuously operated ventilation systems.

62.2-2016-This Standard updates 62.2-2013. This standard makes major changes and clarifies the intent of 62.2-2013's intermittent ventilation requirements. Short-term average ventilation is defined to be a 3-hour based equivalent ventilation rate. The Standard further defines scheduled ventilation systems based on annual relative exposure to indoor pollutants. A new definition, "Real Time Control" calls for active ventilation control that provides equivalent exposure based on a minimum of daily to a maximum of yearly equivalent exposure rates.

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Brennan Less and Iain Walker, Nov. 2016, Smart Ventilation Control of Indoor Humidity in High Perfromance Homes in Humid U.S. Climates, Ernest Orlando Lawrence Berkeley National Laboratory. LBNL-1006980, https://eta.lbl.gov/sites/all/files/publications/1006980.pdf

This paper summarizes recent simulation efforts and field studies and presents the results of simulation work that looks at 13 different smart ventilation control strategies. The objective of the simulations was to reduce the number of hours of high indoor humidity (greater than 60% RH).The simulation evaluated high performance, single-family homes that meet the U.S. DOE Zero Net-Energy Ready home requirements, using three house sizes: 100 m3, 200m3, and 300m3, three internal moisture gains: 3, 6.5 and 11.8 kg/day, and six hot-humid climates-two in Florida, Miami and Orlando.

Key findings of past work summarized in the paper are: *High indoor humidity generally does not occur during cooling system operation and most problems occur during winter and shoulder season transitions or during late evening and early morning hours; Internal moisture generation has a strong impact on indoor humidity; Sensible cooling load drives cooling system moisture removal, in particular duct location (house vs. attic) and thermostat setting; Mechanical ventilation has non-negligible but secondary impacts on indoor humidity levels; Supplemental dehumidification is required in high performance homes in humid climates, irrespective of mechanical ventilation rates; Homes using supplemental dehumidification strategies are able to reduce, but not eliminate hours of indoor relative humidity above60% (on average from around 30% of annual hours to 15% of hours >60%; dehumidifier capacity and set points interact such that all high humidity hours are not eliminated). Supplemental humidity control strategies have mixed effectiveness and first costs from $150 to $2,000 Research estimated that supplemental dehumidification in high performance homes requires approximately 170 kWh per year with a 60% RH set point and estimated that dehumidifiers operate 10% of the year in high performance homes with annual energy use of 976 kWh/year.*

Field research in conventional homes suggests that dehumidifiers use between 300 and 2,000 kWh annually, averaging 1,000 to 1,200 kWh per year.

The simulation compares the results from the smart control algorithms to baseline simulations using a constant fan to provide 62.2-2013 ventilation rates. Control algorithms were of four generic types: scheduled, sensor-based, relative dose target, and cooling system tie-ins, and hybrids of these. Simulations are performed by REGCAP - *LBNL's in-house residential building energy and ventilation simulation tool with mass, heat, and moisture transport models. (extracted from LBNL-5969E, Commissioning Residential Ventilation Systems July 2012, Walker et.al.)*

The paper concluded:

- *High indoor humidity was not an issue in many combinations of location, house size and moisture gains. The most problematic cases were small homes with high moisture gains, where between 5 and 40% of annual hours were >60% RH.*
- *Smart ventilation controls were effective at reducing indoor humidity levels, and they maintained air quality equivalent to or better than a continuous fan sized to 62.2-2013. The best performing strategy used both indoor and outdoor sensors and a cooling system tie-in. It was able to* ***reduce 16% of annual hours <60% RH in a small Miami home using under 300 kWh****.*
- *Estimated energy use for smart controls was in the same range as that used by mechanical supplemental dehumidification strategies.*
- *In the most challenging cases, indoor humidity remained >60% for 20 to 25% of annual hours despite use of smart controls, and use of supplemental dehumidification in humid climates may be necessary to achieve acceptable levels in these high performance homes. Our next steps are to evaluate how smart ventilation controls interact with and compare to a supplemental mechanical dehumidification strategy.*

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W. Turner and I. Walker, Dec. 2012, Advanced Controls and Sustainable Systems for Residential Ventilation. Ernest Orlando Lawrence Berkeley National Laboratory. LBNL-5968E. https://buildings.lbl.gov/sites/all/files/lbnl-5968e.pdf

This paper looks at ventilation energy use in all 16 California climates. It uses a baseline house with no ventilation and compares, using simulations, standard ASHRAE 62.2 ventilation and a controlled ventilation system, "Residential Integrated Ventilation Controller" (RIVEC). RIVEC monitors all of the house's ventilation devices, bath and kitchen fan, dryers, etc. and occupancy. One of the main objectives of RIVEC is to eliminate vent fan operation during peak demand periods. RIVEC control shifts the ventilation load away from peak demand periods.

