Flexible Residential Test Facility: Impact of Infiltration and Ventilation on Measured Cooling Season Energy and Moisture Levels

D. Parker, J. Kono, R. Vieira, P. Fairey III, J. Sherwin, C. Withers Jr., D. Hoak, and D. Beal
BA-PIRC

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Flexible Residential Test Facility:
Impact of Infiltration and Ventilation on Measured Cooling Season Energy and Moisture Levels

Prepared by:

Danny S. Parker, Jamie E. Kono, Robin K. Vieira, Philip W. Fairey III,
John S. Sherwin, Charles Withers Jr., David Hoak, and David Beal

BA-PIRC/Florida Solar Energy Center
1679 Clearlake Road, Cocoa, FL 32922

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Definitions

AC	Air conditioning
ACH50	Air changes per hour (at 50 Pascals between inside and outside)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
C	Air leakage coefficient
CFM	Cubic feet per minute
CO_2	Carbon dioxide
ELA	Effective leakage area
EqLa	Equivalent leakage area
FRTF	Flexible Residential Test Facility
FSEC	Florida Solar Energy Center
n	the exponent in the building leakage curve defined by the equation: $Q = C \times P^n$ where Q is airflow into the building (in CFM), C is the Coefficient, and P is the pressure difference between inside and outside
Qn	Normalized air distribution system leakage
RH	Relative humidity

Acknowledgments

Executive Summary

Air infiltration and ventilation in residential buildings are a very large part of the heating loads, but empirical data regarding the impact on space cooling have been lacking. Moreover, there have been few data on how building tightness might relate to building interior moisture levels in homes in a hot-humid climate. To address this need, Building America has conducted research in two identical laboratory homes in Central Florida to measure specific impacts.

To assess the moisture and cooling load impacts of airtightness and mechanical ventilation in homes in hot-humid climates over the summer, two identical laboratory homes designed to model existing Florida building stock were sealed and tested to 2.2 ACH50. One lab was made leaky with leakage through the attic and windows to a tested value of approximately 8 ACH50. The other lab was held tight and equipped with a mechanical ventilation system to meet minimum ventilation airflow rates recommended for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-2. Testing was conducted over the summer of 2012 to evaluate the energy and moisture effects of differing building leakage rates. The testing also examined the impact of mechanical ventilation according to ASHRAE Standard 62-2-2010 in the tighter building by alternating 2-week periods of mechanical ventilation and no ventilation for a portion of the summer.

The comparative summer testing showed that tighter buildings, exemplified by the west structure, had little if any air conditioning (AC) energy savings and only modest differences in moisture content under natural infiltration. The lack of energy savings in the tighter home was largely because the outdoor temperature was nearly as often below as above the desired thermostat set point. Thus, increased air infiltration during nighttime hours when the temperature outside is lower than the desired cooling set point actually reduces the AC load. The less airtight east house showed only a mild increase in moisture levels in the home, likely due to increasing AC runtime that quickly removed any excess moisture from increased infiltration. This occurs because vapor compression AC equipment removes more moisture as runtime increases. There is also an impact on the machine sensible heat ratio; as the internal level of absolute moisture increases (the wet bulb), the machine's operating sensible heat ratio drops.

Unlike natural infiltration, mechanical supply ventilation revealed much more significant changes to energy use and moisture levels when added to the tight home. Cooling energy increased by 20%–38% or about 4 kWh/day. Part of this increase resulted from the mechanical ventilation system fan itself, which added 1.8 kWh/day of energy use to the cooling system energy use.[1] The power use of the ventilation equipment was approximately 75 Watts. While this is a commercially available unit, there is equipment that might have system power that is less than half of this level with a more modest impact on fan energy use. The mechanical ventilation system also elevated building moisture levels—interior relative humidities (RHs) were modestly increased by 2%–5%.

The interior moisture data collected suggest that leaky residential buildings (as exemplified by the loose building) will not result in as large an increase in moisture levels as when ASHRAE

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[1] Given equipment coefficient of performance, we would estimate that cooling energy would likely be increased by ~0.5 kWh/day from the heat of added fan energy.

Standard 62-2 levels of ventilation are provided in a tight building in Central Florida without enthalpy recovery. In the leaky building, average RH usually did not exceed 50%, except toward the end of the season when the sensible cooling load declined. However, even with mechanical ventilation during periods with high cooling loads, interior RH usually stayed below 60%. This means that while interior moisture levels were increased by mechanical supply ventilation, they were generally in an acceptable range. They did, however, increase cooling energy use.

However, moisture-related results in winter were quite different. The 2011–2012 winter infiltration study found significant moisture problems in an older Florida home with a very tight envelope at 2.2 ACH50 (Vieira and Sherwin 2012). This study provides additional evidence that many of the moisture problems in residences in Central Florida likely occur during winter when there are no sensible cooling loads and no humidity removal.

Later in the test period, we used a carbon dioxide tracer gas technique to examine the evenness and sufficiency of airflows into the two buildings relative to ASHRAE Standard 62-2. Without mechanical ventilation, both buildings showed much lower than recommended effective ventilation rates—particularly the tight building where average observed air change rate was only 0.04 ACH. However, even the leaky building (with 0.27 ACH) experienced long periods where the interior flow rates were half what would be recommended by Standard 62.

The summer 2012 testing at the Flexible Residential Testing Facility (FRTF) suggests that further experimentation should be done in the future to examine likely interactions with duct system leakage as well as the potential of enthalpy recovery ventilation systems, which may help address moisture issues while providing more comparable energy performance.

By providing specific data on infiltration and ventilation impacts in a hot and humid climate, this study reveals the impact on AC energy and interior moisture levels. While building airtightness was found to only slightly influence space cooling and interior moisture levels, mechanical ventilation had a more pronounced impact, suggesting that enthalpy recovery ventilation systems could be valuable. The results of this study provides important input to designers, homeowners, the air conditioning industry, utilities, and policy makers when determining cost-effective and comfortable energy efficiency improvements for homes in hot-humid climates.

1   Background

1.1   Literature Search

Early assessments of the impacts of air infiltration in buildings have estimated that air leakage was responsible for a third of heating and cooling loads (Sherman et al. 1980; Hekmat et al. 1986). However, these studies largely concentrated on heating loads, which are known to strongly depend on building air leakage. Very few studies have attempted to measure the impact of air infiltration or ventilation on cooling loads alone. Another very detailed simulation study of office buildings in climates around the United States (Emmerich et al. 2005) found that while air infiltration and ventilation were responsible for 33% of the heating loads, they actually reduced cooling loads by 3.3%. Although these were commercial buildings and not residences, this finding was true even in cooling-dominated climates such as Savannah, Georgia and Tucson, Arizona. Part of this stems from the fact that nighttime temperatures are often lower than the cooling thermostat set point—an attribute sometimes advocated to reduce cooling by the use of forced ventilation (an economizer cycle) during these periods (Blondeau et al. 1997).

Data from Japan suggest that occupants can have a large influence on building ventilation rates due to opening of windows during nighttime hours (Iwashita and Akasaka 1997). In Central Florida, Cummings and Tooley (1989) used simulation to show that an increase in the infiltration rate from 0.10 to 0.90 ACH could increase space cooling by 31%, but without data to know what the realistic range of air change rates prevailing in homes might be. In the same study, the authors also found that space heating was much more sensitive to infiltration rate, increasing by 127% over the same range.

Studies of the impact of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62.2 (ASHRAE 2010) and associated mechanical ventilation in homes on cooling loads are even more limited. Wray et al. (2000) estimated impacts via simulation, showing the largest impacts of mechanical ventilation in extreme climates, which included humid ones. Although indicated energy penalties were small and were based on simulation, not measurement, they were not inconsequential, and the indicated benefits relied on base building infiltration rates that were not verified. Other relevant simulation estimates were made by Robertson et al. (1998), who found that, depending on the strategy used for compliance, heating and cooling loads in Houston, Texas could be increased by up to four times that of the most effective strategy (balanced enthalpy recovery). No specific empirical studies could be located in our literature search, nor those of earlier investigators (Barley 2001).

One concern of added ventilation in humid climates is the increase of interior moisture levels. As such, it is useful to examine work that investigates how increased relative humidity (RH) may influence occupant health. For instance, Arundel et al. (1986) and Fisk et al. (2010) show that higher interior RH is associated with the incidence of allergies, prevalence of dust mites, and upper respiratory infections. Moreover, Baughmann and Arens (1996) suggest the same as well, indicating that problems with non-biotic agents such as formaldehyde were adversely increased. Most of the studies identify levels exceeding 60% RH as being problematic.

There are also some questions about the existing calculation methods to estimate the impact of infiltration or ventilation. Infiltration is customarily assumed to increase the heating and cooling loads of a building by an amount equal to the mass flow rate of the infiltration times the enthalpy

sometimes neglected. However, the situation in real buildings may be more complex. Some
research has suggested that natural air infiltration in buildings can behave very differently from
mechanical ventilation, where the building may function as a heat exchanger. For instance,
Claridge and Bhattacharyya (1990) conducted calorimetric measurements on a small test cell
with measured amounts of infiltration introduced under a variety of conditions. The
measurements showed that infiltration can lead to a much smaller change in the energy load than
is customarily calculated; changes as small as 20% of the calculated value have been measured
in the cell. The data also suggest that the phenomenon occurs in full-sized houses. However,
other work on this same phenomenon was done by Walker and Sherman (2003), who showed
that the effect was only about 1% for well-insulated buildings, although potentially much larger
for poorly-insulated structures. In any case, the impact of natural air infiltration may be
somewhat different from the impact of mechanical ventilation air of a similar quantity.

The summer Flexible Residential Test Facility (FRTF) study on infiltration and mechanical
ventilation focused on the following research questions:

- How does the airtightness of a home affect its moisture levels, temperature, and air
  conditioning (AC) loads during the cooling season?

- How does supply mechanical ventilation, meeting ASHRAE Standard 62.2, affect a
  home's moisture levels, temperature, and AC loads during the cooling season?

- How does air infiltration from natural infiltration compare to the ASHRAE Standard 62.2
  ventilation requirements?

Additionally, the following research question was developed during the study:

- How does the level of moisture generation within a home affect its moisture levels and
  AC loads?

2 Methods

2.1 Facility

The state of Florida provided funding for the design and construction of two reconfigurable, geometrically identical, full-scale, side-by-side residential building energy research facilities at the Florida Solar Energy Center (FSEC), as shown in Figure 1. The Building America Partnership for Improved Residential Construction has instrumented these flexible research homes and will monitor them to conduct research on advanced building energy efficiency technologies under controlled conditions.

Figure 1. Completed flexible residential test structures on FSEC campus

The purpose of the FRTF is to provide a controlled research environment that serves two main purposes. First, it is used to research and evaluate advanced energy-efficiency technologies and operational strategies. Second, it serves as a venue to help validate building simulation programs and algorithms. Details of the 1,536-ft^2 single-story buildings (volume = 13,050 ft^3) and their instrumentation are provided in the "Flexible Residential Test Facility Instrumentation Plan" (Vieira and Sherwin 2012).

Of particular significance to this report is the substantial effort that went into creating equal air leakiness in the buildings. Initial construction created reasonably tight buildings (3.62 and 3.82 ACH50), but FSEC staff further sealed leakage points until they were each able to achieve 2.2 ACH50. The air distribution systems were very tight: 13 CFM25/100 ft^2 (Qn = 0.013) in each home. Each home was then configured with controllable duct leakage and air leakage. The air leakage was designed to create the type of distribution and diffusion of air leakage represented in a number of Southern slab-on-grade homes:

- Both homes were configured with four controllable ceiling leakage sites providing ~70% of leakage area needed to achieve ~8 ACH50 (see Figure 2). Seventy percent through the ceiling was able to be verified using calibrated flow hood to measure air through ceiling leak sites when the house was at –50 Pascals with reference to outside.

- The remaining 30% of leakage area was achieved using metal shims at all windows (Figure 3).

**Figure 2. Ceiling penetration for planned leakage (left);
attic view of hole that diffuses airflow (right)**

Figure 3. Metal stand-off shims used to add vertical plane leakage to the east building

FSEC staff experimented with different configurations of holes and air pathway restrictions until we were able to achieve an "n" or flow exponent value in a range from 0.6 to 0.7 while bringing in 30% of the air through the windows and obtaining an ACH50 value near 8. An "n" value between 0.6 and 0.7 was established because this is the typical range found in measurements in homes across the United States (Sherman et al. 1986). Once the air leakage design was established in the first home, the same design was copied in the second home to obtain matched leakage results.

Airtightness testing was repeated on both homes in the tightest house envelope configuration and in the leakiest house envelope configuration at 9 ACH50. The detailed test results are summarized in Table 1 and Table 2. These tests were done with a very tight duct system having only Qn = 0.013 (0.013 CFM25 leakage to outside/100 ft^2 of conditioned space).

It is noted that having leakage concentrated in the ceiling plane can have large influences on the resulting infiltration dynamics because the building is shielded from most wind-related effects (Walker and Wilson 1998). However, the authors believe this arrangement is very typical of homes in the Southeast where slab-on-grade floors have no leakage and windows and doors are relatively well-sealed, but ceiling penetrations for recessed light cans and bathroom and kitchen fans make the ceiling a major site for building leakage.

Table 1. Building Tightness Comparison of Tight House Configuration (Tight Duct System)

	ACH50	CFM50	C	n	EqLa	ELA
East Lab Tight	2.26	540 (± 0.7%)	36.0 (± 8.6%)	0.692 (± 0.023)	55.8 (± 3.5%)	29.6 (± 5.5%)
West Lab Tight	2.18	520 (± 0.6%)	36.0 (± 8.9%)	0.683 (± 0.023)	53.7 (± 3.7%)	28.5 (± 5.8%)

Notes: Values in parentheses are the 95% confidence limits on the estimates; C, air leakage coefficient; n, exponent in the building leakage curve defined by the equation: $Q = C \times Pn$; EqLa, equivalent leakage area

Table 2. Building Tightness Comparison of Leaky House Configuration (Tight Duct System)

	ACH50	CFM50	C	n	EqLa	ELA
East Lab Leaky	7.99	1909 (± 1.8%)	177.3 (± 15.4%)	0.607 (± 0.047)	197.1 (± 5.9%)	104.8 (± 9.6%)
West Lab Leaky	8.06	1926 (± 1.1%)	182.3 (± 11.3%)	0.603 (± 0.031)	198.8 (± 4.3%)	105.7 (± 7.1%)

Notes: Values in parentheses are the 95% confidence limits on the estimates.

During the tests, the west lab building was in the tight configuration (2.18 ACH50), and the east building was nominally in the leaky configuration (7.99 ACH50). However, it is important to note that because of miscommunication, the window shims that create the vertical plane leakage in the building were not in place during the majority of the cooling season. In this configuration, the building had a tested leakage of 6.01 ACH50, although with 94% of its leakage in the ceiling plane.[2] On October 1, 2012, the window shims were reinstalled, and the east building reverted to the original intention of 7.99 ACH50 for the duration of the experiment.

