Handling Humidity

Part 4 – Putting It Altogether; House Moisture Modeling

A Report on Moisture Control in Homes

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FOREWORD

At Build Equinox, we have always included moisture management as a primary aspect of CERV2 smart ventilation design. Our free-to-use ZEROs (Zero Energy Residential Optimization software) model is one of the few residential programs that can predict dehumidification and humidification in residences. Health, comfort and energy impacts of humidity are important!

Moisture is complex and has many facets, however it is an old, old problem that experienced HVACR engineers know how to address. This report discusses sources of moisture in homes, and how to manage moisture. We look around North America to learn how climate zones impact moisture management in homes. More and more regions around the world are experiencing increased temperature and humidity and the need for active comfort conditioning is expanding.

Build Equinox conducts residential research encompassing health, well-being, comfort, sustainable living, and energy efficiency topics. We hope sharing our knowledge will be a benefit to our growing CERV community. It is time to move beyond energy, designing homes with exceptional indoor environments that improve our health, comfort and well-being!

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Part 4 – Putting It Altogether; House Moisture Modeling

Our Handling Humidity – Part 4 report examines whole house energy performance by following our three contractors from the previous Handling Humidity reports: Contractor Loose, Contractor Tight and Contractor Smart. A home in Miami requires substantially more dehumidification than similar homes in Phoenix, Urbana or almost anywhere else in North America. How does energy usage compare among our contractors' homes in these locations? As we will find out, Contractor Smart offers the best of all worlds in every location. Contractor Smart's homes are healthy and comfortable, and the most energy efficient.

We've investigated residential moisture generation and transport mechanisms (Part 1), discussed characteristics of North American climates on moisture transport (Part 2), and examined machines that allow us to alter moisture conditions inside a home (Part 3). Part 4 puts everything together in a home, coupling the impacts of moisture with a home's energy usage and air quality. A 2000sqft example house is used for our study. The house is a ranch home with physical parameters and operation characteristics defined in the next section.

ZEROs (Zero Energy Residential Optimization software), our free-to-use online simulation software, is used to model example homes. To learn how to use ZEROs, read our "7 Steps to an Optimal House" for a logical, step-by-step procedure to design a net zero, economically optimized house like our Equinox House. And, read our 12 month ASHRAE Journal article series that covers important aspects of economically optimized, net zero house design.

Field data from 3 years of moisture measurements are compared to ZEROs simulation results to validate ZEROs moisture modeling capability. Monthly house moisture and energy characteristics for Miami, Phoenix and Urbana are then discussed. Miami is a climate requiring year-around dehumidification. Phoenix is an arid climate with a brief dehumidification season and mild winter climate that requires no indoor moisture management. Urbana, as a northern climate, has a need for summer dehumidification and, depending on construction, ventilation, occupant behavior, and occupant preference may require winter humidification.

Our Example Home – Equinox House

Our example home is similar to Equinox House. Table1 is a list of primary features of Contractor Loose, Contractor Tight and Contractor Smart constructed homes. The example home is not economically optimized for each location. For example, economically optimized insulation for Urbana should be 10-12inches thick (assuming R3 to R4 per inch insulation resistance) while economically optimized homes in Miami and Phoenix have thinner insulation. The performance differences between the example home and a locally optimized home are not significantly different because the example home is an excellent home (if sealed to 0.6ACH and smart ventilated) is an excellent home anywhere, but one could save some money by optimizing. Learn how to use ZEROs, and find optimal home characteristics for your location!

Figure 1 is a photograph of Equinox House taken in the spring of 2011, 6 months after completion. Figures 2, 3, and 4 are views of a 3D Sketchup model of Equinox House (the model can be downloaded from Google's 3D Warehouse). Our example house is a simple ranch floor plan similar to Equinox House. Contractor Loose's home is 6ACH50 while Contractor Tight and Contractor Smart both build 0.6ACH50 homes. Contractor Loose and Contractor Tight ventilate their homes with 80% HRVs using 90cfm ventilation air flow as specified by ASHRAE 62.2-2016. Contractor Smart uses a CERV with air quality control setting of 1000ppm of carbon dioxide. All three homes include a heat pump water heater (HPWH), and a comfort conditioning heat pump. Occupant energy usage and hot water usage listed in Table 1 are typical of North American homes.

ZEROs assumes a dehumidification Energy Factor (EF) of 1.5 liters per kWh. Moisture is removed by a combination of air conditioning, CERV (smart) ventilation, and HPWH operation. For humid climates, such as Miami, a dehumidifier may be included for additional moisture removal capacity. Our Handling Humidity – Part 3 report discusses dehumidification performance and showed an EF of 1.5 to be typical of today's air conditioners and dehumidifiers. ZEROs predicts the combined contribution of all systems that reduce moisture.

A CERV smart ventilator and a HPWH contribute to dehumidification, however, their contributions are not the primary purpose of their operation. That is, the CERV is responsive to air quality needs of the home, and its contribution to dehumidification is dependent on fresh air and recirculated air operation modes. Similarly, a HPWH operates based on a home's hot water needs, which are independent of a home's moisture management needs. As presented in our Part 3 report, CERV and HPWH dehumidification contributions are significant and beneficial, however, their contributions are dependent on occupant behavior and activities.

Table 1 Example House parameters

Parameter	Value
Occupancy	2
Floor Area (sqft)	2000
Window Area (sqft)	200 (south facing)
Wall Insulation (“)	12
Roof Insulation (“)	12
Loose/Tight/Smart ACH50	6/0.6/0.6
ASHRAE 62.2 Ventilation	90cfm (80% HRV)
Smart IAQ Ventilation	1000ppm (CERV control)
Base Elec (W)	200
Elec/Occupant (W/person)	50
Hot Water (gal/person-day)	18
HPWH COP	2
Dehum EF (kg/kWh)	1.5
Heat Pump HSPF	10
AC SEER	14
Indoor Temp Range (F)	68 – 72 (winter-summer)
Humidity Range (%RH)	30 – 60 (winter-summer)

Figure 1 Photograph of Equinox House in 2011 near the spring Equinox. Note the clerestory shading of the upper “Equinox overhang”. During winter, the white, uplifted overhang and the 2/12 pitch, white roof below concentrate solar radiation on the clerestory. The overhang excludes direct solar radiation (85% of clear sky solar energy) from spring equinox to fall equinox.

Figure 2 3D Sketchup view of Equinox House floor with corridor attic space shown. The CERV smart ventilator and HPWH are located in the corridor attic space.

Figure 3 Roofless view of Equinox House showing additional detail of CERV ventilation ductwork. Fresh air is supplied to living room and bedrooms, and exhaust air is removed from kitchen, bathrooms (2 ½ baths) and laundry room.