Simulations used REGCAP - *LBNL's in-house residential building energy and ventilation simulation tool with mass, heat, and moisture transport models. (extracted from LBNL-5969E, Commissioning Residential Ventilation Systems July 2012, Walker et.al.)* Baseline for simulation comparisons is no whole house ventilation. Simulations looked at all 16 California climates. Three different house sizes and constructions were evaluated. Each house was simulated using three different infiltration levels. House shells met CEC Title 24 Package D. Ventilation equipment simulated was taken from the Home Ventilation Institute's 2011 Directory.

The results show that RIVEC systems can reduce the energy penalty from ventilation by more than 40% without compromising long-term and short-term exposure.

- Strategy 1-Whole-house fan. RIVEC control reduced annual vent energy from 38% to 52%, mean of 46% or 592kWh.
- Strategy 2-Heat Recovery Ventilator. RIVEC control savings range from 25% to 38% with means of 31% or 876 kWh (note that HRV operation includes running air handler fan at the same time for distribution of vent air).
- Strategy 3-Central Fan Integrated Supply and whole house exhaust fan. RIVEC control resulted in 34% to 52% savings with a mean of 43% or 573kWh.
- Predictions of the impact ventilation would have on California housing range from 5% to 32% of total building load. REVIC is assumed to reduce this by at least 25%. This exercise is continued to its end; predicting State-wide saving if implementing REVIC of 3010 GWh.

Conclusions regarding use of the RIVEC controller are:

- Reduce whole-house ventilation energy by at least 40% while in compliance with 62.2-2010.
- No acute exposures
- Energy reductions are robust across climate, house size and leakage rates.
- Predicted household savings of 500 to 7500 kwh/year based on climate.
- Reduce peak power by up to 2kW for a typical house.

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P. Fairey et.al., August 2014, Vent Right and Then? Mechanical Ventilation, Dehumidification and Energy Use in Humid Climates. Florida Solar Energy Center, FSEC-PF-460-14. http://fsec.ucf.edu/en/publications/pdf/FSEC-PF-460-14.pdf.

This paper covers the impacts of mechanical ventilation and includes simulation results and preliminary results from two monitored full-scale lab homes with simulated occupancy, designed to be typical existing Florida homes. The monitored homes were configured to compare tight and leaky envelopes with and without mechanical ventilation. The simulations were conducted using EnergyGauge USA, a residential building energy analysis and rating program developed by the Florida Solar Energy Center. The simulations were of new, high-performance homes with mechanical ventilation in 12 American cities, including Orlando FL, as well as older homes in Orlando FL with and without air tightening and mechanical ventilation.

Conclusions reached from the monitored lab homes include:

- Very tight construction (2 ACH50) risk excessive and potentially damaging indoor moisture levels without ventilation
- Summertime indoor humidity levels for a tight home (2 ACH50) employing 62.2-2013 exhaust ventilation will be greater than found in a loose (8 ACH50) unvented home. The

simulation work indicates that application of an ERV in lieu of the exhaust ventilation will significantly reduce indoor humidity.

- The loose (8 ACH50) home may not achieve 62.2-2013 ventilation levels due to small infiltration driving forces.
- Standard air conditioning summertime usage removes significant moisture from the house, reducing summer interior RH concerns

Conclusions from the simulation results are:

- When air-tightening an unvented existing home from 11 ACH50 to 5 ACH50 with dehumidification and 62.2 ventilation the energy use for the ventilation and dehumidification may be larger than the potential heating and cooling energy saved.
- In humid climates tight, high-performance homes with ventilation experience significant periods of interior humidity above 60%. The majority of the high humidity situations occur during floating hours with no space conditioning requirements. High interior humidity is worst when an ERV is employed.
- If the desired maximum interior humidity level is raised from 60% to 65% a large fraction of the hours of concern are eliminated.
- Modeling of both new and existing homes show operating costs are not significantly impacted by choice of ventilation system

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Brennan Less, Walker, I., and Tang, Y. 2014. Development of an Outdoor Temperature-Based Control Algorithm for Residential Mechanical Ventilation Control. Ernest Orlando Lawrence Berkeley National Laboratory.https://publications.lbl.gov/islandora/object/ir%3A1005599

This is a summary of methodology and simulations used to develop a simple, outdoor temperature based control strategy to reduce the energy impact of ASHRAE 62.2-2013 ventilation. One and two story, 2100 ft2 buildings were simulated in fifteen different U.S. DOE climate zones, including Miami and Houston (1A and 2A). The building's insulation varied by climate zone. Six different infiltration levels, from 0.6 ACH50 to 10 ACH50 were modeled. Four different temperature-based ventilation control strategies were modeled, a fixed temperature of 5 C, a fixed percentile or two methods based infiltration using the enhanced ventilation model from ASHRAE Fundamentals. Simulations used REGCAP - *LBNL's in-house residential building energy and ventilation simulation tool with mass, heat, and moisture transport models. (extracted from LBNL-5969E, Commissioning Residential Ventilation Systems July 2012, Walker et.al.)*

The work only looks at controlling ventilation based on a minimum temperature threshold. The recommendations for Miami, in Climate zone 1A, were to do nothing, and the results for Houston showed very small savings (best case 250 kWh to 480 kWh). The paper concluded that in approximately 35% of the test cases they would recommend no temperature-based control. Controlling for maximum temperatures, humidity differences or other strategies appropriate for hot, humid climates was not investigated in this paper.