2.2 Internal Gains

Due to the shoulder months of the extended cooling season in Central Florida, internal gains substantially increase cooling loads during periods when the outside conditions are otherwise moderate. This is particularly true in newer, tighter homes. Furthermore, internal moisture generation in a tight home without ventilation will lead to high moisture levels. The laboratories have automated (computer controlled) heat and moisture loads scheduled by time of day based on the Residential Energy Services Network lighting, appliance, and miscellaneous energy usage amendment schedule (Lighting, Appliance and Miscellaneous Energy Usage Profile Amendment 2011). The schedules approximate Building America benchmark hourly schedules (Fang et al. 2011) as shown in Figure 4.

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[2] This has the likely effect of generally reducing the experienced building infiltration rate for a given absolute leakage. However, this configuration is not unlikely in the real world where much of the leakage in Florida buildings is concentrated in the ceiling plane from recessed can lights and bathroom and kitchen fans.
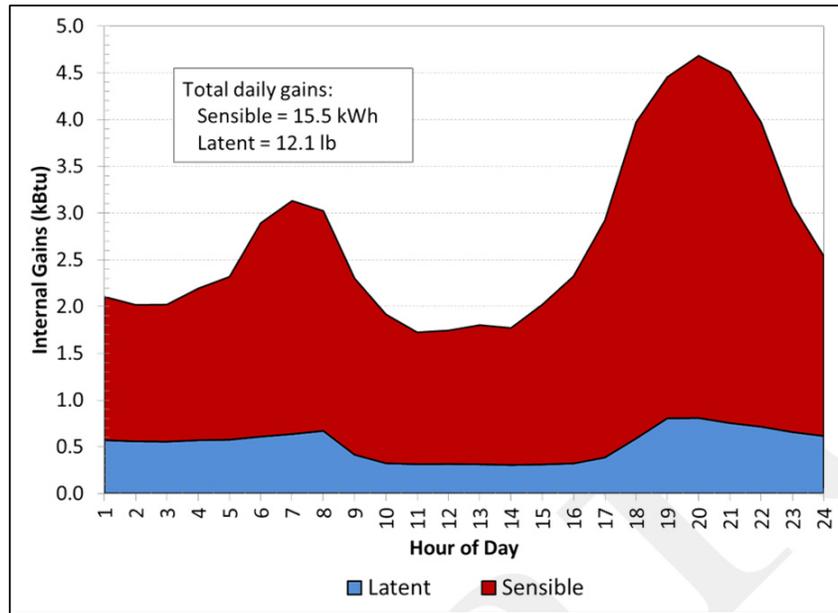
Figure 4. Daily load schedule for both homes

For this experiment, the latent load was lowered to 6.05 lb/day of moisture, half of the latent load used during the winter time frame. As internal moisture generation rate in real homes is uncertain, this was done as a parametric exercise to see how internal moisture generation level might influence results. However, beginning on June 22, the moisture level was brought back to 11 lb/day in accordance with the Building America Benchmark-computed level for moisture generation in a home of this size and configuration.

Some of the internal sensible heat gains were produced by the house's oven. Due to variability in stove elements, the west home oven produced more heat from the same automation schedule, resulting in slightly higher internal loads.

3   Experimental Methods

3.1   House Leakage Characteristics

For the infiltration test, the west laboratory home served as the tight home and had the leakage sealed off at the ceiling plane. The leaky east laboratory home used the ceiling penetrations and window shims to obtain the results shown in Table 3.

Table 3. Leakage Measurements in FRTF for Experiment

Leakage Parameter	Leaky Home East	Tight Home West
CFM50	1909	520
ACH50	7.99	2.18
C	177.3	36.0
n	0.607	0.683
ELA* (in.^{2})	104.8	28.5
Specific Leakage Area	0.00053	0.000119

*effective leakage area

The west home served as the tight home, with a tested ACH50 of 2.2. The west home alternated every 2 weeks between having no mechanical ventilation and having mechanical ventilation in order to compare the energy savings and moisture impact of a tight home with and without ventilation.

3.2   Forced Ventilation

Forced ventilation was also evaluated as an option for providing adequate air turnover in tight homes. In mid-August, an energy recovery ventilation system (Honeywell ER-200) was installed in the west building, allowing the west home to have whole-house ventilation. However, the enthalpy recovery section of the unit was deactivated, and it operated as a supply fan only. The exhaust fan was not operated, so the system was supply only and unbalanced.

When in use, the system provides 63 ($\pm$ 3) CFM of outdoor air into the space continuously, which was verified using a calibrated flow measurement setup. Measured power use of the ventilation system was 74 ($\pm$ 2) Watts continuous or 1.77 kWh/day. After installation, the west home alternated between continuous ventilation from the whole-house ventilation system and no ventilation.

3.3   Data Collection Schedule

Temperatures and RHs inside the laboratory buildings were extensively monitored with more than 100 channels of temperature and humidity measurements as well as the condensate removed by the air conditioner. Power uses of both the air handler and compressor were also recorded. During October, carbon dioxide (CO_2) was released and monitored inside the homes to estimate infiltration rates.

The summer 2012 infiltration and ventilation testing was divided into several test periods, as summarized in Table 4.

Table 4. Summer 2012 Infiltration/Ventilation Testing Schedule

Period	Dates	West		East		Moisture Loading Level	Good Data Quality?
		Infiltration	Mechanical Ventilation?	Infiltration	Mechanical Ventilation?		
I	5/10–6/21	Tight	No	Moderate[3]	No	Low	Yes
II	6/23–7/31	Tight	No	Moderate	No	Normal	Yes
–	8/16–8/31	Tight	Yes	Moderate	No	Normal	No
III	9/1–9/13	Tight	Yes	Moderate	No	Normal	Yes
–	9/14–9/30	Tight	Yes	Moderate	No	Normal	No
IV	10/2-10/8	Tight	No	Normal	No	Normal	Yes
V	10/10–10/20	Tight	Yes	Normal	No	Normal	Yes
VI	10/25–11/8	Tight	No	Normal	No	Normal	Yes

The homes began cooling-related testing on April 17, 2012, when the AC systems were both set to 77°F. However, official data collection did not start until May 10, after thermostat calibrations were performed, key measurement thermocouples were installed, and a condensate collection system was installed.

From May 10 to August 15, the buildings were operated with no supplemental ventilation. During period I, from May 10 to June 21, the internal moisture release level was half that estimated (6 lb/day released) to examine how reduced internal moisture gain would influence cooling season performance.

During period II, June 23 to July 31, the released moisture level was increased back to the normal level of 11 lb/day. As the exact level of internal moisture in Florida residential buildings remains uncertain, this variation likely spans the possible variation in moisture generation due to lower occupancy.

Beginning August 16, the tighter west building began an alternating schedule of forced ventilation and no ventilation. However, installation and debugging of the ventilation system and the CO_2 tracer gas dosing systems caused the August data to be unreliable.

During period III, September 1–13, the west building operated with continuous forced ventilation. During the second half of September, it was intended for the west building to operate without ventilation. However, the ventilation system was somehow triggered on for 4 days inadvertently during this period, making the data from this period largely unusable.

On October 1, the error with the vertical plane leakage rate in the east building was altered to the intended configuration with the leakage in the vertical sides of the building restored. This had a large impact in the resulting building air leakage and air change rate.

During periods IV and VI, October 2–8 and October 25 to November 8, the west home was unvented. During period V, October 10–20, the west home operated with forced ventilation.

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[3] Moderate leakage is 6.8 ACH50 (1,436 CFM50; n = 0.621) with 94% of the leakage located in the ceiling plane; Normal leakage for the east unit is 8.0 ACH50 (1,909 CFM50; n = 0.607) with 71% of the leakage located in the ceiling.

3.4   Infiltration Measurements

CO_2 dosing and measurement equipment was installed during August to measure infiltration in the two homes. The dosing equipment (Dakota Instruments, INC model 6AGC1AL5-09CA2) consisted of two parallel CO_2 tanks located in the garage and precisely metered on their release by digital flow meters that are recorded by instrumentation (the calibrated accuracy of the dosing equipment was 0.4%). Measurements came from Velaire CO_2 transmitters (Ventostat 8000) with a stated full-range accuracy of $\pm 7\%$. However, a secondary calibration was performed with the result that the instrument was responding within an accuracy of $\pm 2\%$. A single interior transmitter was located at the center of each building. Type-T copper-constantan thermocouples are used to measure temperatures against a platinum reference junction on the Campbell data logger. Full range accuracy of the differential measurements is +0.2°F. Humidity measurements are made using Vaisala HMP50 transmitters with a stated accuracy of + 3% from 0%–90% RH. Power is measured by WattNode WNB-3D-240P Watt hour transmitters using revenue-grade current transducers with an accuracy of 0.5%. Texas Instruments TR-525i tipping buckets are utilized to introduce interior moisture as well as to measure air conditioner condensate with a 1% volumetric accuracy. Instruments were scanned each 10 s with integrated averages obtained every 15 minutes.

Ambient outdoor CO_2 sensors were also installed. Because the buildings are unoccupied, it is possible to measure the building infiltration rate using a known CO_2 gas emission rate as a tracer gas. The rise in the concentration of indoor CO_2 can be used to then estimate the building infiltration and ventilation rates with outdoor air based on calculated dilution to produce the observed concentration. An initial problem with this setup was experienced when it became apparent that the outdoor CO_2 sensor had to be quite remote from the homes to prevent the effluent CO_2 from the leaking buildings from corrupting the reference outdoor CO_2 measurement. This was corrected by moving the sensor 20 ft away at a height of 10 ft.

The dosing and monitoring equipment was installed during August, and because of issues with the monitoring and ventilation equipment, reliable CO_2 data were not available until October 1.

5   Summer Infiltration and Ventilation Test Result

5.1   Measured Outdoor and Indoor Temperature and Moisture Conditions

Figure 5 through Figure 9 show the time series data of the hourly observations taken at the FRTF during the entire summer. Dashed vertical lines divide the period into the various test periods that are summarized in greater detail below.

Figure 5 shows the hourly dry bulb outdoor temperatures superimposed against the measured interior temperatures at the thermostat in each building. The x-axis is the Julian date during the period stretching from day 131 (May 10) to 313 (November 8). Note that the temperatures maintained at the thermostat remained very close to the target of 78°F with the exception of the cooler period at the end of the summer period in early November. It is also noteworthy that even during the hottest part of summer, the ambient air temperature is often lower than the thermostat set point temperature during evening hours—a fact with ramifications for the impact of infiltration and ventilation in Florida's climate.
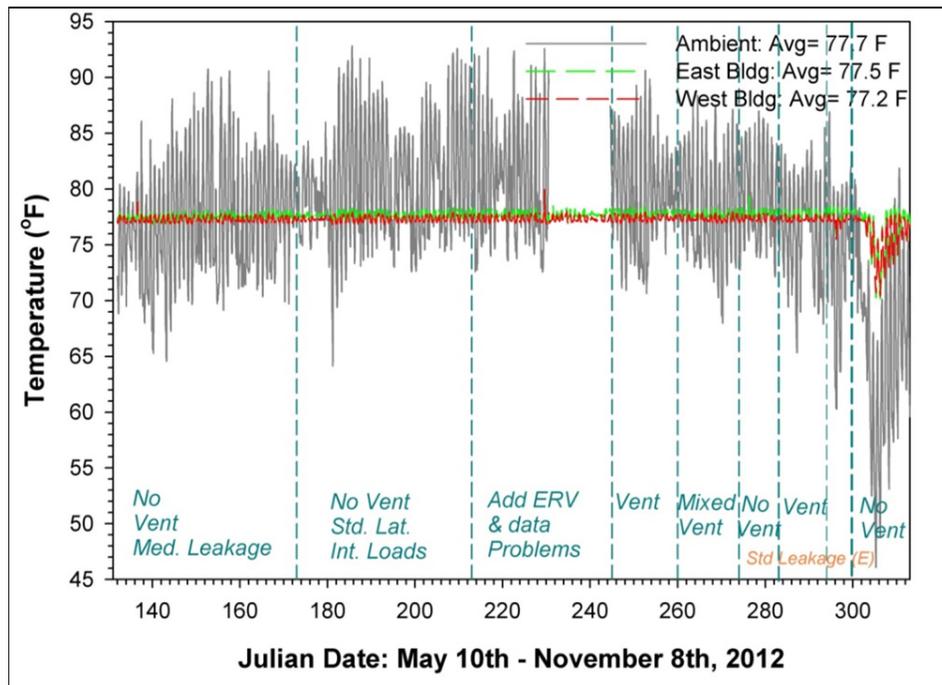
Figure 5. Outdoor ambient air temperature and interior temperature by the interior thermostat in the two test buildings during the entire summer

Figure 6 shows the same description of the summer period, but indicates the indoor RH in the two test buildings. It is readily seen that the indoor RH with ongoing AC of the buildings was typically 38%–51% during the time before forced ventilation was added. However, it is clear from the data that the indoor RH approached 60% beginning in August in the west building when 63 CFM of outdoor air was introduced. The RH becomes much higher in early November (65% or more) when the need for AC ends.
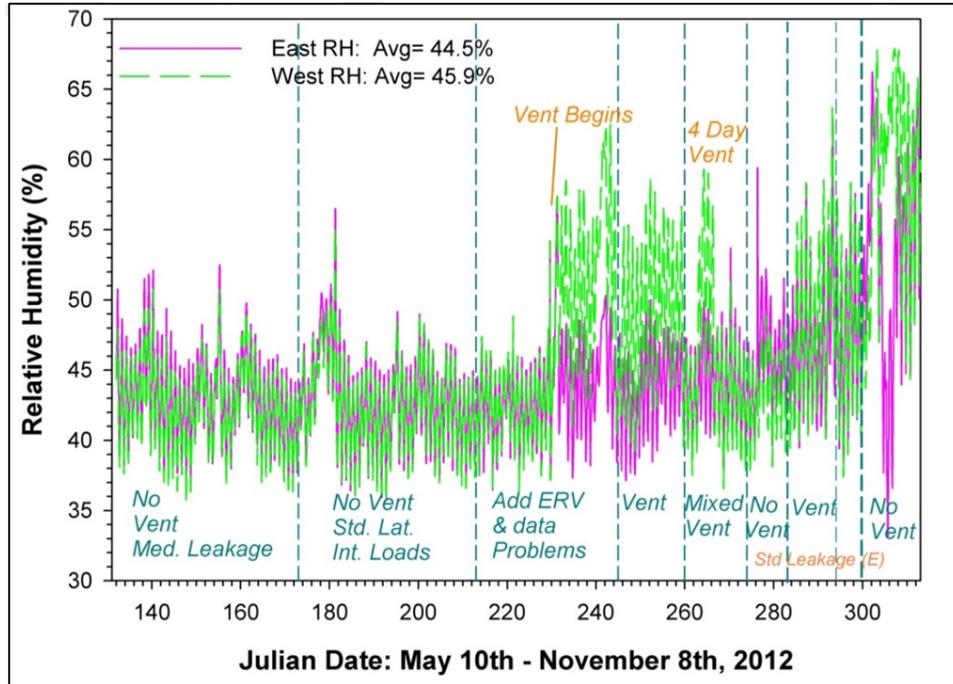
Figure 6. Measured indoor RH by the thermostat in the two test buildings during the entire summer