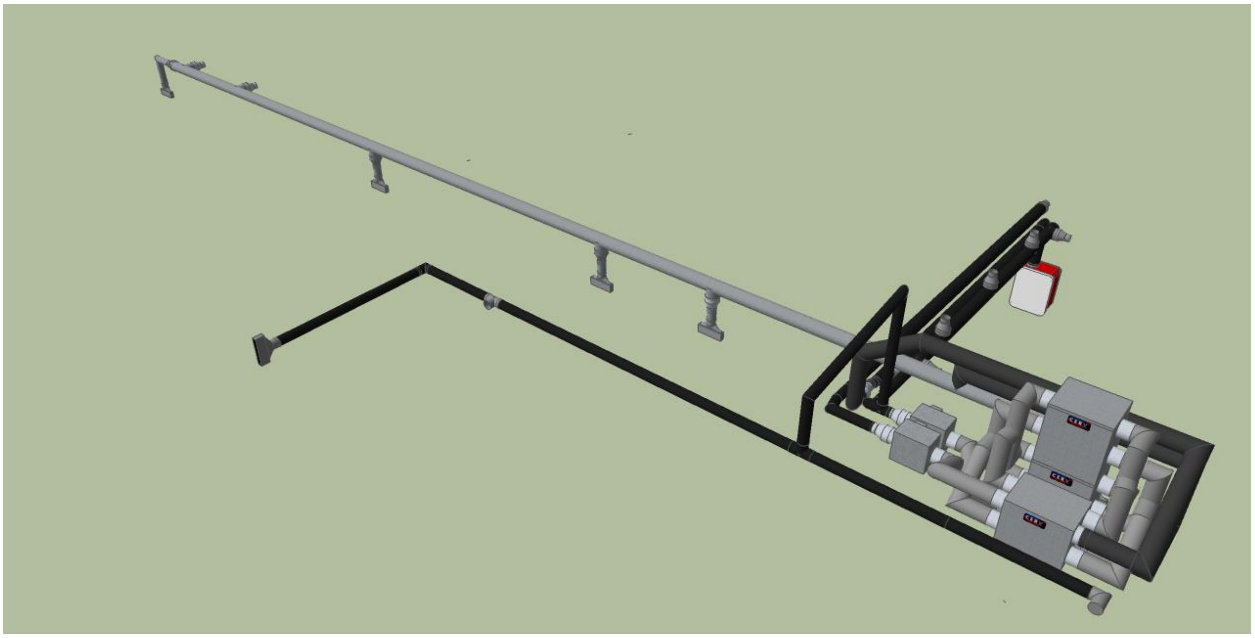

Figure 4 3D Sketchup model showing CERV (gen 1) ventilation system. Black ducts are insulated supply ducts and gray ducts are uninsulated return ducts. Note that gen 1 CERV units are modules (separate air handler, heat pump and fan modules) in contrast to the current, self-contained, CERV2 unit.

Validation of ZEROs Energy and Moisture Predictions

ZEROs is a true design model that simulates comfort, energy, indoor air quality, solar PV production, heating capacity, cooling capacity, dehumidification, humidification, economics, and finance. Unlike certification models that continuously harangue designers that this feature is out of compliance, or that specification is not sufficient, ZEROs allows the user to design the house they want.

ZEROs includes "sensitivity" parameters that guide designers toward economically optimized designs. Financial modeling incorporated into ZEROs allows one to determine how a homeowner's monthly bills vary as house mortgage, home insurance, monthly utility bills and real estate taxes vary with design selections. And, ZEROs is free to use! Try it out and give us feedback.

ZEROs energy performance prediction capability has been investigated by comparing prediction results to "benchmark" building simulation models and to field data. The "computational engine" of ZEROs has been validated using DOE's "BESTEST" procedure (L. Martinez, Simplified Floor-Area-Based Energy-Moisture-Economic Model For Residential Buildings, PhD dissertation, Mech Science & Engr Dept, University of Illinois, 2009). Our Vermod report compares ZEROs predictions to an extensive set of field data collected from 13 identical homes over a two year period.

Figure 5 compares ZEROs dehumidification predictions for Equinox House with 3 summers (2011, 2012, 2013) of field data. The summer of 2013 started wet, but turned very dry during July and August, leading to 35% less dehumidification than average years. 2011 and 2012 were more typical years, and compare favorably with ZEROs predictions that are based on long term, monthly averaged weather data.

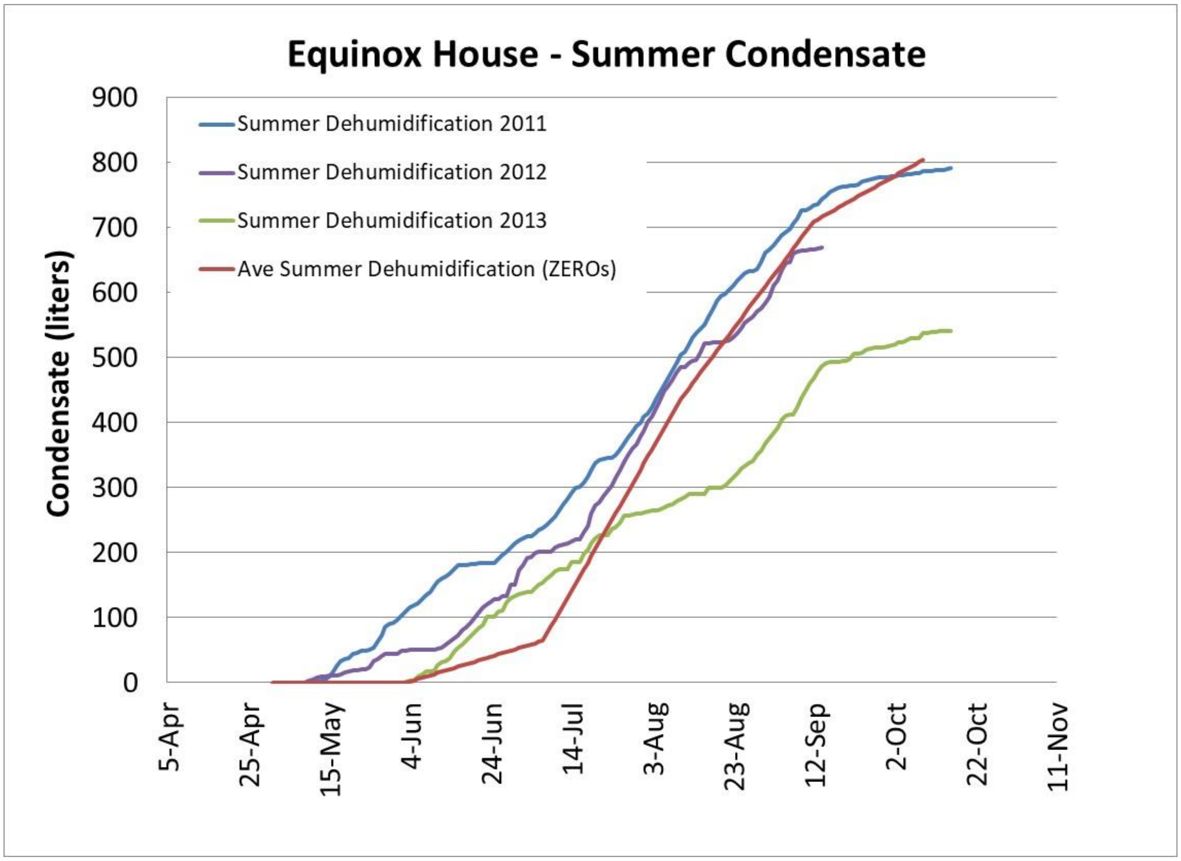

Figure 5 Comparison of ZEROs dehumidification predictions for Equinox House (condensate) with 3 summer seasons of condensate collection data. 2013 was a year with severe drought during July and August.

Monthly Dehumidification and Humidification Characteristics

Dehumidification comparisons among Contractor Loose, Contractor Tight and Contractor Smart for homes in Miami, Phoenix and Urbana are shown in Figures 6, 7, and 8. Figure 9 shows winter humidification predictions for Urbana. Miami requires dehumidification every month of the year, on average, while Phoenix requires no dehumidification nor humidification for most of the year.

Miami is our most humid example location, although all of Florida and the entire Gulf Coast are similar (see Handling Humidity – Part 2 for climate effects). A factor of 10 reduction in blower door infiltration (6ACH50 to 0.6ACH50) lowers Contractor Tight's dehumidification by nearly 50% in relation to Contractor Loose's home.

Note that Contractor Loose's home exceeds Florida's current lax construction standards of 7ACH50. Florida requires no active ventilation for homes with 3ACH50 or greater infiltration. As discussed in our Smart Ventilation and Smart Air Distribution reports, extremely leaky homes (10ACH50) have poor air quality. A 3ACH50 home would have horrible, unhealthy indoor air quality. Florida's current building standards are the result of builder/developer lobbying efforts to lower construction cost and increase profits, shifting a greater expense burden to home occupant health cost. Florida is in the heart of moldy homes, and a quarter of moldy home occupants needlessly suffer from house induced environmental illnesses.

Contractor Smart's Miami home reduces dehumidification to approximately half of Contractor Tight's dehumidification load, and a quarter of Contractor Loose's dehumidification load. Peak daily average dehumidification capacity is nearly 90 liters per day of condensate for Contractor Loose's home while Contractor Smart only requires 25 liters per day. As we will discuss in the next section, the shift to a tighter, smart ventilated home is one that also increases the SHR (Sensible Heat Ratio), allowing a home's air conditioner to shoulder more of the latent conditioning load.