In 3 to 10 ACH50 test homes, substantial energy savings have been shown to result from the smart control of ventilation systems based on outdoor temperature, while maintaining equivalence with ASHRAE 62.2-2013 through fan oversizing. Limited savings were realized in milder climates for tighter homes. Energy reductions generally increased with climate severity, and in nearly all cases, they were greatest in airtightnesses 3 and 5 ACH50. Simulations demonstrated annual HVAC energy savings ranging from approximately 100 kWh to 4,000 kWh. Using a sequential optimization tool, fans were oversized by an average of 34% (ranging from approximately 5% to 150%), and equivalence with 62.2-2013 was maintained in all of these cases. Temperature controlled ventilation is not recommended in climate zone 1 or in most of the very airtight cases (i.e., 1.5 and 0.6 ACH50).

As a general guiding principle, energy savings increased with reductions in mechanical fan runtime, resulting from higher cut-off temperatures. These reductions in runtime required larger fan sizes in order to maintain equivalence with 62.2. This dynamic was not consistent in more airtight homes, where higher cut-off temperatures often necessitated substantially larger fans to maintain equivalence, which led to increased HVAC energy use. The simplest strategy (a 5°C cut-off) was in fact the most effective across a variety of climate zones, though it was not effective in all cases where savings were identified.

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Eric Martin et.al, August 2014. Measured Cooling Season Results Relating the Impact of Mechanical Ventilation on Energy, Comfort, and Indoor Air Quality in Humid Climates, Florida Solar Energy Center. FSEC-PF-461-14 http://fsec.ucf.edu/en/publications/pdf/FSEC-PF-461-14.pdf

Ten homes in Gainesville FL were studied to evaluate the impact of ASHRAE 62.2-2010 ventilation. The homes were U.S. DOE Builders Challenge complaint (HERS <65). Homes were three to four years old. All homes had an existing central fan integrated supply ventilation system (CFIS) providing approximately 20% of the ASHRAE 62.2 requirements. Larger bath exhaust fans, capable of meeting 62.2 vent rates, were installed. Six houses flip-flopped, or ran alternating ventilation systems for two week periods all summer- two weeks with CFIS, two weeks with continuous exhaust ventilation (CEV) from June 28 till October 15, 2013. As controls two houses each were run continuously with either CFIS or CEV.

The report concluded:

- *The continuous exhaust ventilation systems result in approximately 9% more space conditioning energy use on average to maintain the desired temperature set points in the homes*
- *Resulting RH and dew point are higher in the homes while under continuous exhaust.*
- *Preliminary analyses of the data indicate that concentrations of acetaldehyde and nitrogen dioxide… exhibiting decreased concentrations with increased ventilation rate.*
- *In some cases, concentrations of VOCs and formaldehyde increased significantly from the runtime ventilation condition to the continuous exhaust condition in the flip-flop homes.*

- *It is hypothesized that this may be a result of the exhaust-only ventilation method pulling make-up air through the building envelope and increasing emission rates of any solvents or other volatile chemicals contained in the materials used to construct the envelop…,further data collection and analysis are necessary to…confirm this hypothesis.*

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Lubliner, Michael, Paul Francisco, Eric Martin, Iain Walker, Brennan Less , Robin Vieira, Rick Kunkle, Zachary Merrin, Practical Applications and Case Study of Temperature Smart Ventilation Controls – DRAFT3, ASHRAE Transactions *draft*, May 2016 [likely to be published in Jan. 2017]

Paper presents both simulation and whole-house monitored results studying smart ventilation control. The monitored houses are in cold and marine climates. The marine climate home was a renovated 1640 ft2 two-story building with a 5 ACH50. The cold climate house was a 900 ft2 single-story house on an unfinished basement, 9 ACH50. Simulations were carried out with LBNL's REGCAP and a beta version FSEC's EnergyGauge USA.