Figure 7 shows the dew point temperature outdoors and indoors in the two buildings during the summer monitoring period. Unlike the RH values shown in Figure 6, the dew point temperatures indicate the absolute moisture content of the air. As before, we see little influence of the lower or standard interior moisture loads on the achieved interior dew points, which are demonstrably much lower in moisture content than that seen outdoors. This is because the vapor compression AC system largely removes the additional moisture, as shown in Figure 8 where condensate flow rates were considerably elevated at the higher internal moisture release rate. Thus, the interior air and cooling machine characteristics reach equilibrium with the interior absolute moisture level by operating longer with slightly longer runtimes. This is consistent with published research on the operation characteristics of unitary air conditioners (Henderson and Rengarahan 1996).
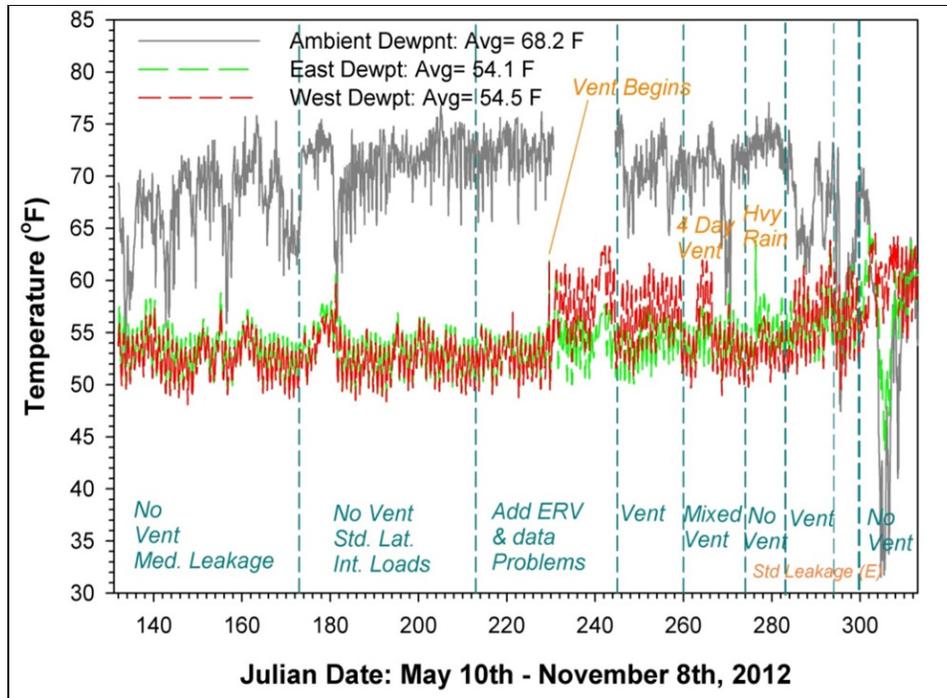
Figure 7. Measured indoor and outdoor dew point temperatures in the two test buildings during the entire summer
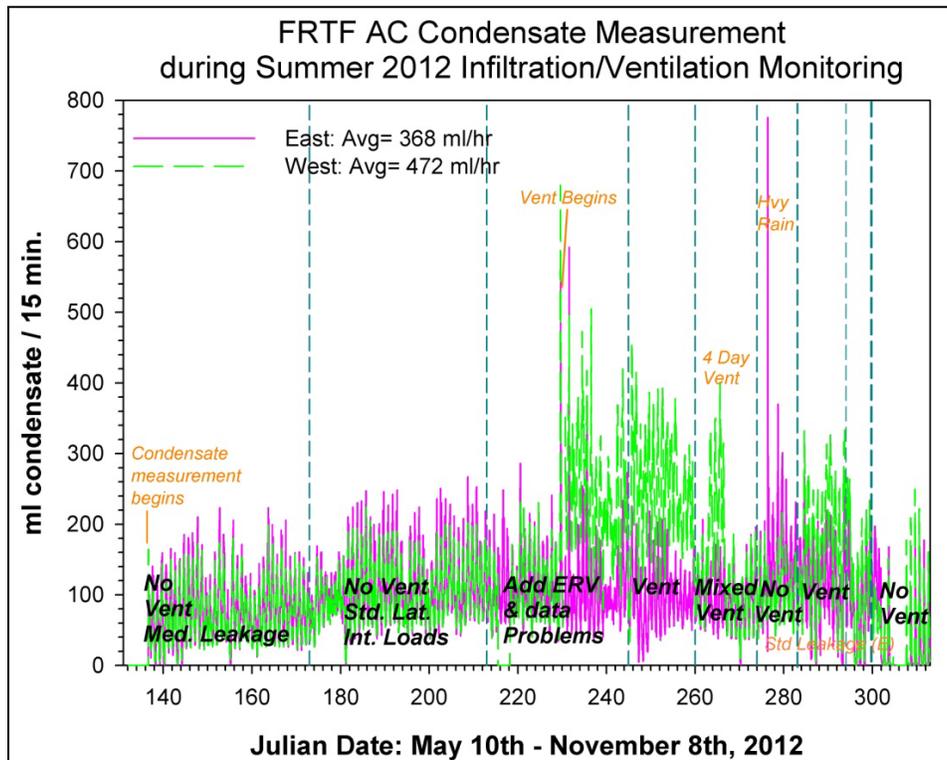
Figure 8. Measured air conditioner condensate in the two test buildings during the entire summer

However, we also see a pronounced impact from the addition of forced ventilation in the west building beginning in mid-August. The interior dew points are typically elevated by 3°F or more. Later in October, we can see that during a no-vent period, the tighter west building has lower interior moisture than the east home during a period with heavy rainfall. On the other hand, at the end of the monitoring period in early November, when the outdoor dew points are much lower than those indoors and there is no longer much need for AC, the leakier east test building achieves lower interior moisture levels by its greater air infiltration during this period.

Figure 8 shows the measured air conditioner condensate volume measured each hour during the monitoring period. Here, we can see that when the internal moisture level is raised to 11 lb/day in late June, both air conditioners remove more moisture, which largely explains the fact that the measured interior dew points in Figure 7 were largely stable. However, we do clearly see that when forced ventilation begins in the west building in August, the measured condensate that is collected increases significantly. Further, during the non-ventilation period from October 2–8, when there were heavy rains, we see the leakier east building with greater removed condensate. Finally, we see the collected condensate drop dramatically in both buildings in the final test period at the end of the Central Florida cooling season in early November 2012.

5.2   Energy Comparison

The measured air conditioner and air handler compressor power was continuously measured during the test period to evaluate how measured cooling energy use was influenced by building air leakage and mechanical ventilation. Average summer AC from May 1 to September 30 averaged 23.4 kWh/day in the east building and 24.4 kWh/day in the west building.

The final time series plots in Figure 9 show the measured hourly AC during the summer. The power consumption of the 74 Watt ventilation fan is plotted separately in blue. The nature of the "on-off" power consumption data of the single-speed air conditioner during this time makes it impossible to discern trends other than the fact that the needed cooling energy drops rapidly towards the end of summer. However, as shown in the tabular and graphical data summaries that follow for the various periods, it is possible to see some influences when the data are summarized as power demand profiles over the 24-hour time domain during each test period.
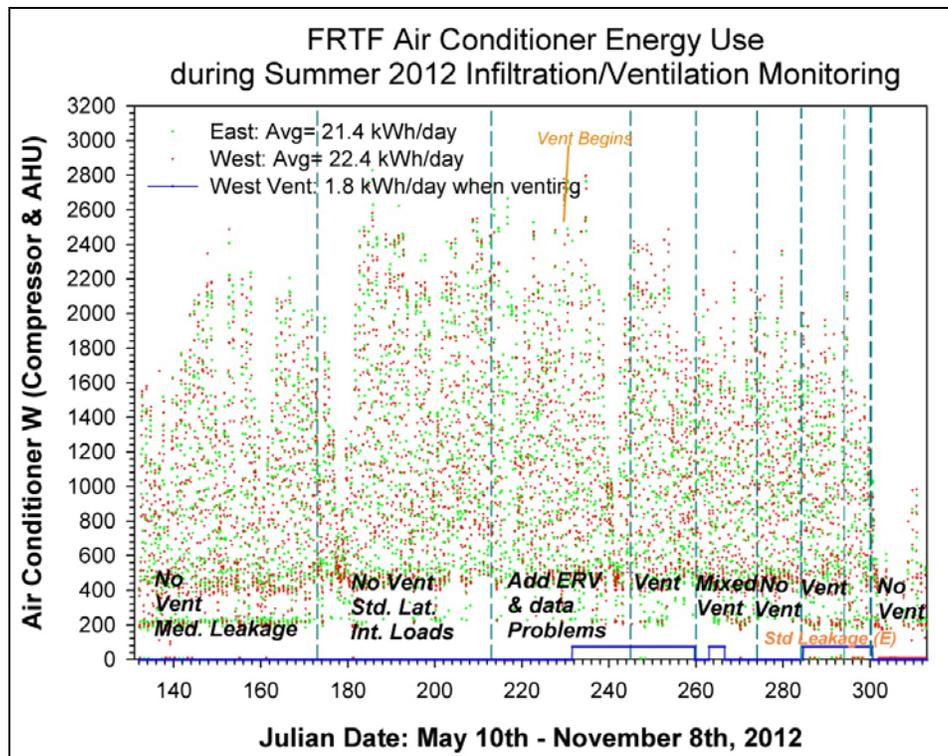
Figure 9. Measured air conditioner and ventilation system power in the two test buildings over the entire summer

5.3 Evaluation During Individual Test Periods

From April 17 to August 16, and periodically from August 16 to October 24, the west home was operated with no mechanical ventilation to compare the performance of a very tight home to a leaky home.

Beginning August 16 (roughly every other 2–3 weeks), the west home was ventilated using an energy recovery ventilation system to evaluate the energy and moisture impacts of forced ventilation in a tight home. However, due to a variety of issues (a CO_2 tracer gas system was being installed in the building during August), the first consistently operated ventilation period was from September 1–13, 2012. The second valid period with ventilation was during the cooler period from October 9–23. The contrasting non-ventilated period was from October 25 to November 13, at which point the cooling season experiments were declared over.

5.3.1 Test Period I: May 10 to June 21, 2012

Test data were taken during the first evaluation period of the summer (Table 5) with a lower internal moisture release rate of 6 lb/day. As internal moisture rates are uncertain, this lower rate would represent the lowest rate of moisture generations associated with human respiration, bathing, and cooking. There was little difference observed between the east building with moderate leakage and the much tighter west building. Air conditioner power was very similar in the two buildings, as were the interior moisture indicators: RH averaged 42%–43% with interior dew points of about 53°F. The various summarized performance indices are shown in Figure 10 through Figure 13.

Table 5. May 10 to June 21, 2012 (Natural Air Infiltration, Low Moisture Generation)

	East	West	Δ	%
Thermostat Temperature (°F)	77.5°	77.3°	−0.2	−0.4
RH (%)	43.0%	42.4%	−0.6	−1.4
Dew Point (°F)	53.3°	52.6°	−0.7	−1.3
Condensate (L/day)	6.81	6.25	−0.56	−8.2
Air Conditioner Power (kWh/day)	19.70	21.00	+1.34	+6.8
	Average	**Minimum**	**Maximum**	
Ambient Temperature (°F)	77.4°	64.6°	90.7°	−
Ambient RH (%)	72.9%	36.6%	95.0%	−
Ambient Dew Point (°F)	67.3°	52.0°	75.8°	−