Phoenix and other southwest locations have some dehumidification need during the July, August, September monsoon period. Figure 7 shows ZEROs predictions for our 3 homes in Phoenix. The monsoon season is not an extreme one, with dehumidification ranging from 8 liters per day (Contractor Smart) to 18 liters per day (Contractor Loose). The remaining 9 months of the year have comfortable average indoor humidity that automatically ranges between 30 and 60% relative humidity.

Urbana's dehumidification season spans June through September as seen in Figure 8 and Figure 5. Urbana's peak dehumidification needs are a bit less than half of Miami's, and Contractor Smart's home reduces dehumidification to about 1/3 of Contractor Loose's 40 liter per day peak July load.

All three homes in Urbana have negligible moisture management needs during March, April and May, and in the fall during October and November. Humidification is required in Contractor

Loose and Contractor Tight homes from December through February in order to maintain a minimum 30% indoor relative humidity. Contractor Smart's home will automatically maintain an average 30% relative humidity. As discussed in Handling Humidity - Part 2 (see Figure 5), Equinox House automatically maintains 40% relative humidity throughout the winter. Equinox House has 50 indoor plants that contribute an extra liter per day of healthy humidification to the home.

During the winter, Contractor Smart's CERV2 ventilated home is making good use of moisture in both indoor air and outdoor air streams. CERV2 recirculation mode (~80% of time in "low" polluter homes), circulates outdoor air through the heat pump's cooling coils. Moisture condenses and freezes on the cooling coils. The latent energy removed from the outdoor air is converted into sensible heat pumped into the indoors.

CERV2 ventilation mode (~20% of the time) exhausts indoor air through the CERV2's cooling coils in order to extract energy from the exhaust air and recycle the heat into the fresh air stream. The CERV2 condenses and freezes moisture from the indoor air exhaust stream, again converting the latent energy into sensible heating pumped into the fresh air stream. The latent energy to sensible heating energy is most pronounced with outdoor temperatures ranging between 20F and 50F when significant levels of moisture are in the outdoor air. Handling Humidity - Part 3 (see Figure 32), shows the gen 1 CERV in Equinox House converted heating season latent energy from 450 liters of water into 300kWh of sensible heat.

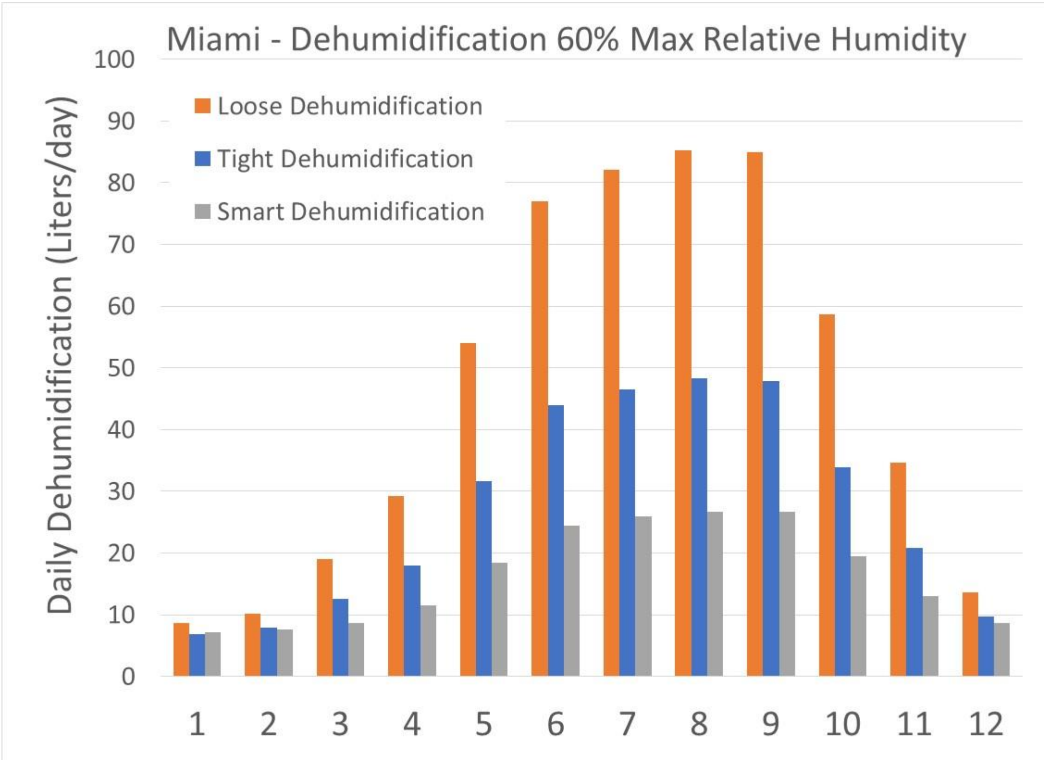

Figure 6 Daily dehumidification for Contractor Loose, Tight and Smart homes located in Miami.

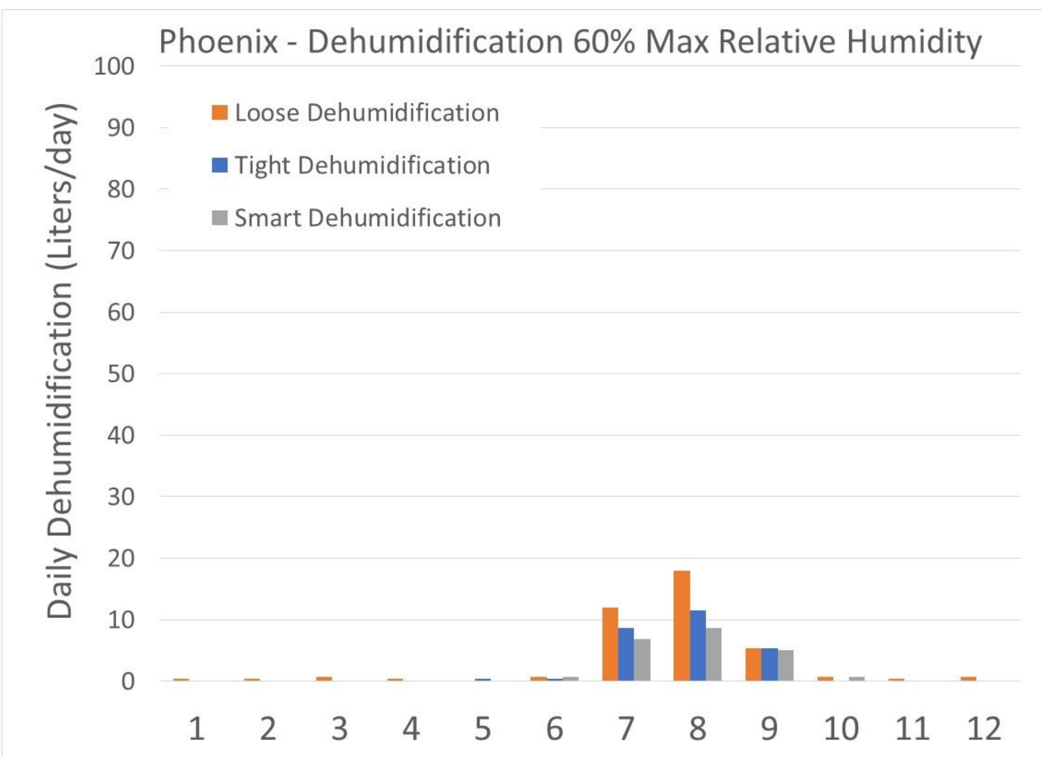

Figure 7 Daily dehumidification for Contractor Loose, Tight and Smart homes located in Phoenix.