Both homes had whole-house exhaust fans installed in the bathrooms. Both homes' ventilation operation alternated weekly between continuous ventilation fan operation and an outdoor temperature controlled smart ventilation controller. The larger, tighter marine climate house's fan operated at 40 CFM when running continuously and when in "smart" operating mode provided 90 CFM when the outdoor temperature was above 57 F. The cold climate house's fan provided 30 CFM when running continuously or 80 CFM above 55 F when using "smart" controls.

The paper estimates the cost of simple outdoor temperature-based ventilation controller to be $80 installed. EnergyGauge simulations project savings of $7 to $23 per year in the monitored houses. The impact of the smart control system on the homes' CO2 level and interior humidity was not as significant as other factors beyond control.

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William J.N. Turner, Jennifer M. Logue, Craig P. Wray, July 2012 Commissioning Residential Ventilation Systems: A Combined Assessment of Energy and Air Quality Potential Values Ernest Orlando Lawrence Berkeley National Laboratory. https://buildings.lbl.gov/sites/all/files/lbnl-5969e.pdf

The paper presents an effort to quantify and monetize the health impacts of poor indoor air quality. The report examines the costs of addressing poor IAQ through insuring that ventilation systems are commissioned to insure they are operating as desired. Costs include Time Dependent Valuation (TDV) of energy costs and Disability Adjusted Life Year (DALY) for health costs.

The paper concludes: *Our results show that health benefits dominate over energy benefits when converted to US dollars using DALY and TDV approaches. This was independent of house size and climate. The potential health impacts were large when ventilation rates were insufficient to dilute the emitted indoor contaminants. Providing minimum airflow rates to comply with*

ASHRAE Standard 62.2 alone is not a sufficient metric for commissioning whole-house ventilation systems and ideally, decisions about tuning should be made with knowledge on indoor pollutant emission rates, ventilation airflow rates, and outdoor air quality. The metric should be NPV of the combined energy and IAQ benefits to the consumer and commissioning cost decisions should be made relative to that value even if that means ventilating to exceed the ASHRAE 62.2 minimum. Identifying that diagnostics are needed to quantify emission rates will hopefully spur industry to develop an appropriate tool for the commissioning community. Identification of low emission products contained within the home via labeling schemes could be part of the commissioning process. As a consequence of combining energy costs with monetized IAQ costs we now have the beginnings of an approach to optimize the ventilation rates of homes.

The paper's applicability to Florida's climate is found in the conclusion that there are substantial health benefits from ventilating a house at a minimum of ASHRAE 62.2-2010 levels. What is not examined is the potential for health impacts from injecting hot, humid air into the house, potentially raising the humidity indoors to a level conducive to fungal, mold and bacteria growth. The authors' method of monetizing life and health are debatable, but the conclusions seem clear, ventilation can produce a healthier indoor environment.

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Martin, Eric. January 2014. Impact of Residential Mechanical Ventilation on Energy Cost and Humidity Control. NREL-60675. Golden, CO: National Renewable Energy Laboratory. http://www.fsec.ucf.edu/en/publications/pdf/NREL-60675.pdf.

Paper is twofold; a multi-point review of codes, modeling work, and Building America Teams' experience combined with new simulation work relating to energy and humidity impacts from ASHRAE 62.2-2013 ventilation.

The code review outlines ventilation requirements in International, state-wide, and Canadian jurisdictions. The BA Team review discusses previous BA Team's ventilation system recommendations, which were 62.2-2010 compliant but, were operated to provide approximately one third to one half 62.2. Discussed modeling results compare a home meeting the required ventilation through infiltration to standard and high-performance houses in multiple climates and ventilation systems. Further work looked at the impact of duct system location, and thermostat set-points.

Simulation work used 12 cities in 5 U.S.DOE climate zones including Houston and Orlando. Two building types were modeled to determine the energy and humidity impacts of the ventilation. They feature U.S. DOE Zero Energy Ready Home program compliant construction, two leakage rates, two orientations, three ventilation systems (exhaust fan (EX), Energy Recovery Ventilator (ERV), and Central Fan Integrated (CFI-uses Air handler fan)), three ventilation rates (100%,75%, and 50% 62.2-2013), and with and without dehumidification to RH <60% . Simulations used EnergyPlus V7.1 (E+) and EnergyGauge USA V3.0.01P (EG)

Total annual operating costs are for the buildings are reported. Results show that the impact of different vent systems are fairly irrelevant in Orlando and Houston, and that ALL simulated results were within $90/ year in operating costs. Supplement dehumidification for the hot, humid climates was projected to be \$10-\$58/year with a dehumidifier EF of 1.47L/kWh (probably unrealistically low).

RH above 60% was reduced by ERVs by one third to one half compared to CFI and EX (EGUSA). Hours above 60% in Orlando occurred mainly during “floating” (no space conditioning) hours. Mechanical ventilation in a tight house is projected to raise the RH by almost 10% compared to a leakier unventilated house in Orlando. Supplemental dehumidification is also needed in the unventilated house to maintain RH below 60% in Orlando.