Generally, the data showed that when AC is consistent, with the distribution of leakage in our test buildings, building tightness does not appear a large factor influencing either cooling energy use or interior moisture levels. This is not surprising, for as shown in Figure 10, the temperature outside in the May–June time frame is as often lower outside as it is higher for much of the day. This influence is seen graphically in Figure 10 where the energy use in the tighter west building is lower during the hottest part of the day, but higher during the cooler nighttime hours. Thus, greater building leakage is not likely a large factor in energy use. The only seen influence was that the interior RH in the looser east building was about 0.5% higher (statistically insignificant at the accuracy of the measurement), with about an 8.2% increase in the AC condensate collection during the period.
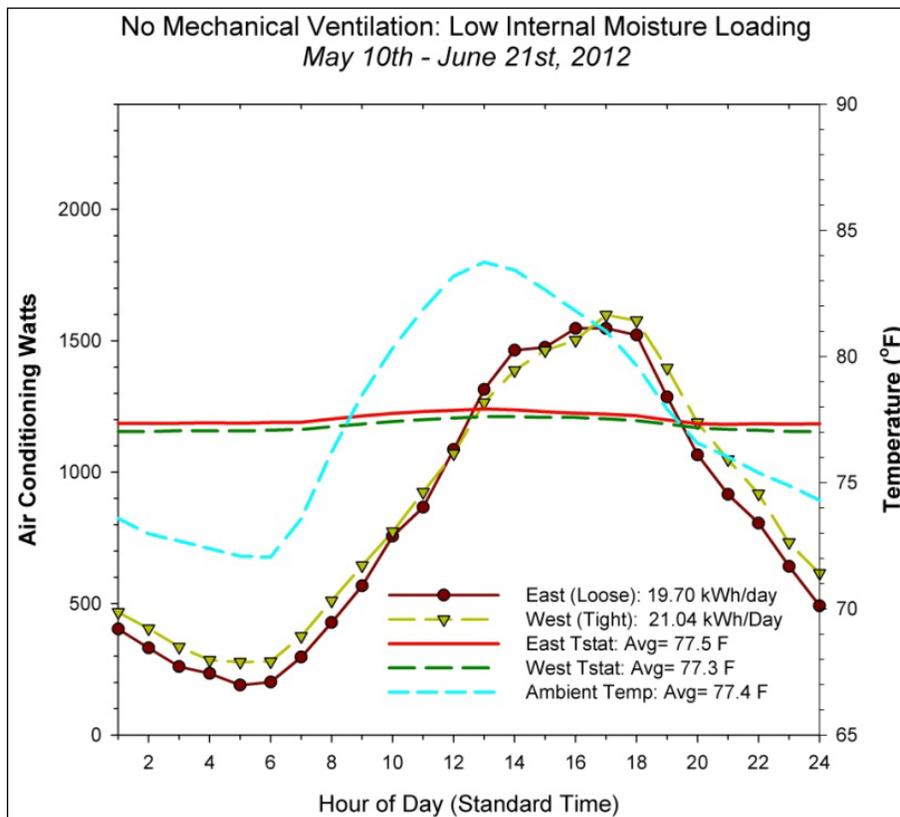
Figure 10. AC energy use, May 10 to June 21, 2012: natural infiltration, low moisture release
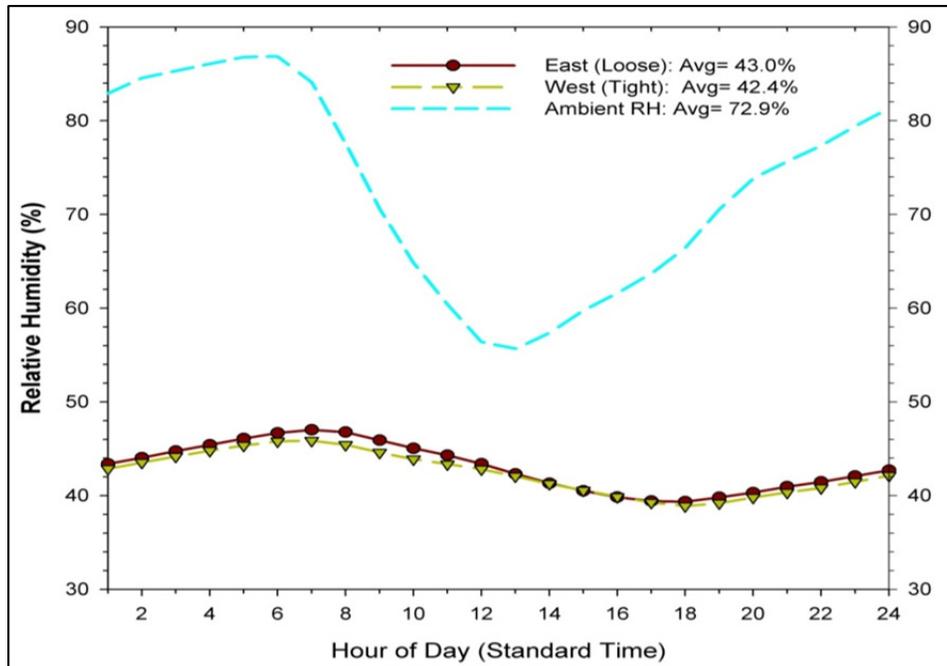
Figure 11. Comparative RH, May 10 to June 21, 2012: natural infiltration, low moisture release
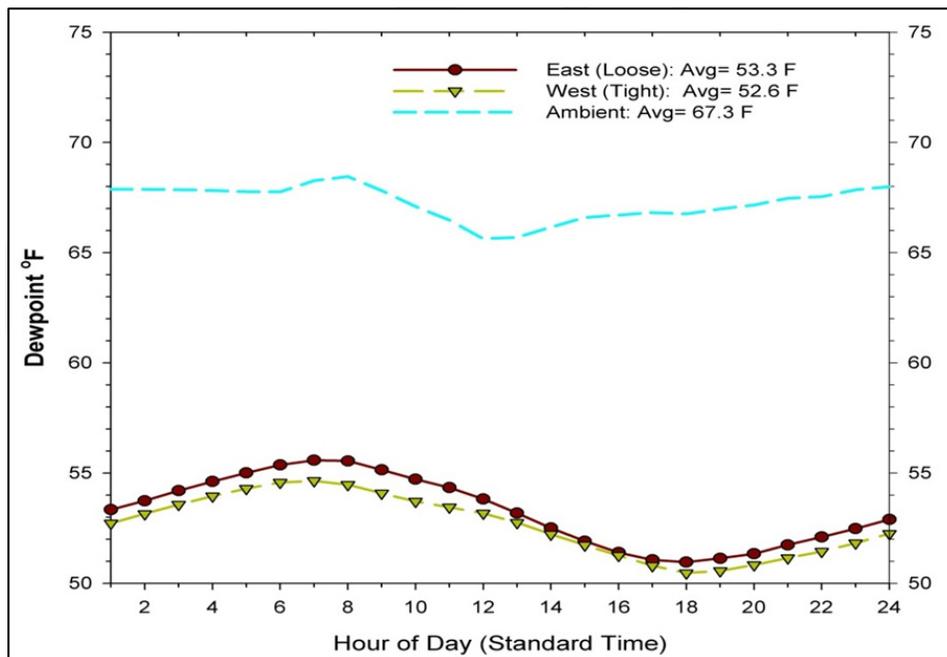
**Figure 12. Comparative dew point temperatures, May 10 to June 21, 2012:
natural infiltration, low moisture release**

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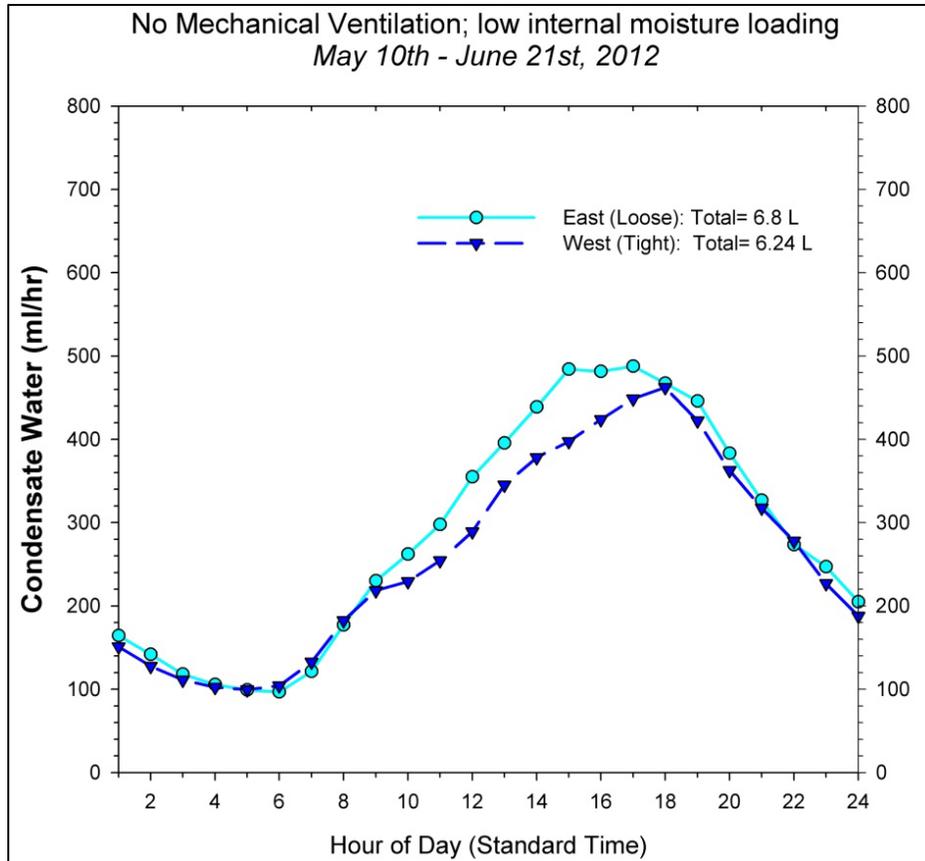
**Figure 13. Comparative condensate removal, May 10 to June 21, 2012:
natural infiltration, low moisture release**

5.3.2   Test Period II: June 23 to July 31, 2012

The period from June 23 to July 31 (Table 6) included a higher internal moisture generation level
for the two test buildings than the first test period (11 lb/day of moisture versus 6 lb/day in May).
This rate is in general agreement with the recommended levels within the Building America field
test protocol (Fang et al. 2011), although considerably lower than the design levels suggested by
the ASHRAE 160 Standard (ASHRAE 2009). Even with the higher moisture loading, the data
showed similar interior temperatures, RHs, and dew points in the two test buildings. Collected
condensate was also similar in the two structures, but considerably higher than the earlier May
period by about 4 L/day. Air conditioner power use was also very similar in the structures with
no significant differences within the period.

Table 6. June 23 to July 31, 2012 (Natural Air Infiltration, Standard Moisture Generation)

	East	West	Δ	%
Thermostat Temperature (°F)	77.7°	77.3°	–0.4	–0.5
RH (%)	42.8%	42.6%	–0.2	–0.4
Dew Point (°F)	53.2°	52.7°	–0.5	–0.9
Condensate (L/day)	10.62	10.35	–0.27	–2.5
Air Conditioner Power (kWh/day)	27.64	28.30	+0.66	+2.4
	Average	**Minimum**	**Maximum**	
Ambient Temperature (°F)	80.7°	64.1°	92.8°	
Ambient RH (%)	74.6%	36.7%	94.2%	
Ambient Dew Point (°F)	71.2°	56.1°	76.8°	

The key differences from the May test period were higher collected condensate and much higher air conditioner power—about 7 kWh (+40% and +35% in the east and west structures, respectively). A portion of the increase was due to the higher latent loads (approximately 9,000 Btu/day), but most was due to the naturally increasing sensible loads during the hottest weather during test period II. The fact that the interior RHs and dew points did not change appreciably is coincidental and due to the approximately 40% longer runtimes seen during the latter period, which removed much more moisture as evidenced by the condensate differences. The various summarized performance indices are shown in Figure 14 through Figure 17.
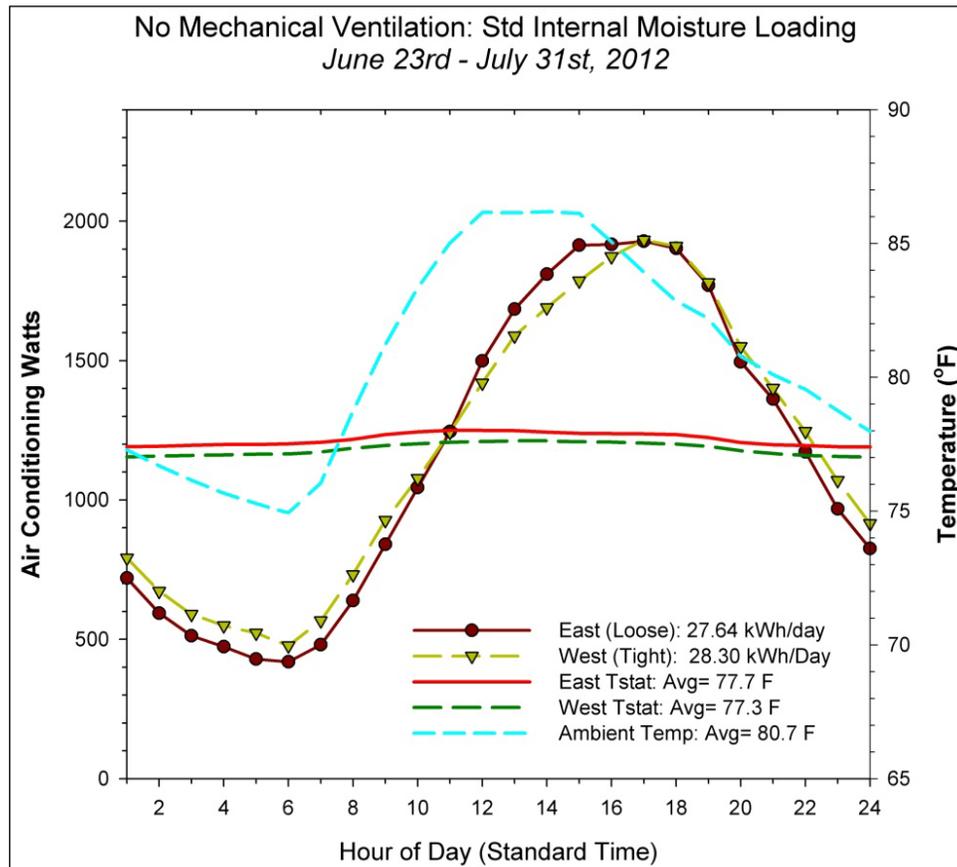
Figure 14. AC energy use, June 23 to July 31, 2012: natural infiltration, standard moisture release
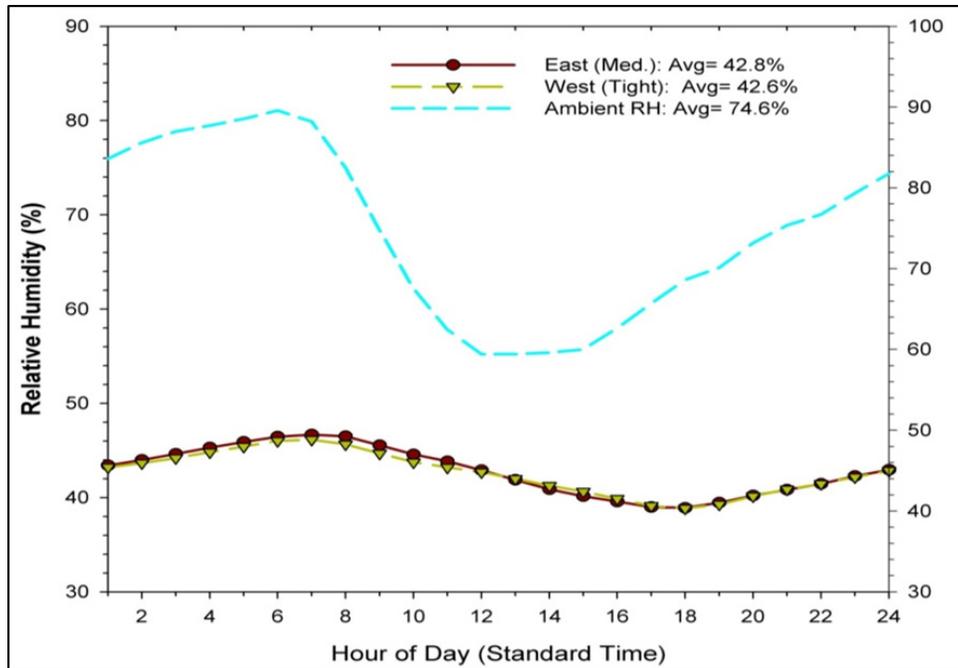
Figure 15. Comparative RH, June 23 to July 31, 2012: natural infiltration, standard moisture release
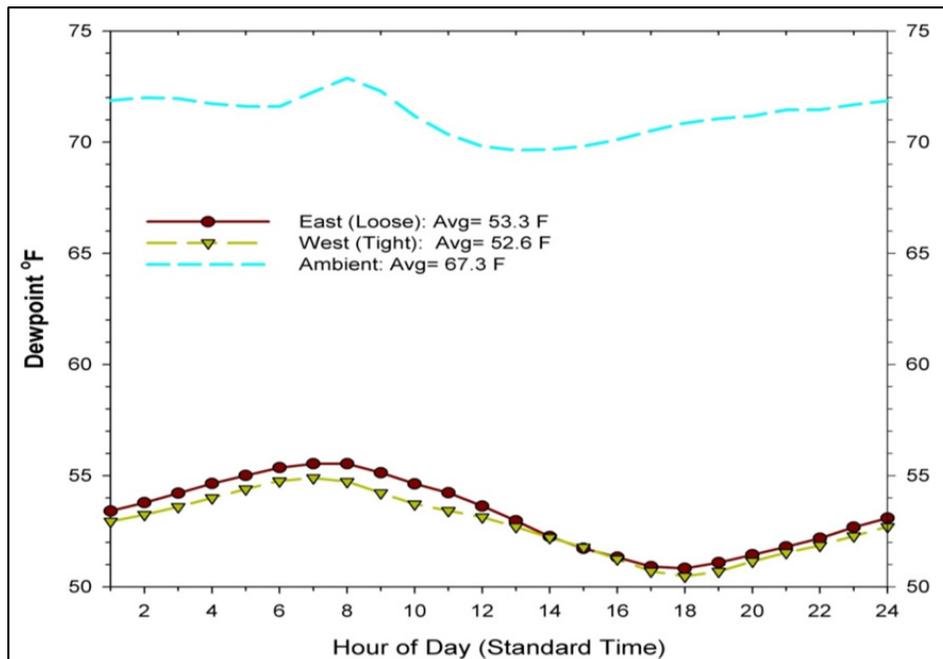