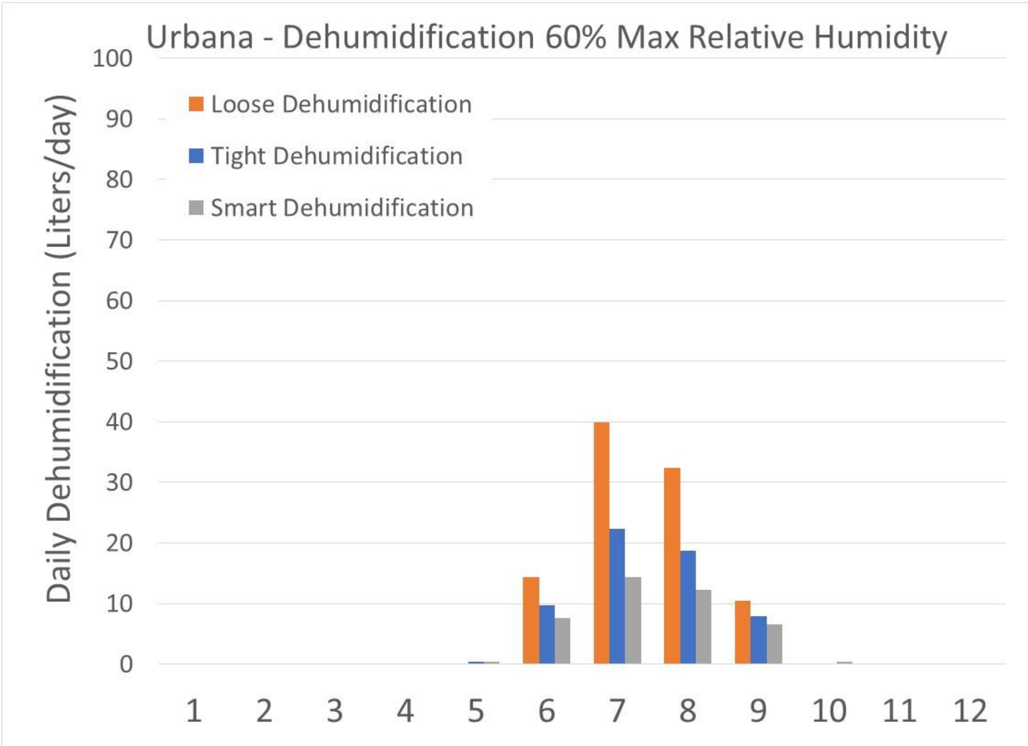

Figure 8 Daily dehumidification for Contractor Loose, Tight and Smart homes located in Urbana.

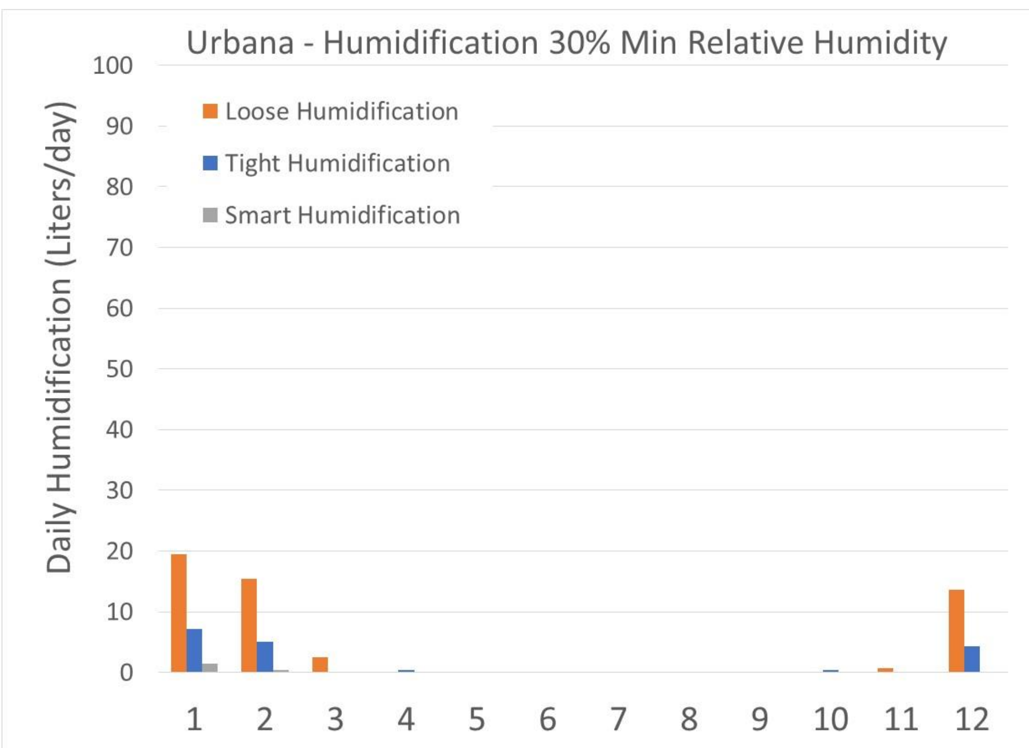

Figure 9 Daily humidification for Contractor Loose, Tight and Smart homes located in Urbana.

Monthly Heating, Sensible Cooling, and Latent Cooling Characteristics

Monthly trends for average heating, sensible cooling and latent cooling capacity (kWt = thermal kW) for our three contractors in three locations provide perspectives on latent (moisture) conditioning relative to other comfort conditioning loads. Figures 10-12 show results for our example Miami house, Figures 13-15 show results for the Phoenix house, and Figures 16-18 show results for the Urbana house.

Contractor Loose's Miami house (Figure 10) is dominated by latent cooling loads. Summer latent cooling capacity is double sensible cooling capacity requirements, indicating additional dehumidification beyond the capability of most air conditioners. Winter sensible cooling loads are greater than latent loads and should not require auxiliary dehumidification. Contractor Tight's Miami home (Figure 11) decreases summer latent cooling capacity requirements however latent cooling continues to dominate summer month cooling requirements and necessitates a dehumidifier. Contractor Smart's Miami home (Figure 12) reduces average daily latent cooling capacity to a similar level as sensible cooling capacity requirements during the humid summer months. Although "on average", Contractor Smart's home could manage most of its moisture load more efficiently with an air conditioner, a dehumidifier would be beneficial for periods with high external and internal moisture loads.

Phoenix also requires cooling every month of the year on average, however, only 3 months typically require dehumidification. The remainder of the year requires no latent conditioning. During months when no dehumidification nor humidification are required, an air conditioner will reduce indoor humidity to a level where the indoor air dew point temperature is similar to the cooling coil (evaporator) temperature. That is, air conditioners automatically adjust their sensible heat ratio as the humidity ratio changes. Figures 13, 14, and 15 show that sealing does not impact latent loads significantly. Overall cooling loads are improved by better sealing, and by smart ventilation.

Urbana requires dehumidification from June through September as shown in Figures 16, 17, and 18. Sealing a home reduces latent conditioning by 50%. Contractor Loose's home would need a dehumidifier in order to keep indoor humidity below 60%, however Contractor Tight's home reduces latent conditioning needs relative to sensible cooling such that no additional dehumidification beyond the air conditioner's capacity should be required. Contractor Smart's home further reduces both latent and sensible cooling loads and similarly requires no additional dehumidification.

Sealing the Urbana home from 6ACH50 to 0.6ACH50 reduces winter heating by more than 50%. Smart ventilation reduces winter heating capacity by another 25%, as well as keeping indoor humidity levels more comfortable.

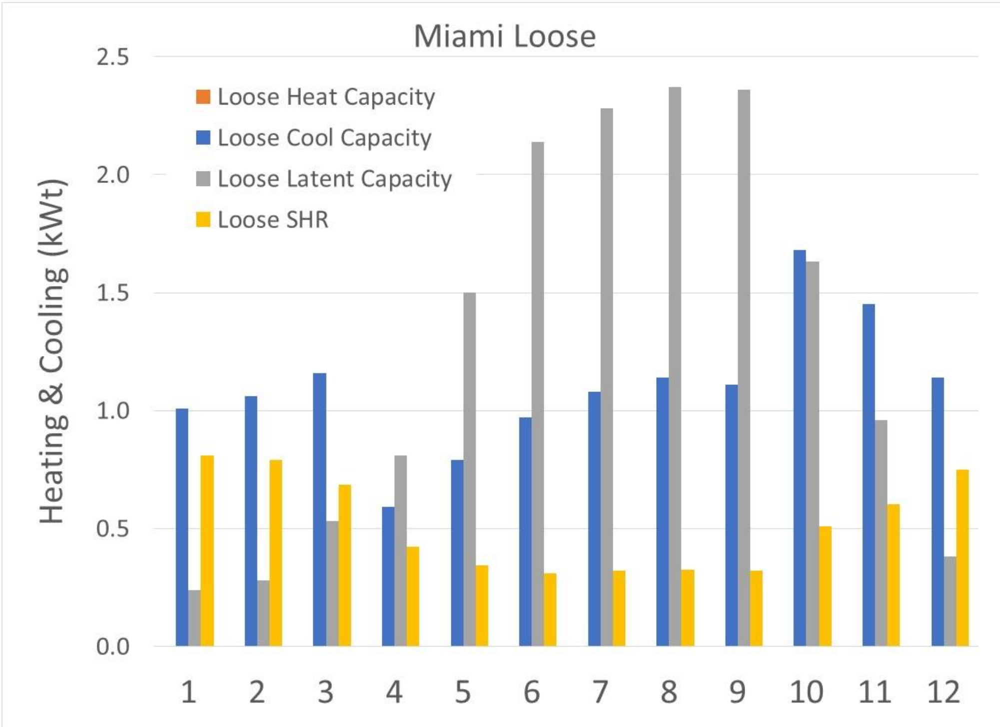

Figure 10 Average cooling capacity (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Loose's Miami house.