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Iain Walker, Max Sherman and Brennan Less, May 2014 Houses are Dumb without Smart Ventilation Lawrence Berkeley National Laboratory. LBNL-6747E https://publications.lbl.gov/islandora/object/ir%3A1005394

Paper is based on California Title 24 concerns, and thus looks at California homes and California time-of-use power rates. The paper discusses smart ventilation controller requirements, practicalities of different control strategies, and show examples of actual controllers. They conclude the technology is absent from the residential market place due to: mechanical ventilation being a fairly new idea, controls add first cost, homeowner unwilling, and existing equipment is not always appropriate. They posit the impact of 62.2-2010 ventilation adds around 10% to HVAC energy use versus a similar house with no ventilation. Paper proposes smart ventilation control based on one or several of: outdoor air quality, outdoor thermal conditions, utility rates, occupancy, exogenous (other) ventilation fans, key contaminates, and infiltration. Sensors available could measure: occupancy, humidity, temperature, or third party signals. Currently indoor pollutant sensors are not appropriate for control of smart ventilation due to high cost in confusion as to the best pollutant to sample.

Paper concludes smart ventilation control can reduce the ventilation related energy use by 40% while maintaining or improving indoor air quality, however this includes time-of-use factors. The existing systems to control ventilation are rudimentary or overly complex, and not really applicable to residential ventilation control. Viability of the technology would be advanced by adjustments to codes and standards crediting smart controllers, better/cheaper sensors, and more software and communications hardware to improve cloud and network communications of smart controllers.

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J. Sonne, Withers, C., Vieira, R. June 2015. Investigation of the Effectiveness and Failure Rates of Whole-House Mechanical Ventilation Systems in Florida. Florida Solar Energy Center FSEC-CR-2002-15 http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-2002-15.pdf

Paper reports on a 21 home field study investigating the failure rate and effectiveness of whole-house ventilation systems. Study encompassed a home-owner survey and testing of the ventilation system.

Key testing results:

- Of the 21 houses tested only three were found to have ventilation systems with performance approaching the designed amount of airflow. Of these three two were turned off, meaning only one of the houses of the 21 was delivering the required ventilation rate.
- Of the 21 houses nine had inoperable ventilation systems
- Of the 12 operable systems five were deemed to have significant performance issues.
- *Performance issues were identified including failed controllers and dampers, partially disconnected or crushed ducts, dirty filters, and outdoor air intakes installed directly over the air conditioning condenser unit hot air discharge.*

Key survey results: *When asked if they are satisfied with the overall performance of the ventilation system, 10 of the 21 homeowners answered "yes," two answered "I guess," eight answered "I don't know" or similar and one answered "no".*

Specific code-related recommendations include:

- General labeling of components
- Written summary documents for homeowner
- Some kind of failure alarm
- No filter access that requires ladders to access.
- Reduce code specified house tightness to 7 ACH50 for all of Florida.
- Builder test report for ventilation system.

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Danny Parker et al., September 2016. Flexible Residential Test Facility: Impact of Infiltration and Ventilation on Measured Cooling Season Energy and Moisture Levels FSEC-CR-2038-16 http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-2038-16.pdf

The report summarizes the summer of 2012's experimental work in two identical, side-by-side residential buildings on FSEC's Cocoa FL facility. One building was configured as a "leaky" building, with an ACH50 of 8, the other building was "tight" with an ACH50 of 2.2. The tight building had mechanical ventilation which was switched on and off for approximately 2-week periods.

When not ventilating the tight building there was virtually no difference in A/C energy use, and minimal differences in interior RH compared to the leaky building. When the tight building was mechanically ventilated at ASHRAE 62.2-2013 rates there was a significant increase in cooling energy (20-38%) combined with modest increases in interior RH (2%-5%) and dewpoint.

We found that building tightness, mechanical ventilation, and infiltration all operate in concert with the outdoor conditions and indoor moisture generation rates to produce indoor moisture conditions. Sometimes low infiltration lowered indoor moisture levels (during moist/rainy periods) and sometimes high infiltration, whether from a leaky envelope or mechanical venting, was beneficial (such as during periods with "free" cooling or dehumidification due to diurnal weather patterns). The issue then becomes, on balance, which conditions predominate in a given *climate and during which seasons. Also critical is how this interacts with AC operation, which can counteract most moisture variation, even doubling indoor moisture generation rates.*

We saw that mechanical venting operates similarly to natural venting, in that under moist outdoor conditions it leads to higher indoor humidity, but this same effect in Florida's winter would operate in reverse with drier outdoor air. We also saw indication that mechanical venting seems to have a slightly different effect than natural ventilation to a similar rate, although such a hypothesis would need more rigorous experimentation.