Figure 16. Comparative dew point temperatures, June 23 to July 31, 2012: natural infiltration, standard moisture release
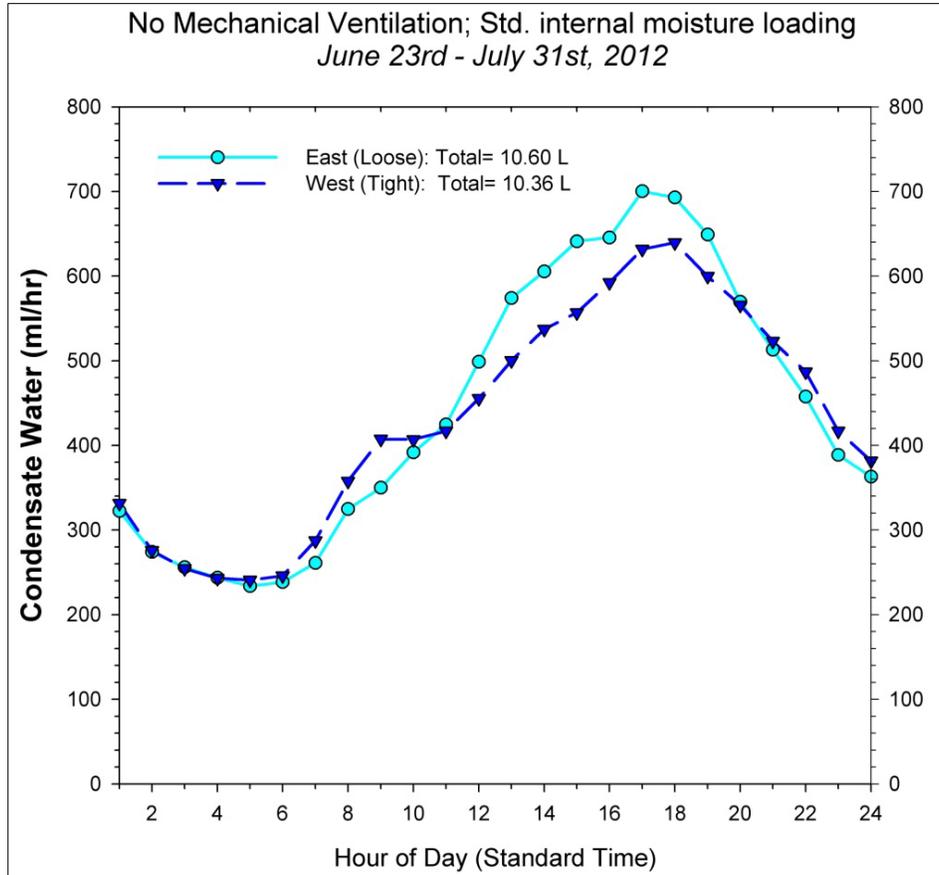
Figure 17. Comparative condensate removal, June 23 to July 31, 2012: natural infiltration, standard moisture release

5.3.3 Test Period III: September 1–13, 2012

The period from September 1–13 (Table 7) featured the first valid data collection period when the ventilation system was active in the tighter west building. While temperature conditions by the thermostat were similar, the ventilated west building experienced higher interior moisture levels. This was evidenced by the interior RH, which averaged nearly 6% higher during the test period, and an interior dew point that was elevated by 3°F. The collected condensate moisture during the test was more than doubled in the ventilated building: 8.9 versus 24 L/day. This represents a latent heat of approximately 50,200 Btu/day or about 4.9 kWh/day at a coefficient of performance of 3.0. Closely mirroring these approximations, the air conditioner power was increased by 23% (5.2 kWh/day) and by 30% (7.0 kWh/day) when the power of the ventilation fan was included. This result is not surprising as simulation research on the moisture impacts of ASHRAE Standard 62-2004 (Walker and Sherman 2007) indicated that compliant mechanical ventilation systems would increase interior humidity levels by 5%–10% in homes in humid climates. Further, empirical research by Rudd and Henderson (2007) found that homes with mechanical ventilation in humid climates without supplement dehumidification experienced higher interior moisture levels. The various summarized performance indices are shown in Figure 18 through Figure 21.

Table 7. September 1–13, 2012 (West Unit Vented)

	East	West	Δ	%
Thermostat Temperature (°F)	77.8°	77.4°	–0.4	–1.8
RH (%)	43.5%	49.2%	+5.7	+13.1
Dew Point (°F)	53.8°	56.8°	+3.0	+5.6
Condensate (L/day)	8.94	23.99	+15.06	+168.4
Air Conditioner Power (kWh/day)	22.90 kWh	29.88 kWh	+7.00	+30.5
	Average	**Minimum**	**Maximum**	
Ambient Temperature (°F)	79.5°	70.6°	90.6°	
Ambient RH (%)	74.9%	47.3%	94.5%	
Ambient Dew Point (°F)	70.3°	64.0°	75.6°	
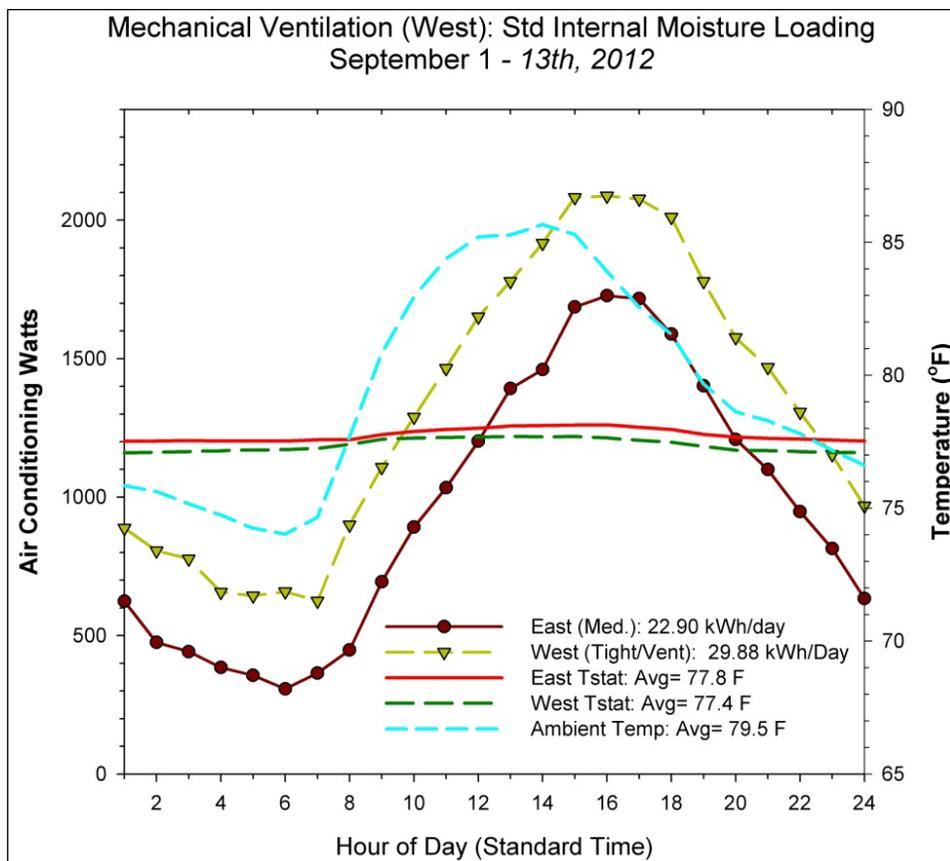
Figure 18. AC energy use, September 1–13, 2012: west ventilated
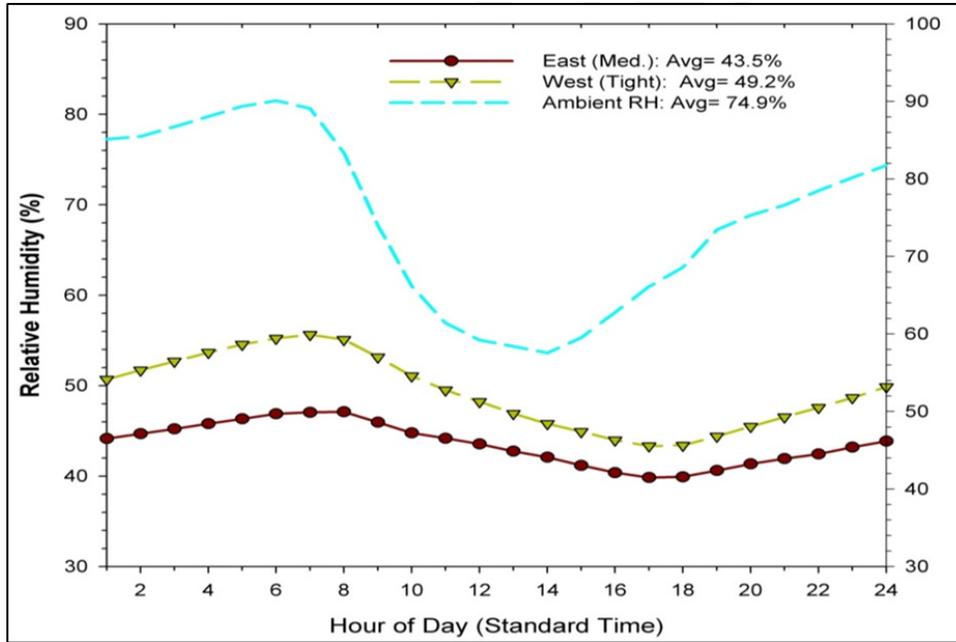
Figure 19. Comparative RH, September 1–13, 2012: west ventilated
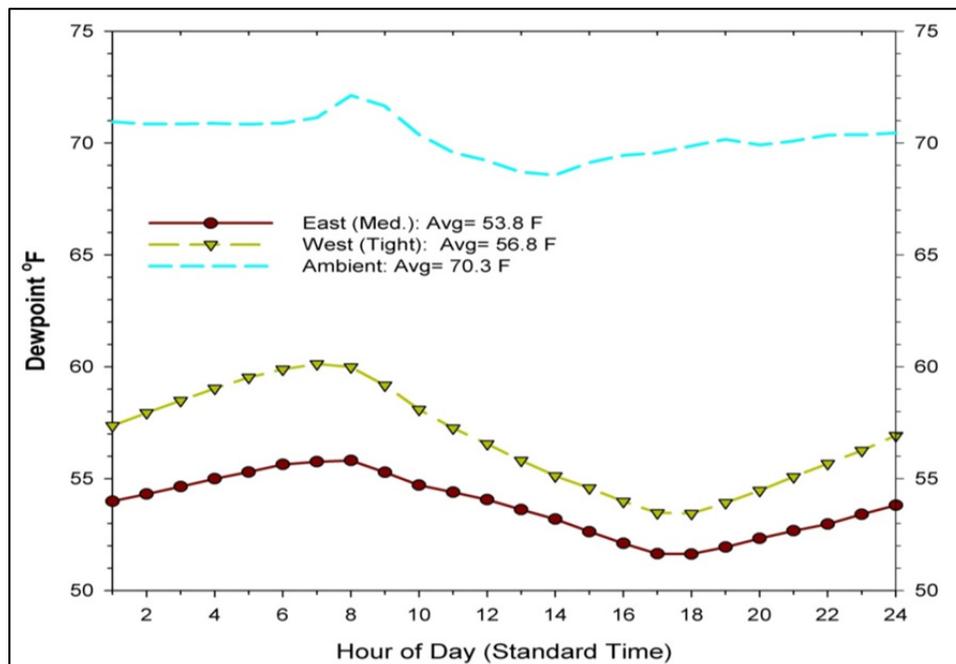
Figure 20. Comparative dew point temperatures, September 1–13, 2012: west ventilated

23
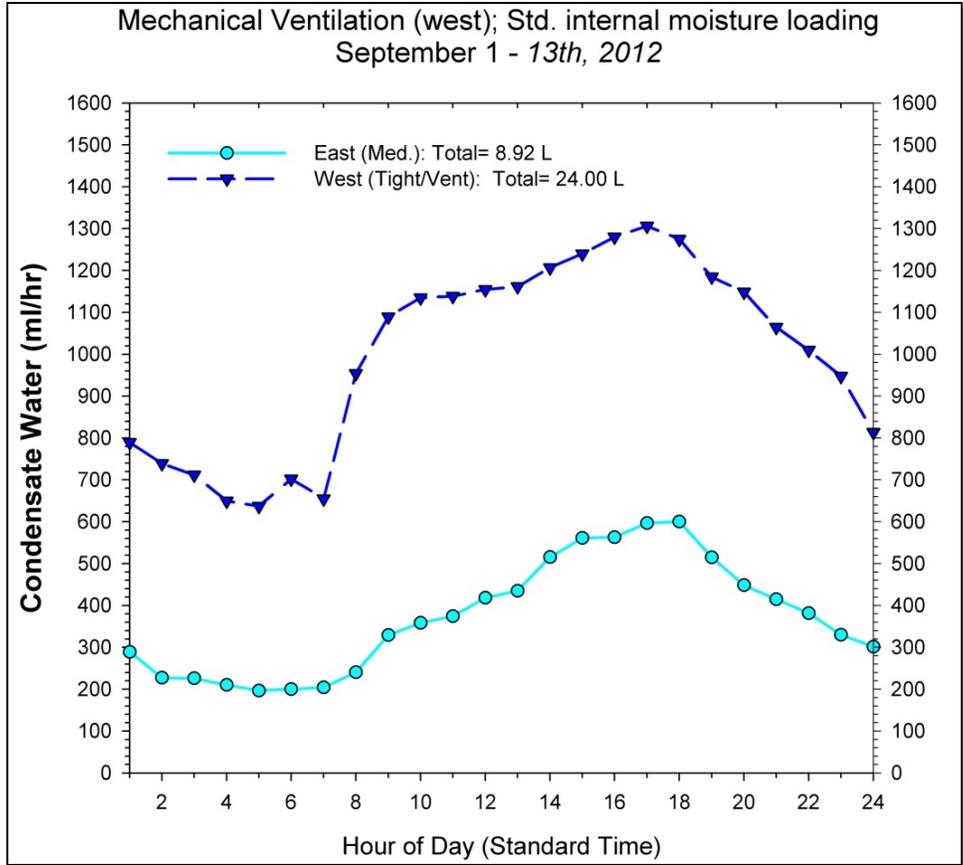
Figure 21. Comparative condensate removal, September 1–13, 2012: west ventilated

5.3.4   Test Period IV: October 2–8, 2012[4]

The test period the first week in October (Table 8) included the change back to the leaky configuration in the east test building, although with no forced ventilation in the tighter west building. The weather during this period was characterized by such heavy rainfall that the leakier east building actually had higher interior moisture, as indicated by RH, interior dew point, and collected condensate. Air conditioner power was nearly identical in the two buildings. The various summarized performance indices are shown in Figure 22 through Figure 25.

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[4] The prior test period from September 15–30 was intended to be a period when no forced ventilation was used. Unfortunately, the ventilation system was inadvertently activated for 4 days during this period, making it unsuitable for further analysis.