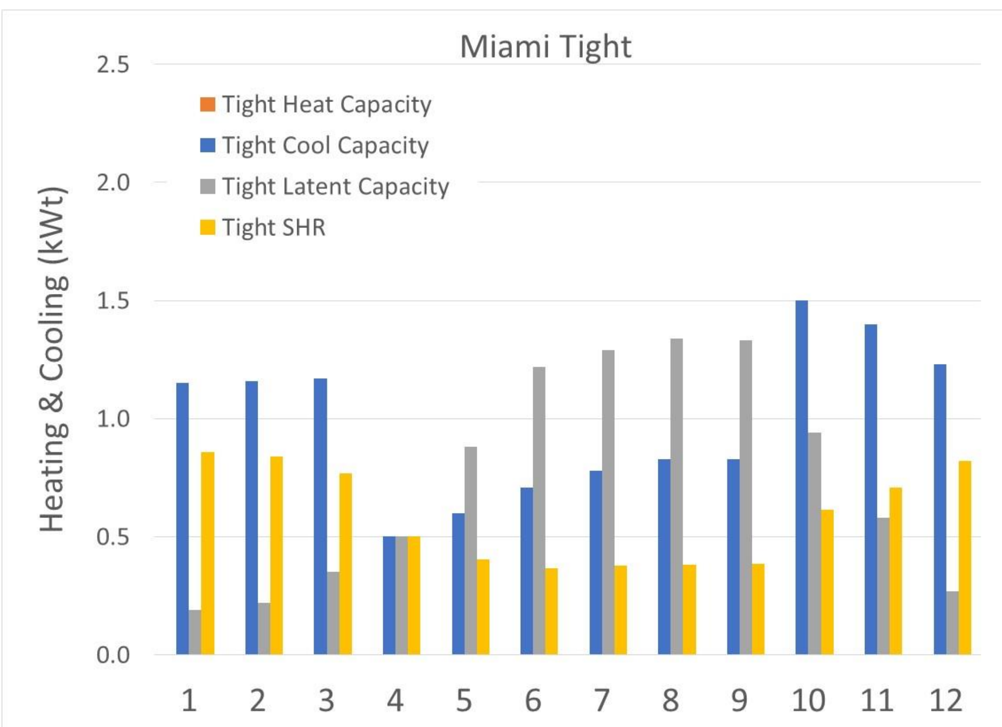

Figure 11 Average cooling capacity (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Tight's Miami house.

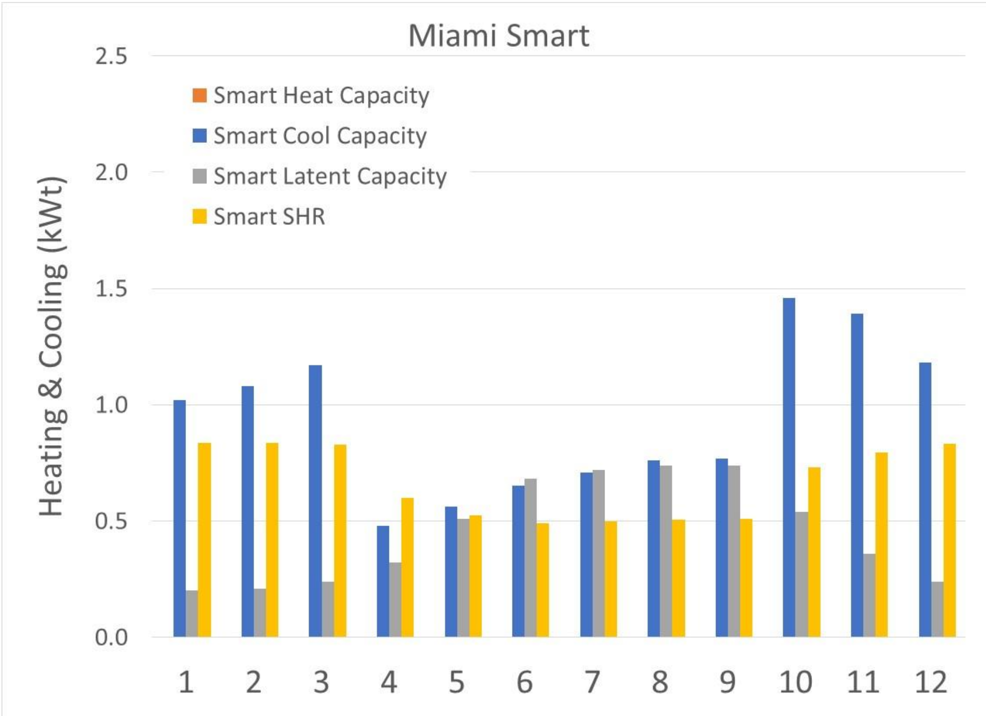

Figure 12 Average cooling capacity (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Smart's Miami house.

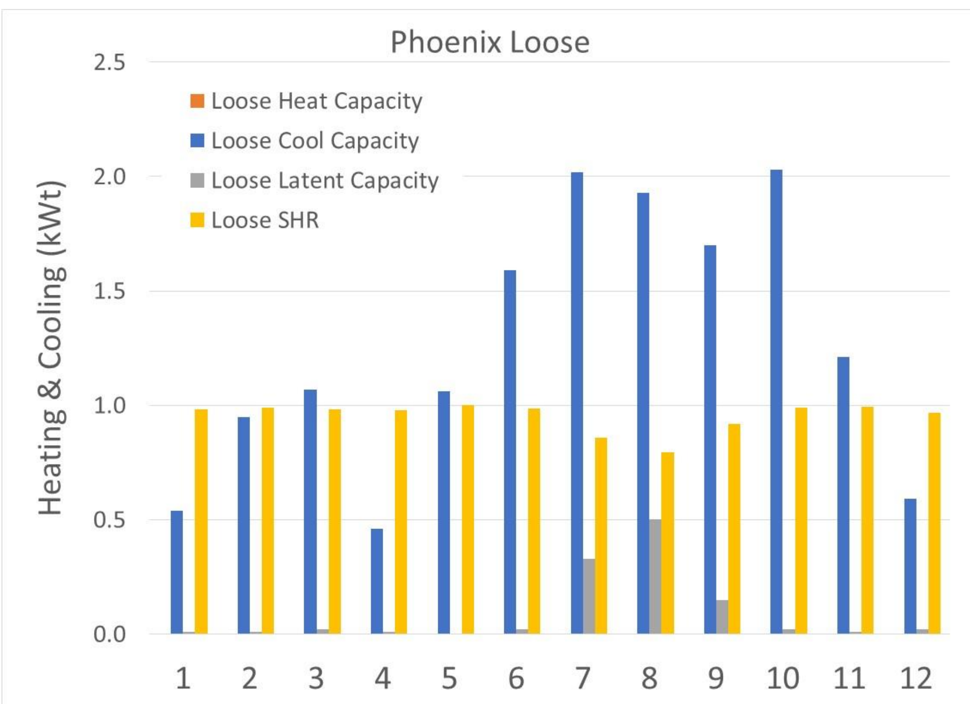

Figure 13 Average cooling capacity (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Loose's Phoenix house.