Consistent with past findings and simulation estimates, the introduction of mechanical ventilation will generally increase the energy usage of an airtight home and may affect indoor humidity, but this is necessary because of the highly variable and often insufficient air ventilation rate provided by even a fairly leaky home in a hot-humid climate, which can have limited natural driving forces during the cooling season.

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Sonne, J.; Vieira, R. June 2014. A Review of Home Airtightness and Ventilation Approaches for Florida Building Commission Research. FSEC-CR-1977-14. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1977-14.pdf

This report, written for the Florida Building Commission, *presents a* Florida specific *literature review, examination of experimental data, and calculations of energy impacts of using or not using various types of ventilation systems and presents alternative approaches to achieving acceptable levels of ventilation while avoiding the risks associated with tight home enclosures and potential mechanical system failures.*

The first task comprised a literature review consisting of over 40 sources. The review reports on:

- Measured airtightness data
- Airtightness and whole house ventilation requirement trends
  - Energy use considerations.
  - Moisture considerations
- Ventilation options
- Industry ventilation recommendations
- Ventilation system failure concerns
- Health-based ventilation considerations

The second task presented alternative approaches to providing acceptable levels of ventilation. Specific conclusions are:

- No code requirements for further tightening of buildings beyond the 2012 IECC mandate of 5 ACH50 in Florida.
- There is limited information regarding the health impacts of whole house ventilation.
- System design for Florida should include:
  - Flexible flow rate
  - Efficient fans
  - Positive pressure

    - Air intake properly located
    - Provide dehumidifaction.
- Promote balanced systems.
- Limited field studies have shown significant failure rates of installed ventilation systems.

FSEC unpublished work

FSEC is investigating smart ventilation algorithms designed for humid climates that rely on combination of temperature and dew point. Spreadsheet analysis showed some promise. Testing to date has yielded 2 – 3 % savings of cooling energy use by altering the time of venting during the day while still delivering the same amount of required 62-2 ventilation to a lab home. Unlike some climates with more diurnal swings in temperature or humidity, it is difficult to save a good deal in coastal Florida while trying to meet a daily goal. The algorithm is flexible and greater savings appear likely if the time frame for meeting ventilation requirement was extended. Allowing more flexibility in the ASHRAE standard is a topic that builders, DOE and the committee continue to discuss.

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Task 4: Based on the literature search, develop draft rules.

Draft rules will be of a form that can fit into the code document. The rules will describe how to treat the proposed home as well as establishing parameters for the standard reference home.

Dehumidifier Draft Rules

The most important criteria for modeling the performance of humidity control devices is determining the dehumidification setpoint. Based on the research, it appears that a majority of studies focus on maintaining indoor relative humidity to 60% or less. For energy-efficient homes this level will tend to be exceeded during mild weather if there is no dehumidification, and will be exacerbated by mechanical ventilation. The literature provides some insight into the working of common dehumidifiers even though that tended not to be the purpose of the studies. The control and sensors used for many low cost dehumidifiers did not function accurately. Because of this, some would argue for lower setpoints however that would come with a large energy penalty particularly if implemented in homes. A unit that incorrectly measures the humidity such that a 55% RH setpoint turns into a unit that tries to dehumidify to a true dehumidification level of 50% or 45% relative humidity will use excessive energy as that level will be difficult to achieve.

It is the recommendation that the proposed design and the standard reference design have the dehumidification setpoint at 60% relative humidity if a dehumidifier is installed in the proposed home. An alternative is to recommend 65% relative humidity which is still below the threshold of 70% where most materials may start to from mold. Studies show far fewer hours requiring humidity control at 65%. As such, it is unlikely any advanced humidity control strategy would be found cost effective at 65% relative humidity. Similar to the argument described above, a humidistat that is off by 5% or more may not maintain the humidity below 70%. Thus the argument, consistent with the level used in many studies, is to select 60% relative humidity as the level to use for code comparisons. Similar to residential thermostats, the code will have no way of mandating the actual dehumidistat used by occupants.

The second key criteria are what to use for the reference house dehumidification efficiency. The Cadmus group showed that often rated efficiencies are not achieved. Furthermore, standby power of stand-alone dehumidifiers is of concern, with 11 of 21 units they measured drawing standby power of 0.4W to 1.9W. Energy factors are determined under test conditions. EnergyStar[1] has a required level of efficiency of >2 L/kWh for units less than 75 pints/day and > 2.8 L/kWh for units with capacity between 75 and 185 pints/day. EnergyStar indicates the labeled dehumidifiers should save 15% minimum energy savings compared to “typical” dehumidifiers. At this time there are 165 products available on the EnergyStar list, with 150 of the products falling under 75 pints/day. EnergyStar indicates even very damp conditions can be met with dehumidifiers of under 50 pints/day for homes up to 2500 square feet.[2] However, some very large homes are built in Florida so both capacity levels will need to be accounted for. For homes using the larger capacity equipment, the standard reference design level should be equal to 2.43 L/kWh, calculated as 2.8/1.15 which is 15% less efficient than the EnergyStar required value. Similarly for equipment less than 75 pints/day, the standard reference should be modeled with 1.74 L/kWh which equals 2/1.15.