Table 8. October 2–8, 2012 (No Ventilation, East Building Goes to High Leakage)

	East	West	Δ	%
Thermostat Temperature (°F)	77.8°	77.3°	0.5	–0.6
RH (%)	46.3%	43.8%	–2.5	–5.3
Dew Point (°F)	55.5°	53.6°	–1.9	–3.4
Condensate (L/day)	13.68	10.09	–3.59	–26.2
Air Conditioner Power (kWh/day)	22.22	23.28	+1.06	+4.7
	Average	Minimum	Maximum	
Ambient Temperature (°F)	79.0°	72.1°	87.0°	
Ambient RH (%)	82.6%	60.1%	95.1%	
Ambient Dew Point (°F)	73.0°	68.3°	77.1°	
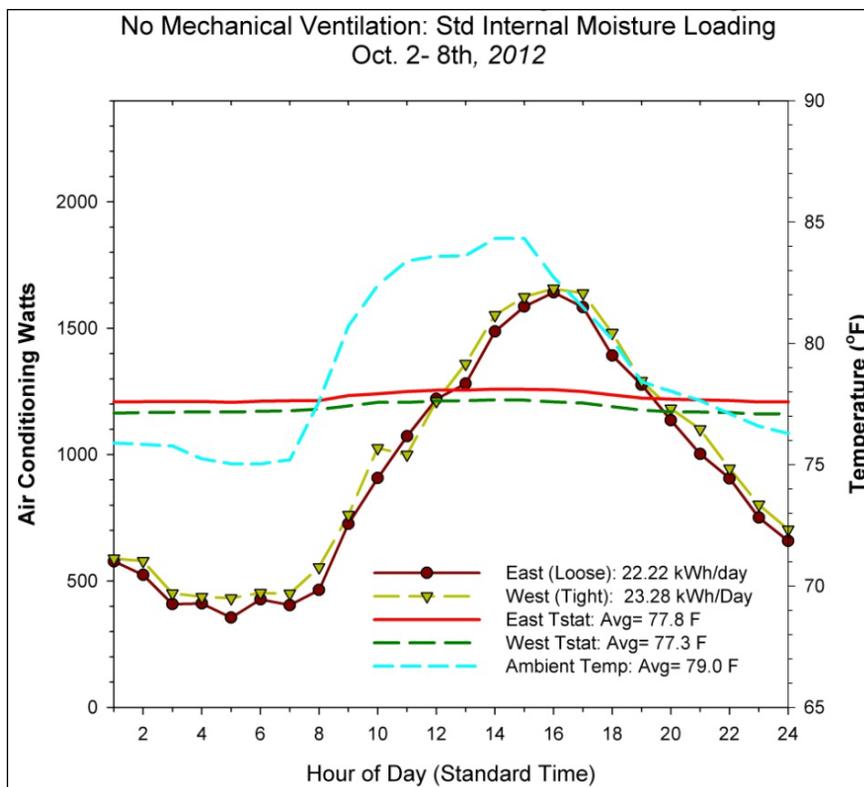
Figure 22. AC energy use, October 2–8, 2012: no ventilation, east building goes to high leakage
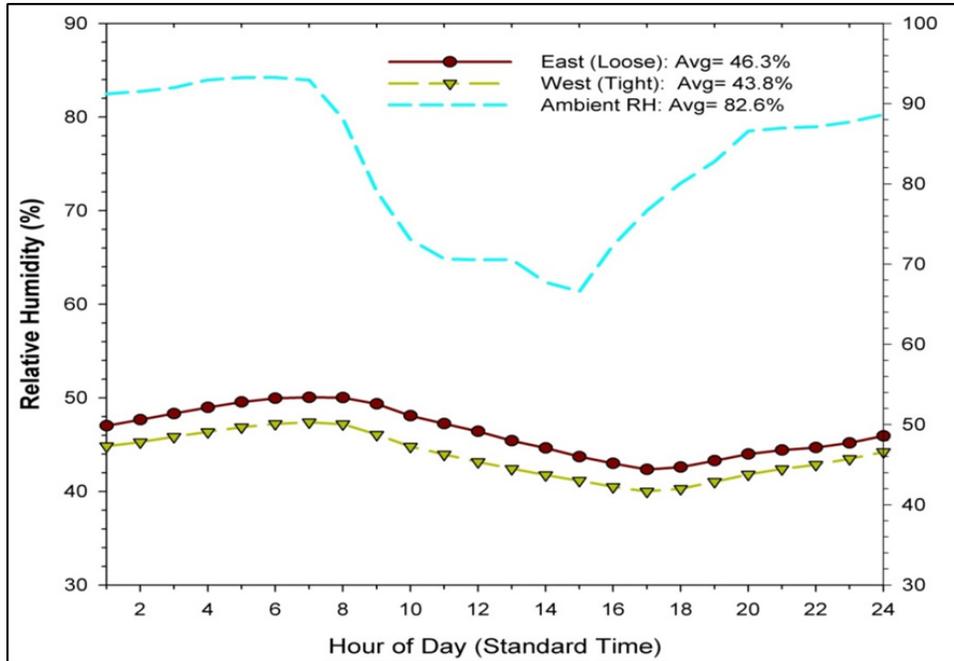
Figure 23. Comparative RH, October 2–8, 2012: no ventilation, east building goes to high leakage
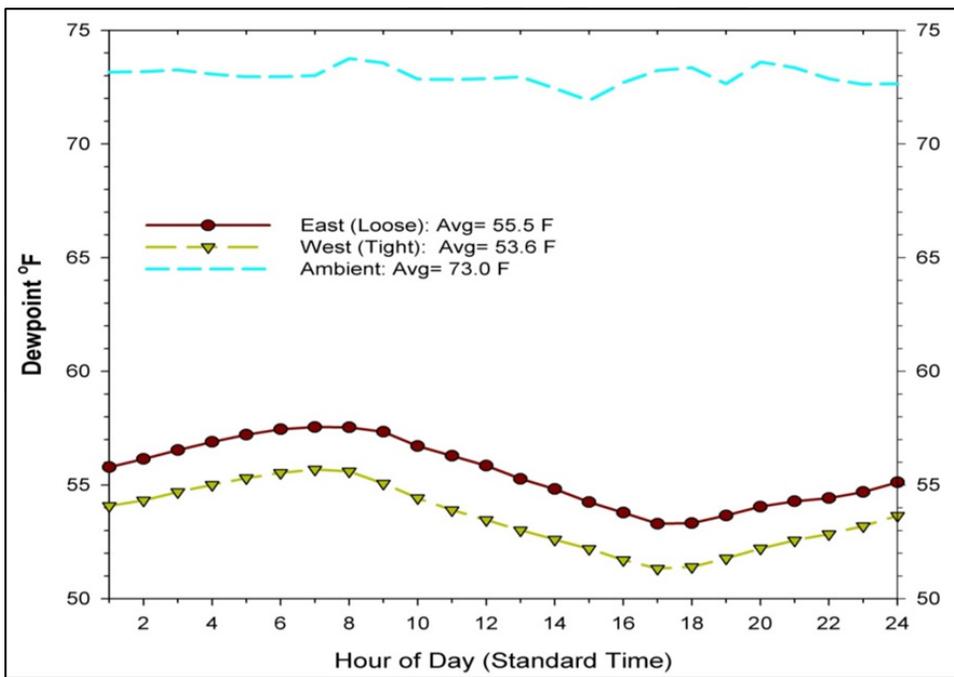
Figure 24. Comparative dew point temperatures, October 2–8, 2012: no ventilation, east building goes to high leakage
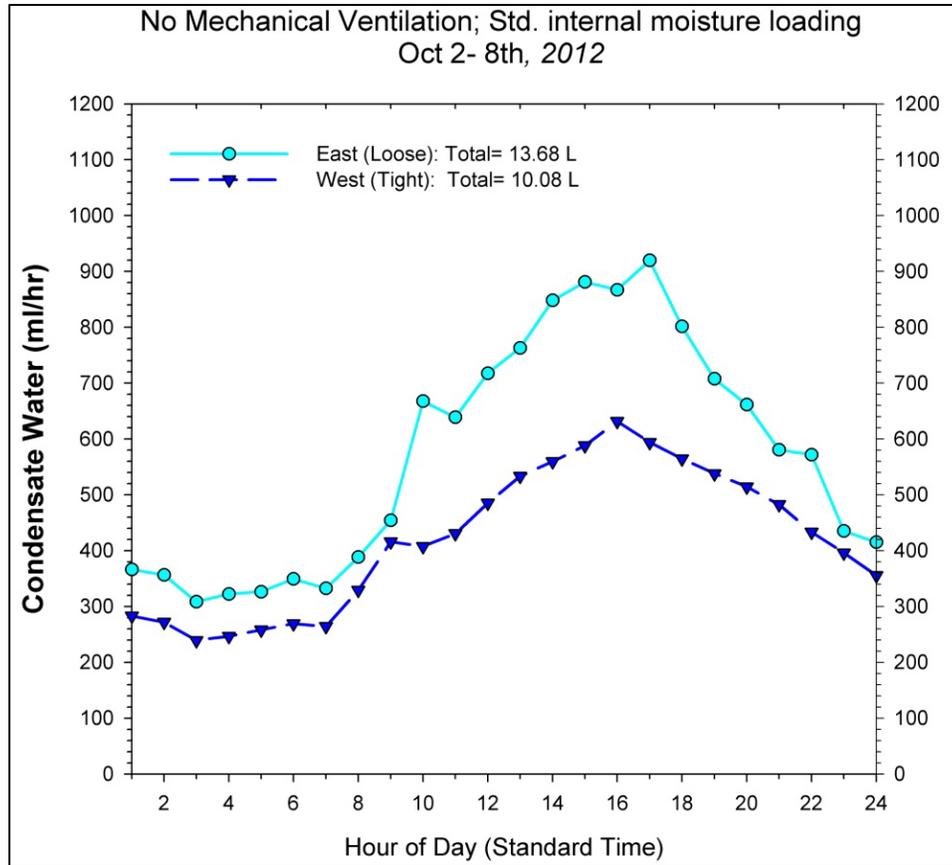
Figure 25. Comparative condensate removal, October 2–8, 2012: no ventilation, east building goes to high leakage

5.3.5 Test Period V: October 10–20, 2012

The period from October 10–20 (Table 9) was during a weather pattern when cooling loads were dropping rapidly, while the ventilation system was operated in the tighter west building. While interior temperature conditions were similar in both buildings, the ventilated building had higher moisture levels: +2.2% RH, a 1°F higher interior dew point, and 60% higher condensate removal by the AC system. Combined AC and ventilation system power was 4.7 kWh/day higher than with the leakier east building—an increase of 27%. The various summarized performance indices are shown in Figure 26 through Figure 29.

Table 9. October 10–20, 2012 (West Unit Vented)

	East	West	Δ	%
Thermostat Temperature (°F)	77.6°	77.3°	–0.3	–0.4
RH (%)	46.9%	49.1%	+2.2	+4.7
Dew Point (°F)	55.7°	56.6°	+1.1	+2.0
Condensate (L/day)	10.30	16.82	6.53	+63.4
Air Conditioner Power (kWh/day)	17.72	22.44	+4.72	+26.6
	Average	**Minimum**	**Maximum**	
Ambient Temperature (°F)	76.2°	62.2°	86.9°	
Ambient RH (%)	72.0%	31.9%	95.2%	
Ambient Dew Point (°F)	65.7°	47.4°	73.3°	