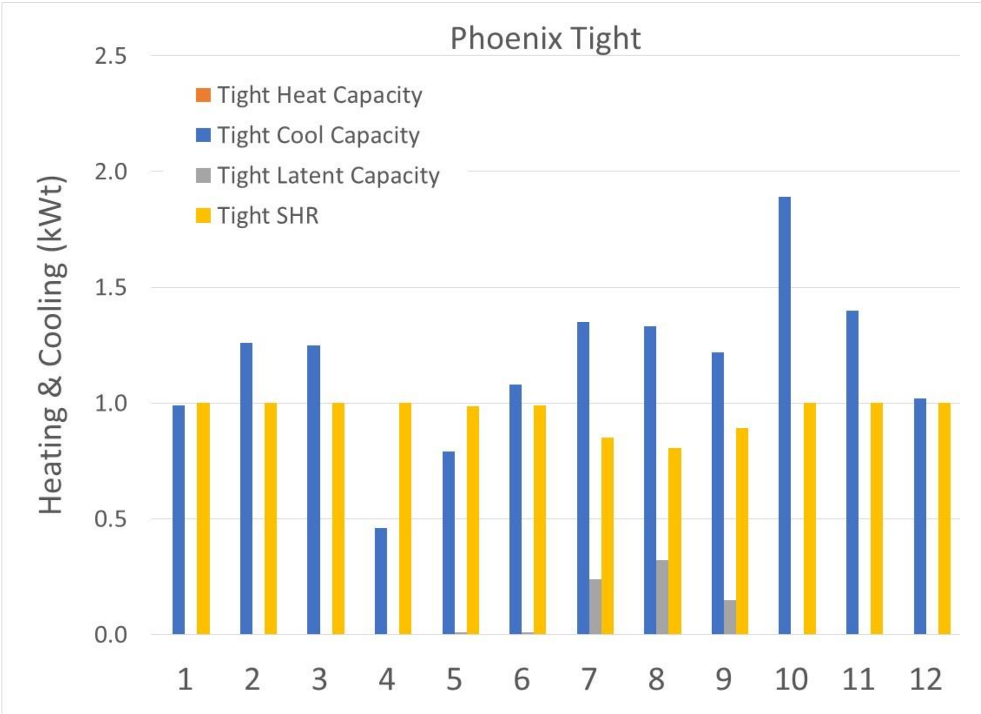

Figure 14 Average cooling capacity (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Tight's Phoenix house.

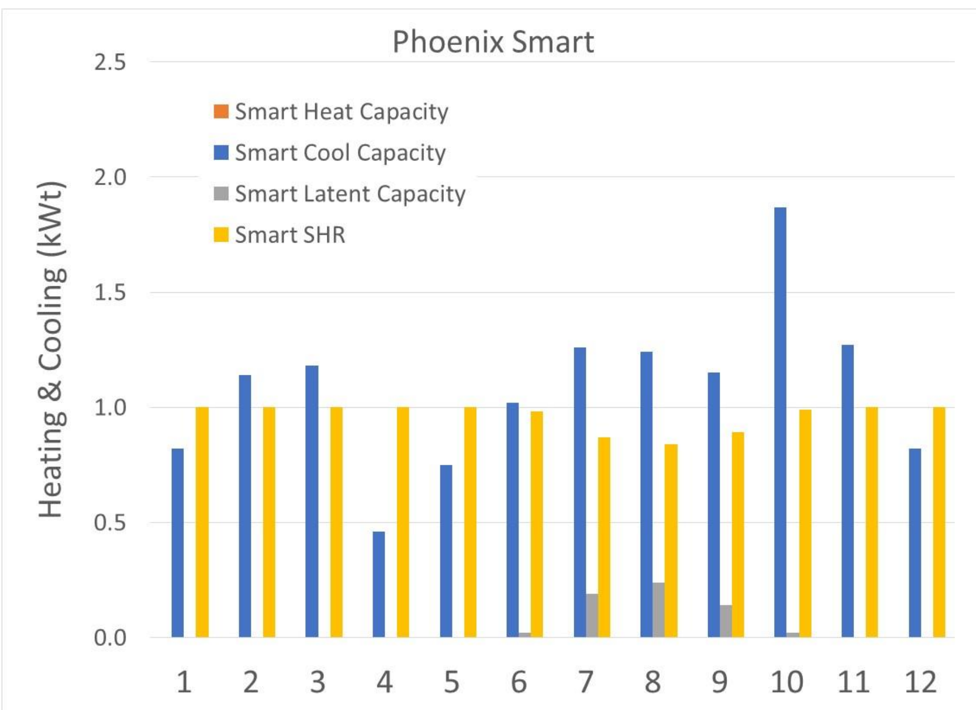

Figure 15 Average cooling capacity (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Smart's Phoenix house.

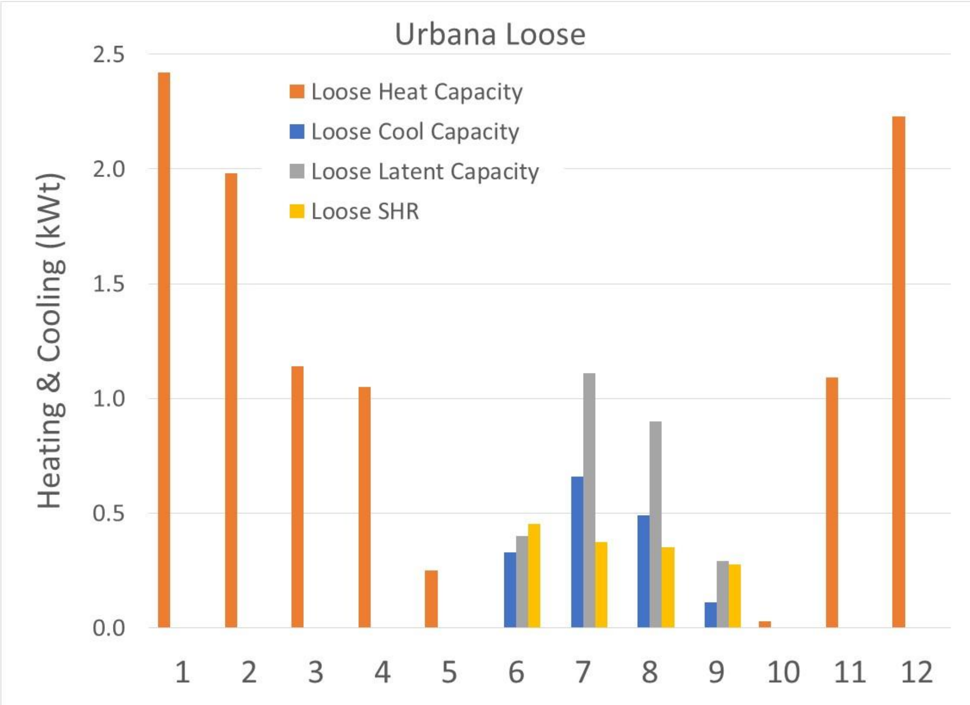

Figure 16 Average cooling and heating capacities (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Loose's Urbana house.