The third criteria are how the heat from the dehumidifier should be handled in the performance simulation program. For the standard reference design where a portable dehumidifier efficiency is being used, the recommendation is that the heat from running the dehumidifier be released into the conditioned space. For the proposed design the heat should be modeled released to wherever the systems’ heat will reject it.

The fourth criteria are when that equipment runs and the capacity of the equipment. Most software is designed to apply the limit to all hours and because the high humidity can occur at various times of year, it is recommended that the criteria simply state the capacity shall meet the load during all hours.

Some HVAC equipment is designed to reduce humidity load when the system runs through modification of the fan speed or other mechanism. However, often the system is not running during hours of high humidity. Those systems will need to be supplemented by a device that runs on a humidistat in order to invoke the standard reference design to employ a dehumidifier.[3] The point is that to obtain credit for a system that may perform better for humidity control, that humidity control needs to be guaranteed through a device designed to maintain the control at all times throughout the year: hours where no heating or cooling are being done and during hours of heating or cooling.

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[1] https://www.energystar.gov/products/appliances/dehumidifiers/key_efficiency_criteria

[2] https://www.energystar.gov/products/appliances/dehumidifiers/dehumidifier_basics

[3] This is not to imply that all systems should have a dehumidistat. Installing control systems that turn on the sensible cooling system whenever an RH setpoint is exceeded can induce problems during times of very low sensible loads. Take a case where a house relative humidity exceeds the setpoint in a mild time of year where perhaps the outside weather is rainy and 65°F. The system may cool continuously. Even though it will remove moisture, it will quickly bring the temperature lower and the relative humidity will remain high. This event actually happened at a Florida house that was unoccupied for a period of time and mold resulted.

It is recommended that these criteria be included in Table R405.5.2 (see below with additions underlined) that performance code compliance software vendors will then have to implement for homes that have a dehumidifying device.

[partial] Table R405.5.2(1)
Specifications for the Standard Reference and Proposed Designs

Building Component	Standard Reference Design	Proposed Design
Heating systems	Efficiency: in accordance with prevailing Federal minimum standards. Capacity: sized in accordance with Section R403.6. Fuel type: same as proposed.	As proposed As proposed As proposed
Cooling systems	Fuel type: Electric Capacity: sized in accordance with Section R403.6. Efficiency: in accordance with prevailing Federal minimum standards.	As proposed As Proposed As Proposed
Dehumidification Systems	None, except where dehumidification equipment is specified by the proposed design Fuel Type: Electric Capacity: Sufficient to maintain humidity at setpoint all hours Efficiency: 1.74 Liters/ kWh if proposed systems are less than 75 pints/day. 2.43 Liters/kWh if proposed systems are greater than 75 pints per day. Location: In conditioned space[4]	As proposed As proposed Sufficient to maintain humidity at setpoint all hours As proposed As proposed[4]
Service water Heating	Fuel type: Use: same as proposed design. Efficiency: in accordance with prevailing Federal minimum standards.	As proposed gal/day = 30 + (10 x N_{br}) As proposed
Thermal distribution systems	Distribution System Efficiency: 0.88 Duct location: entirely within the building thermal envelope. Air Handler location: entirely within the building thermal envelope. Duct insulation: R6	Thermal distribution system efficiency shall be as tested in accordance with Section 803 of RESNET Standards or as specified in Table R405.5.2(2) if not tested. As proposed As proposed As proposed
Thermostat	Type: Manual, cooling temperature setpoint = 75ºF; Heating temperature setpoint = 72ºF	Same as standard reference
Dehumidistat	None, except where dehumidification equipment is specified by the proposed design Setpoint = 60% relative humidity	Same as standard reference

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[4] The performance modeling software should apply heat gain from the dehumidifier to the space specified.

In addition to Table R405.5.2, a change to the Energy Conservation code should be made to indicate the minimum rated energy requirement level of any dehumidifier installed regardless of method of compliance. It is also recommended that the dehumidifier be required to drain to the outside.

New section in energy conservation code:

Dehumidifier (mandatory): If installed, a dehumidifier shall have a minimum rated efficiency of > 1.74 Liters/ kWh if capacity is less than 75 pints/day and > 2.43 Liters/kWh if proposed systems are greater than 75 pints per day.