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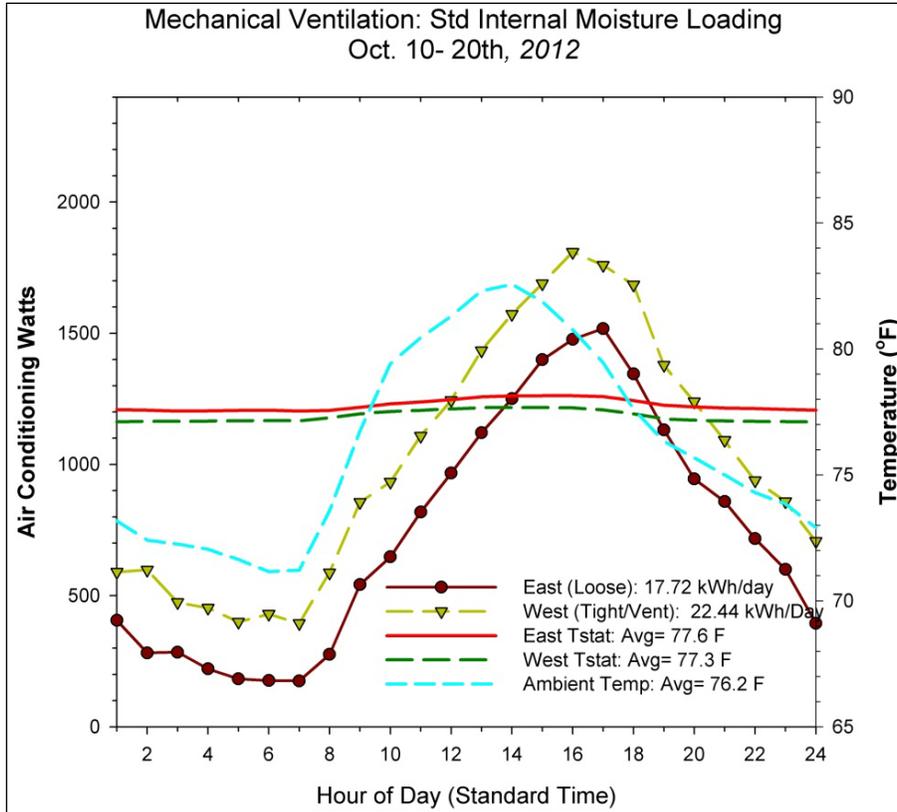
Figure 26. AC energy use, October 10–20, 2012: west unit vented
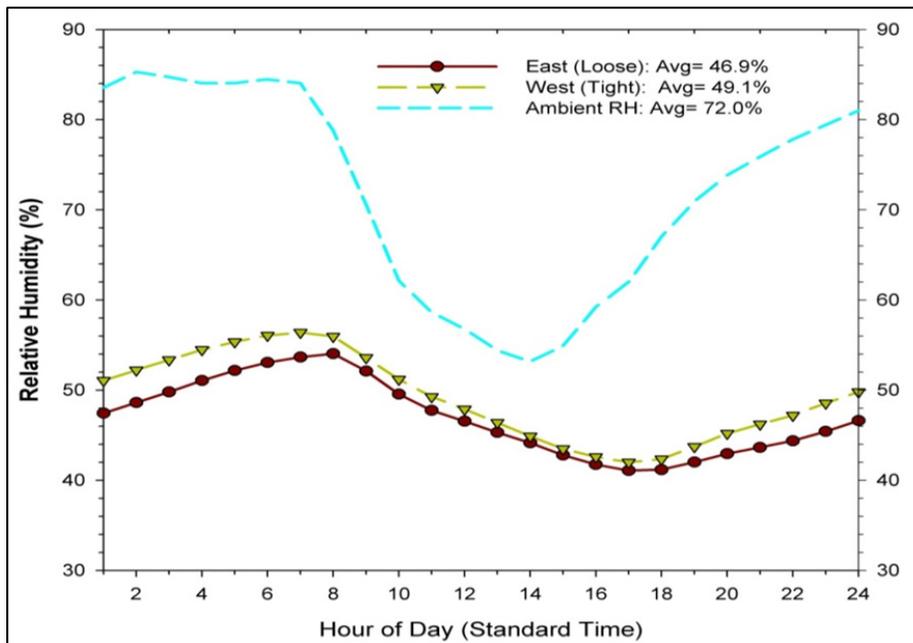
Figure 27. Comparative RH, October 10–20, 2012: west unit vented
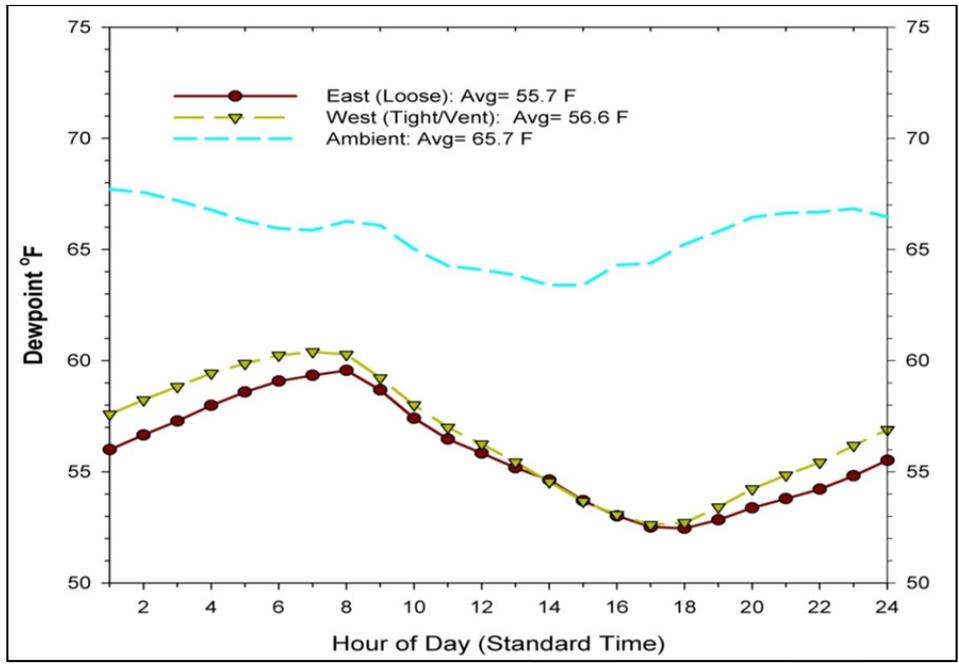
Figure 28. Comparative dew point temperatures, October 10–20, 2012: west unit vented
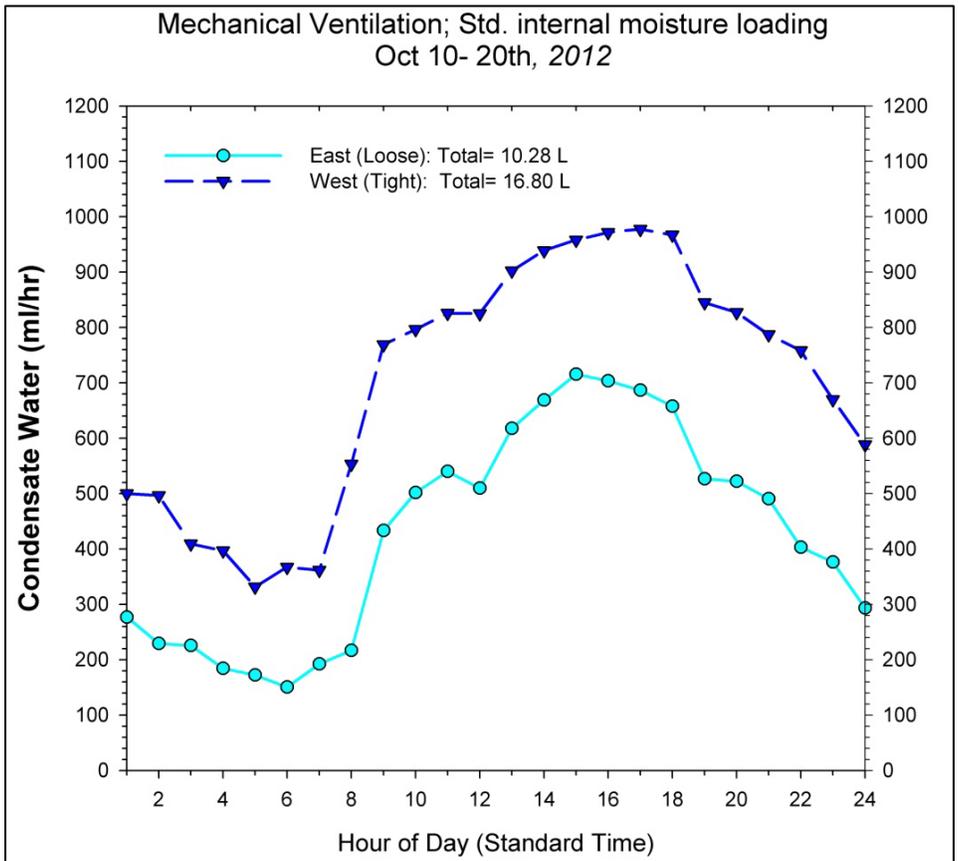
Figure 29. Comparative condensate removal, October 10–20, 2012: west unit vented

5.3.6 Test Period VI: October 25 to November 8, 2012

The final test period came at the end of the cooling season in 2012 (Table 10) ending on November 8. The ventilation system in the tighter west building was off for the entire time, and AC averaged 1.5 to 1.7 kWh/day in the east and west buildings, respectively. The lower cooling use in the looser building is expected, as it was actually cooler outside than inside during the test. As seen in the testing in winter 2011–2012, the tighter unventilated building had much higher humidity levels: 59% versus 53% RH and a dew point of 60°F versus 57°F. Collected condensate was low, as the AC system seldom operated during this 14-day period. Because it was drier outside than inside, the leakier east building yielded lower internal moisture levels created by natural air infiltration. The summarized performance indices during the period are shown in Figure 30 through Figure 33.

Table 10. October 25 to November 8, 2012 (No Ventilation)

	East	**West**	**Δ**	**%**
Thermostat Temperature (°F)	75.8°	75.4°	–0.4	NA
RH (%)	53.1%	59.0%	+6.9	+11.1
Dew Point (°F)	57.3°	60.0°	+2.7	+4.7
Condensate (L/day)	2.57	2.84	+0.27	+10.6
Air Conditioner Power (kWh/day)	2.92	3.46	+0.52	+18.5
	Average	**Minimum**	**Maximum**	
Ambient Temperature (°F)	65.4°	46.1°	81.9°	
Ambient RH (%)	69.4%	26.7%	95.0%	
Ambient Dew Point (°F)	54.0°	31.5°	70.9°	
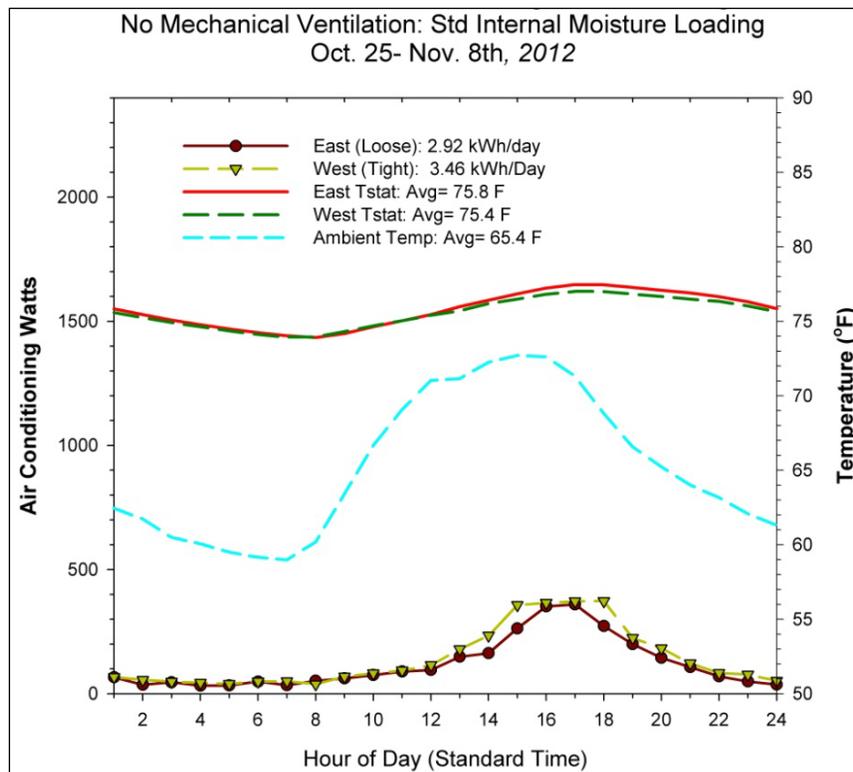
Figure 30. AC energy use, October 25 to November 8, 2012: no ventilation
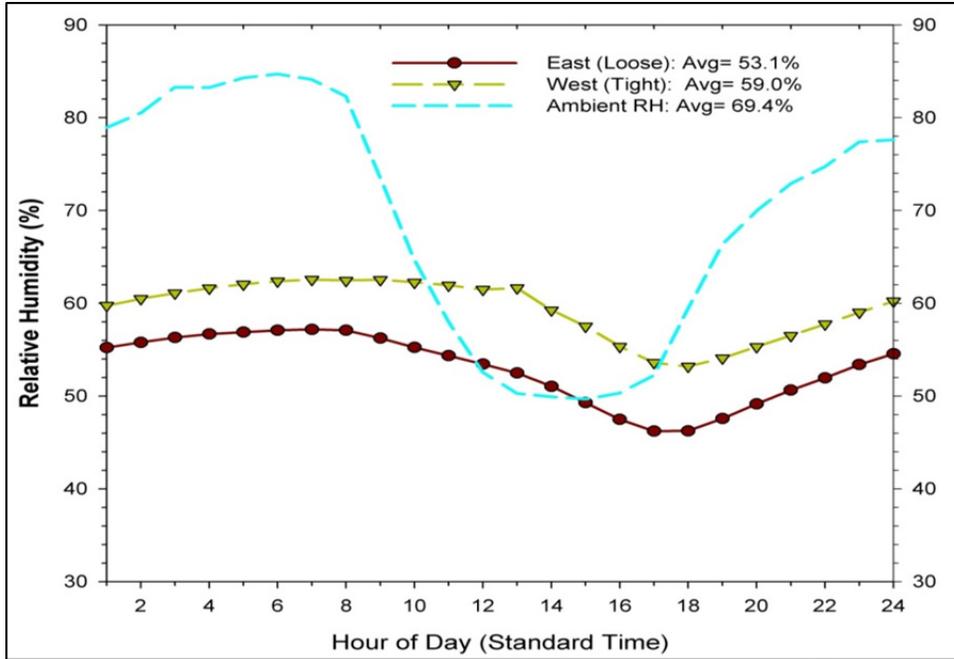
Figure 31. Comparative RH, October 25 to November 8, 2012: no ventilation
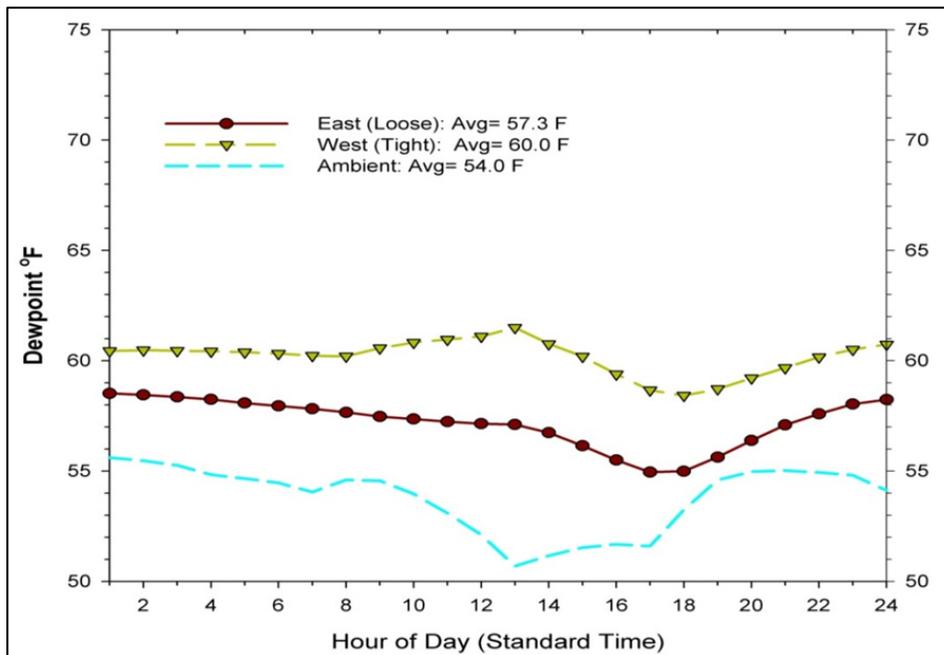
Figure 32. Comparative dew point temperatures, October 25 to November 8, 2012: no ventilation

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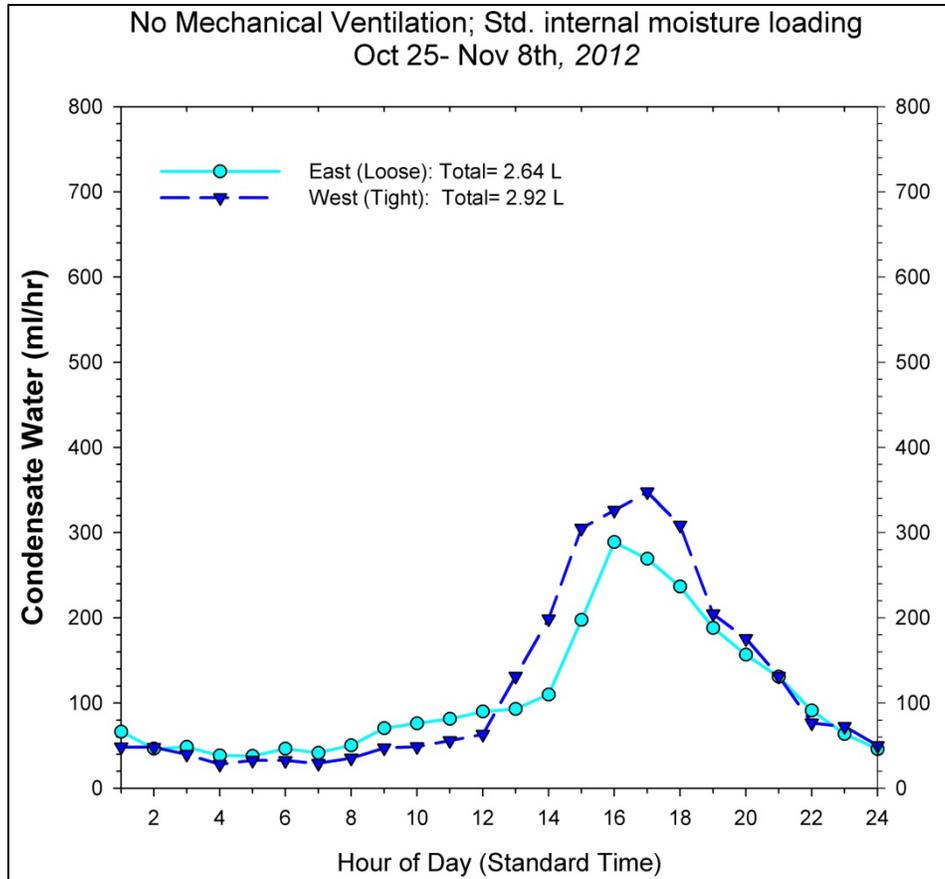
Figure 33. Comparative condensate removal, October 25 to November 8, 2012: no ventilation

5.4 Tracer Gas Testing of Real-Time Building Infiltration and Ventilation Rates

In October 2012, CO_2 dosing and monitoring equipment began to measure CO_2 levels for calculating building infiltration rates.