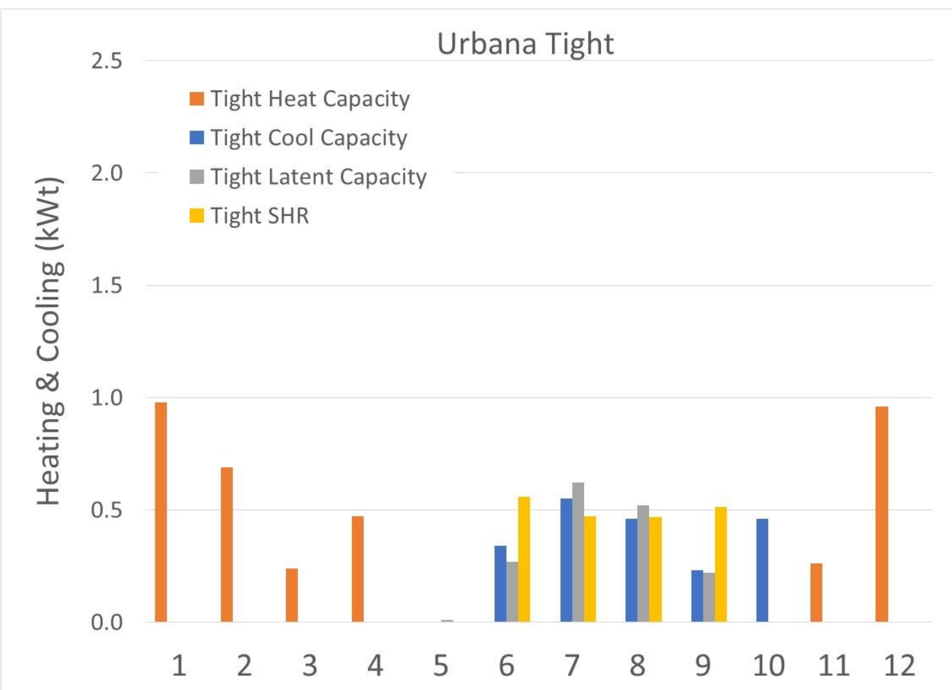

Figure 17 Average cooling and heating capacities (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Tight's Urbana house

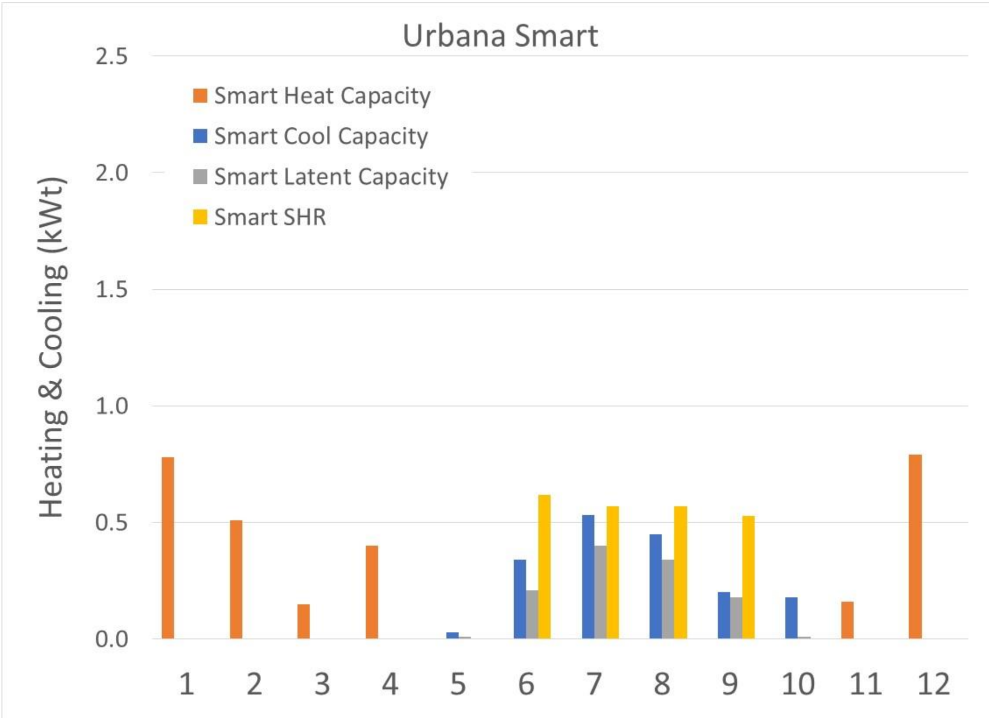

Figure 18 Average cooling and heating capacities (kW thermal) and Sensible Heat Ratio (SHR) for Contractor Smart's Urbana house

Monthly and Total Electrical Energy Load

All homes reduce annual electrical energy usage by sealing and using smart ventilation. Figures 19, 20, and 21 compare the monthly electric utility load for Miami, Phoenix and Urbana, respectively. In high performance homes, Miami's annual energy requirements are high in comparison to Urbana's annual electric energy usage. The overall trend observed for each location is that smart ventilated and highly sealed homes outperform all other homes. A number of other interesting trends are also observed in the performance data.

Contractor Tight's Miami house energy uses 20% less energy than Contractor Loose while Contractor Smart's house uses 45% less energy than Contractor Loose's home. For Phoenix, Contractor Tight's home is only 5% better than Contractor Loose while Contractor Smart's home uses 15% less electric energy than Contractor Loose's house. Contractor Tight's Urbana home uses 25% less energy than Contractor Loose's home while Contractor Smart's home uses 40% less energy than Loose's house.

Note that Contractor Loose's home in Phoenix uses less energy than Loose's house in Urbana while Contractor Smart's Urbana house uses less energy than Smart's Phoenix home. That is, one cannot generalize that one climate is always better than another climate in terms of annual energy usage. A home in Urbana can outperform a home in Phoenix because electric energy loads in the home for cooking, lights, television, etc also contribute to Urbana's winter heating needs. In warm locations such as Miami and Phoenix, electricity used for appliances, lights, etc must be removed by the home's air conditioning system.

Another interesting aspect of these three homes is that a "Loose" home can outperform a "Tight" home during part of the year, as seen in Figure 20 for the Phoenix homes. From November through March, infiltration in a Loose home beneficially reduces the home's cooling load. The Smart home automatically increases fresh air ventilation whenever it determines that outdoor air can help cool the home. An HRV ventilated home must have additional sensors and a bypass damper in order to take advantage nice outdoor conditions.

Contractor Smart's house adds approximately $10,000 to a home's cost for sealing, smart ventilation, and ventilation ducting in relation to a home without any fresh air ventilation. For a 2000sqft home, sealing and smart ventilating is a house construction cost increase of 2 to 4% assuming construction costs of $125 to $200 per sqft. The additional cost written into a home's mortgage would add $50 per month for Smart's improvements. This cost is paid for by energy savings, improved house durability, and occupant health.

The difference between a Loose and Smart Miami home's annual utility bill is $650 per year ($55 per month) based on an electric energy cost of 12 cents per kWh. Contractor Smart's Miami home's increased mortgage is paid for by energy savings. Smart's Urbana home saves $400 per year over Loose's home, which also pays for most of the monthly mortgage cost of the improvements. In Phoenix, energy savings are $120 per year, or $10 per month. In comparison to a home's other utility bills, cell phone and internet costs, the $40 mortgage differential is reasonable.

More valuable than energy savings are improvements in occupant health and well-being. Averaged over the general populace, the difference between a Loose home or Tight home with a Smart home can be estimated on the bases of fewer sick days, fewer respiratory emergencies, and better sleep/productivity. As discussed in our Smart Ventilation report and Smart Air Distribution report, Loose and Tight home do not have good indoor air quality, they simply leak and ventilate excess air into a home causing increased energy usage, but they do not deliver fresh air to home occupants when they need fresh air and where they need fresh air. In addition, a leaky home allows 10 times more outdoor pollutants, particulates, pollens, and other outdoor irritants into a home.

A smart ventilated home that keeps air fresher when and where occupants need it can reduce flu and cold infections by 40%, similar to the effectiveness of flu vaccines (DK Milton, PM Glencross, and MD Walters; "Risk of Sick Leave with Outdoor Air Supply Rates, Humidification, and Occupants Complaints"; Indoor Air; Vol 10, pp212-221; 2000). Milton, et al estimate the annual value of reduced illness with more effective ventilation to be $500 per year per person. In terms of respiratory problems, with nearly 10% of the US populace experiencing asthma at an estimated cost of $3000 per year, the cost of asthma averaged over all households is nearly $1000. We do not currently know the percent reduction of asthma and other respiratory affliction costs due to improved ventilation, but we do know that it will have an impact based on improved indoor humidity, leading to less mold. A 50% reduction of respiratory illness cost, or $500 per year per household savings plus $1250 reduction for reduced illness related to flu and colds ($500 times US household occupancy average of 2.5 occupants per household) added to energy savings is much more than the amortized cost for an improved indoor environment.

Home with smart ventilation will also improve occupant productivity. The amount of productivity improvement has been estimated to be in the range of $5000 per person per year, or approximately 10% productivity improvement, based on doubling building ventilation rates from current ASHRAE ventilation levels. Productivity impact is an active research field and more investigations are required to better define the value of productivity gains. It is clear, however, that more effective fresh air ventilation will improve productivity to some level due to better sleep and improved brain function. Even a 1% productivity improvement per person is a cost improvement of $1250 per household ($500 times 2.5 occupants per household).