It is also recommended that the mechanical or residential codes include a section as follows to avoid water damage from the dehumidifier:

Dehumidifier: a. If installed, a dehumidifier shall automatically drain condensate to the outside. b. A dehumidifier shall have a flow switch that shuts off operation when the retaining capacity of the dehumidifier is full in the event of a clogged drain.

Ventilation Control Rules

The goal of any change is to create appropriate credit for measures that will reduce moisture issues and/or save energy. The current code provides a standard reference design energy use of the fan but does not actually require outside air to be modeled. In the event a builder installs a whole house mechanical ventilation system there should be outside air brought into both the proposed and standard reference design home to avoid the proposed home being penalized for something done for the mechanical code or for perceived health benefits. This is also important for when dehumidifiers are used in conjunction with mechanical ventilation systems so that the humidity removal from ventilation is accounted for in the reference design. It is recommended that the quantity of air brought into the standard referenced design be the same as the average amount brought into the proposed home. This “average” allows the proposed home to provide smart ventilation control.

There are two more criteria required and determining a rule set for these is not straight forward. When modeling a ventilation system the type of system matters. If an exhaust fan is providing the ventilation then the heat from the fan is exhausted and does not heat up the conditioned space. A supply fan system will heat up the space slightly, increasing the cooling sensible load and slightly reducing the relative humidity. A balanced system uses two fans which can double fan energy use and one of the fans provides internal gains to the conditioned space. There are ERV systems that recover the heat and moisture at some rated effectiveness level, but due to increased pressure drop use more energy than the balanced system. Further complicating the matter is the tendency recently to have hybrid systems that use the mechanical system when the unit calls for heating or cooling but augments with an exhaust or supply fan at other times. Placing the same type of system in the standard reference home as the proposed home might negate the extra effort or expense a builder puts into the proposed home.

The only document that tries addressing fan power relative to the system used in the proposed home is the ANSI/RESNET ICC 301-2014 standard. Their method of addressing energy use in the standard home is recommended so as to not penalize a house with an ERV. It is recommended that the air brought in be modeled as a balanced system regardless of what type of system is installed in the proposed home. Proposed changes are given in the changes to Table R405.5.2(1) below with new language underlined and removed language crossed out.

Mechanical Ventilation portion of Table R405.5.2(1)
Specifications for the Standard Reference and Proposed Designs

Building Component	**Standard Reference Design**	**Proposed Design**
Mechanical ventilation	None, except where mechanical ventilation is specified by the proposed design, in which case:	As proposed
	Type of system modeled: Balanced	As proposed
	Annual vent fan energy use: Where proposed home has predominantly a supply or exhaust only system: kWh/yr=0.35*fanCFM*8.76 kWh/y Where proposed home has predominantly a balanced system: kWh/yr=0.70 *fanCFM*8.76 kWh/y Where proposed home has predominantly a balanced system with energy recovery: kWh/yr=01.0 *fanCFM*8.76 kWh/y ~~kWh/yr =0.03942xCFA+29.565x(Nbr+1)~~ ~~where:~~ ~~CFA = conditioned floor area~~ ~~Nbr = number of bedrooms~~	As proposed
	Airflow rate: Same as proposed average airflow rate but not to exceed requirement of ASHRAE 62-2 2016.	As proposed
	Airflow Frequency: Continuous	As proposed

Task 5: Test draft rules in a simulation program.

EnergyGauge USA will be used for this as it already has the ability to add smart ventilation and dehumidification but lacks any rule set for allowing use in codes. The test will allow Florida energy code comparisons to results without smart venting or dehumidification.

This task has not commenced yet.

Expected Outcome and Impact on the Code

Energy code performance modeling rules for dehumidifiers and smart ventilation will be developed, and residential humidity levels controlled in ways that are energy-efficient will be able to be credited if the FBC adopts the changes developed.

Deliverables Update

Deliverable #1 Interim Report

Completed with submission of this February 15, 2017 interim report.

Deliverable #2 Draft of Calculation Procedures (Task 4)

Completed with submission of this February 15, 2017 interim report.

Deliverable #3 Report providing for summary of the literature review, technical information on the problem background, results, final recommendations for code changes, and expected impact for example homes.

Due June 1, 2017.

Provide an update on the estimated time for completion of the project and an explanation for any anticipated delays.

No delays in meeting deliverable due dates are anticipated at this time.

Provide any additional pertinent information including, when appropriate, analysis and explanation of cost overruns or high unit cost

No cost overruns are anticipated.

Identify below, and attach copies of, any relevant work products being submitted for the project for this reporting period (e.g. report data sets, links to on-line photographs, etc.)

Work products are contained in this report.

Hours and budget update

Not available at this time.

This report is submitted in accordance with the reporting requirements of Work Authorization

Rob Vieira

February 15, 2017

Signature of the Grantee's Grant Manager

Date

Robin K. Vieira