Anecdotally, our discussions with smart ventilated home occupants who have respiratory sensitivities indicates an additional positive benefit of lowered stress. Anyone with a respiratory sensitivity worries that any building they enter may trigger a breathing emergency. Having a smart ventilated home with fresh, filtered air provides a safe haven that lowers stress, and perhaps a lowers medication requirements (as a few home occupants have mentioned).

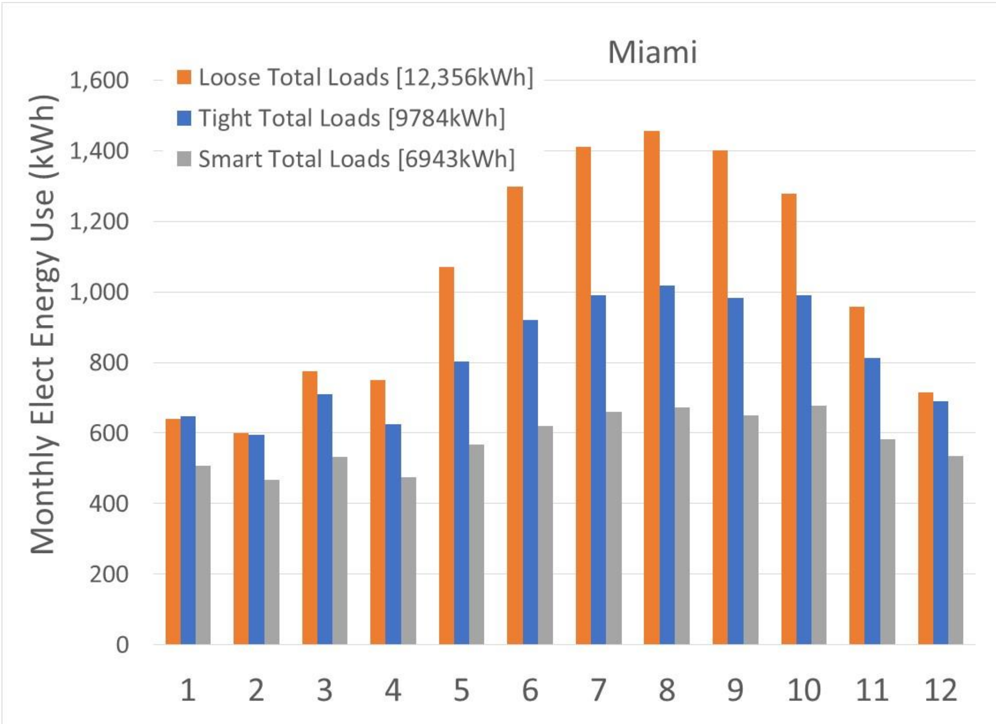

Figure 19 Monthly electric utility usage for Loose, Tight and Smart homes in Miami.

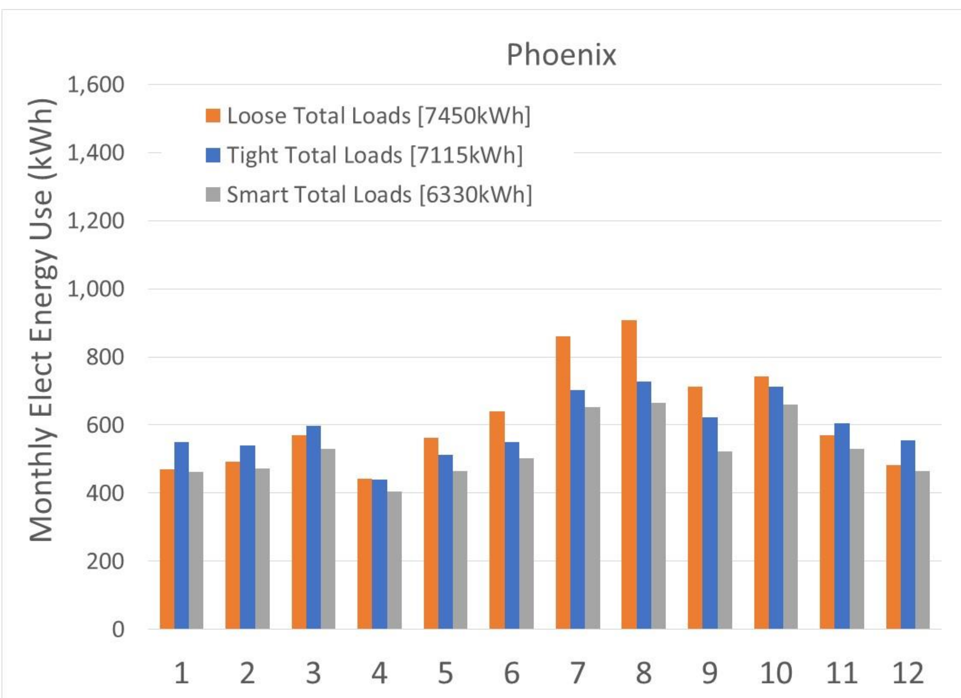

Figure 20 Monthly electric utility usage for Loose, Tight and Smart homes in Phoenix.

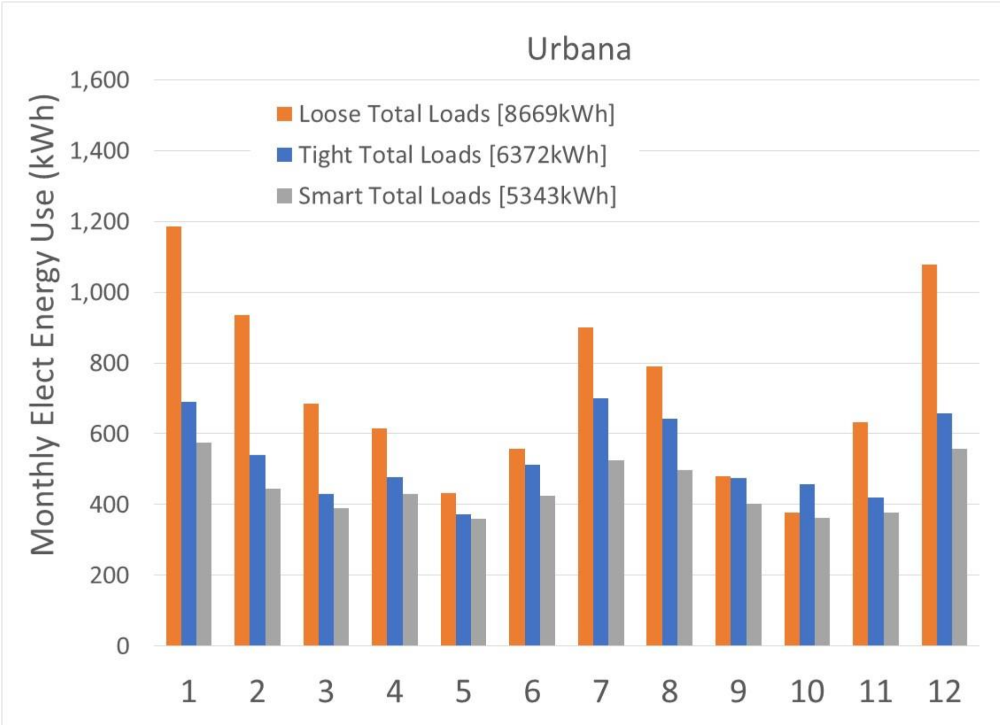

Figure 21 Monthly electric utility usage for Loose, Tight and Smart homes in Urbana.

Summary

Our overall conclusion is that all homes should be tightly sealed and use smart ventilation. A smart ventilated, sealed home reduces energy usage in all climates, and makes moisture much easier to control. Warm and humid climates and cold northern climates benefit the most in terms of moisture management and energy usage reductions.

The benefit of an actively and automatically managed home indoor environment is much more than energy savings. Improved moisture management coupled with low indoor pollutant and particulate levels reduces the probability of airborne illness infection, improves health, improves productivity, and lowers stress.