The first plot in Figure 34 shows the measured outdoor airflow rates and resulting ACH for the second week of October 2012. For this test period, the looser east building is in its standard leakage configuration (8.9 ACH50). The tighter west building (2.2 ACH50) had the supply fan operating for the entire period. Note in the plot that the west building experiences a greater amount of outdoor air as well as a more consistent value. The effective ventilation rate for the east building is only about 40 CFM or 0.18 ACH. However, the west building with the ventilation system saw an average outdoor air introduction rate of 73 CFM or 0.33 ACH. For illustration, a dotted horizontal line is shown that represents the outdoor ventilation rate (63 CFM) and satisfaction of the recommended ASHRAE Standard 62-2 air quality standard for a residence of this configuration. Note that if the 2 CFM/100 ft^2 of default leakage assumed in the ASHRAE Standard 62 is included, the reference Standard 62-2 ventilation rate would be 94 CFM for the test houses. Under this assumption, both the mechanically ventilated home and the leakier one without would significantly fall under the recommended effective ventilation level.
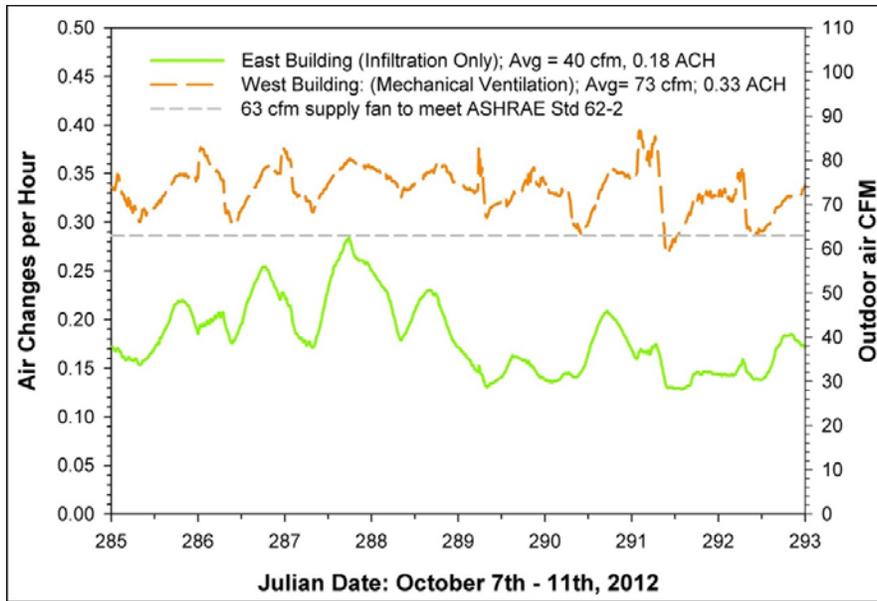
Figure 34. Measured infiltration rate by CO_2 tracer, mechanical ventilation in west building

The second plot (Figure 35) shows similar data for an 8-day period when the buildings were in exactly the same configuration, but with the supply ventilation fan in the tighter west building turned off. The two periods show a dramatic difference in the achieved ventilation rate. Although the end of October and beginning of November were somewhat cooler and windier, the tighter west building showed very low ventilation rates from natural infiltration: an average 9 CFM or 0.04 ACH. On the other hand, the leakier east building showed large response to weather as well as air handler operation (which serves to periodically depressurize the holes in the building shell). Some of the time, its achieved ventilation rate was high enough to satisfy Standard 62, while it was still too low during milder conditions. Average outdoor airflow rate was 58 CFM for an average air change rate of 0.27 ACH.
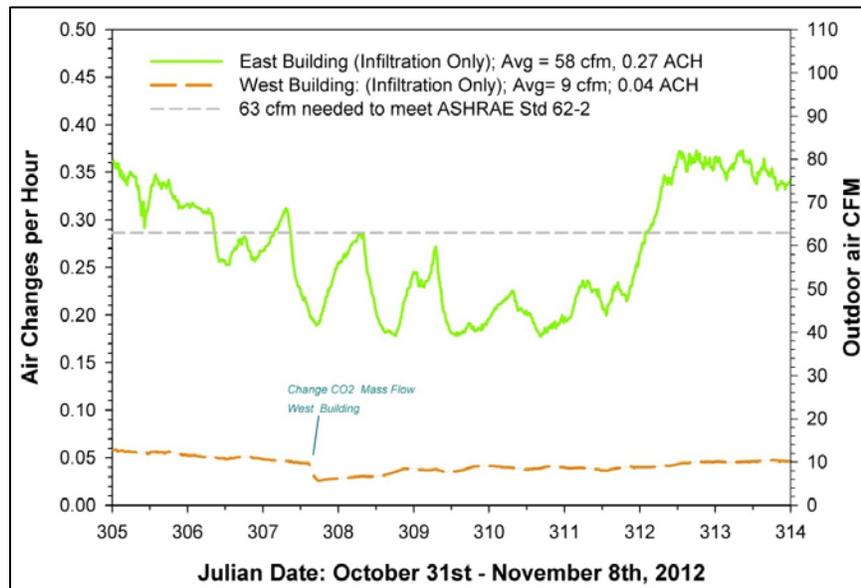
Figure 35. Measured infiltration rate by CO_2 tracer, infiltration only in both buildings

6 Discussion

6.1 Moisture Control

Reviewing the data taken during the summer test periods, we can conclude the following about relative interior moisture impacts of internal moisture loads, leakage rates, and mechanical ventilation:

6.1.1 No Mechanical Ventilation

- Greater internal moisture loads did not lead to significantly higher interior moisture levels when AC is in use and runtime is sufficient to remove the added moisture. As revealed by the comparative test periods in May–June and June–July, much of the possible impact of lower internal moisture generation rates is lost, as the AC equipment simply removes more moisture when the loads are high enough with greater runtime. This is shown by the consistent dew point temperatures during the two periods with much different moisture loading, while the condensate removed was much higher when the internal moisture generation was much higher in the July period. This resulted because the greater AC runtime in the midsummer period was able to effectively remove the added moisture. However, it is very likely that had the moisture generation rate been increased during a period when AC use was declining, the increase in interior moisture would have clearly been seen.

- Tighter envelope leakage with natural air infiltration in summer during AC had only modest impacts on internal moisture levels. Part of this may be due to the ceiling-dominated distribution of leakage in the testing, which is consistent with residences in Florida, but may not be similar to other building foundation types. The low impact of building leakage on cooling was shown by comparing the data from May through July, when natural air infiltration only took place. Dew points were slightly lower in the tighter west building (~0.5°F), and collected air conditioner condensate was also slightly lower. Interior average RHs were low (42–43%), within 1% of each other, and were not significantly different.

- An even higher building leakage rate does show some increase in interior moisture levels in summer—particularly under rainy conditions. This is seen by comparing the data for the period from October 2–8, when the east building with higher building leakage had 46% versus 44% RH, dew points of 56°F versus 54°F, and much greater collected AC condensate (13.7 L/day versus 10 L/day).

- Against our inference from observation that air conditioner operation and dehumidification trump changes in natural air infiltration, it must be added that increased moisture loads during periods with a declining AC unit (such as the October data) will evidence greater moisture load impacts.

In summary, 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.

6.1.2 Mechanical Ventilation

- When 63 CFM of mechanical supply air ventilation was added to the tighter west building, it experienced higher interior moisture levels with AC. For instance, in the September 1–13 test period, the mechanically-ventilated building had 5% higher interior RH, a 3°F increase in the interior dew point, and a 15 L/day increase in the collected AC condensate. This is not a surprising finding, as earlier empirical research by Rudd and Henderson (2007) found that homes with mechanical ventilation in humid climates without supplement dehumidification experienced higher interior moisture levels. We note, however, that no specific moisture-related issues emerged in summer in the lab houses. This was quite different in the winter period when no AC-related dehumidification was available and moisture problems (condensation and mold) were seen.

- Even though the east building had higher building leakage levels, there was still evidence of somewhat higher interior moisture levels under mechanical ventilation. This was evident in the October 10–20 test period. Interior RH was 2% higher, dew points were 1°F higher, and collected condensate was about 2 L/day higher in the west home. It should be noted, however, that these results were dependent on the prevailing weather when it was wetter outside than inside. In winter conditions in Central Florida, where it is often drier outside, the mechanical ventilation could be expected to result in lower interior moisture levels.

- Although slightly higher moisture and energy use were associated with mechanical ventilation, the CO_2 tracer measured ventilation rates indicated that the leaky residential building still fell considerably short of the recommended ASHRAE Standard 62 ventilation levels much of the time, and the tighter west building fell far below that rate (0.04 ACH).

In summary, 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.

Another caution is that the evaluation does not include any duct leakage in either of the test buildings, an unusual configuration for a Florida building. It is nearly certain that there would be large interactions with duct system leakage during the summer, which should be investigated. These could easily lead to considerably higher internal moisture levels because running the AC system would both remove and add outdoor moisture. This study also indicates a need for further testing on mechanical ventilation, including enthalpy recovery, to determine if part of the reduced moisture and energy performance of forced ventilation can be ameliorated. Finally, it has been suggested by project reviewers that an exhaust ventilation system might actually function better to address the observed moisture-related increases.

6.2 Air Conditioning Energy Use

The measured air conditioner and air handler compressor power was continuously measured during the test period to evaluate how measured cooling energy use was influenced by building air leakage and mechanical ventilation. Average summer AC from May 1 through September 30 averaged 11.7 kWh/day in the east building and 12.2 kWh/day in the west building. This compares to measured AC energy use in average Florida homes of 24.5 kWh/day over the same May–September summer time frame, according to monitoring studies from Florida Power and Light Company (Florida Power and Light Company 1999).

The lower-than-average AC energy use is likely due to several factors. The thermostat settings may be somewhat high (78°F), and the air conditioners used in this study are newer and more efficient than the air conditioners in the Florida Power and Light study (seasonal energy efficiency ratio 13 Btu/Wh versus an average seasonal energy efficiency ratio 10 in the Florida Power and Light study). Additionally, the test buildings are operating with almost no duct leakage, which is atypical for existing Florida homes (e.g., Cummings et al. 1990). However, the purpose of this study is to examine the influences of infiltration and ventilation without the complications of duct system interactions.

6.3 Tracer Gas Testing

Tracer gas testing in October 2012 reinforced expectations regarding air infiltration and ventilation. It is noteworthy that the indicated ASHRAE Standard 62 ventilation rate for the lab buildings is 63 CFM of mechanical ventilation and 94 CFM overall, including the 2 CFM/ft^2 allowance for air infiltration.

- Without mechanical ventilation, the tighter building had a much lower leakage rate than the loose one (0.04 ACH versus 0.27 ACH). Both buildings were far below the recommended ASHRAE Standard 62 ventilation rate (0.42 ACH).

- When mechanical ventilation was added to the tighter building, it exhibited higher ventilation (73 CFM versus 40 CFM and 0.33 ACH versus 0.18 ACH).

- A tighter building with mechanical ventilation tended to remain closer to the ventilation target and experience less amplitude in its variation relative to a loose building. The 62-2 compliant target is 94 CFM of ventilation for the laboratory homes. The east structure, relying solely on natural ventilation saw an average ventilation rate of 39.7 CFM (standard deviation = 8.2 CFM) over a weeklong test period with a range of 28–62 CFM against an average for the tight west building with mechanical ventilation of 72.8 CFM (standard deviation = 4.8 CFM) with a range of 58–86 CFM.

7 Conclusions

How does the airtightness of a home affect its moisture levels, temperature, and AC loads during the cooling season in a hot-humid climate?

The comparative summer testing showed that the tighter buildings, exemplified by the west structure compared to the leakier east structure, exhibited little if any AC energy savings under natural infiltration. This was largely because the outdoor temperature was nearly as often below as above the desired thermostat set point (as examples, see Figure 11 and Figure 19). Thus, increased air infiltration during nighttime hours when the temperature outside is lower than the desired cooling set point actually reduces the AC load. The same is true of mechanical ventilation, which will act like an economizer during cooler nighttime hours.

During the first part of the summer, the building moisture levels and temperature levels saw only minor changes between the tight and loose structures, mainly because the buildings were consistently air conditioned, and the AC promptly removed any excess heat or moisture.

The only measurable differences seen in increased infiltration between the homes occurred toward the end of the testing period. The first week of October, period V, featured heavy rainfall, while both homes operated with natural infiltration only. The humidity averaged 2.5% higher, and the dew point averaged nearly 2°F higher in the east (loose) home during this time period, while the AC energy was nearly the same. During the last testing period of the study, the AC loads decreased, and the tight west house had much higher moisture levels, with an RH 6% higher and a dew point 2.7°F higher than the loose east house.

How does mechanical ventilation at ASHRAE Standard 62-2 levels affect a home's moisture levels, temperature, and AC loads during the cooling season?

When mechanical ventilation was added to the airtight home, cooling energy use increased by 27%–30%, or about 5–7 kWh/day when comparing to the nearby building with natural air infiltration only. Part of this came from the fact that the mechanical ventilation system fan itself added 1.8 kWh/day of energy use. Moreover, as shown in Sections 4.3.3 and 4.3.5, the operation of the mechanical ventilation system also appeared to result in measurable increases to the building moisture levels, whereas a leaky building envelope had only modest increases to interior moisture levels (Section 4.3.4). The reason for this disparity is likely because of low driving forces for air infiltration, as seen in the tracer gas testing, resulting in low overall airflow even in the building with substantial ceiling leakage. This means that the leaky building was resulting in less overall outside air being introduced, and hence less impact to energy and moisture levels. It is also possible there are differences due to enthalpy recovery through the building envelope components during natural air infiltration (e.g., Claridge and Bhattacharyya 1990) as opposed to mechanical ventilation. However, this would need further testing and evaluation. One important point to examine would be whether exhaust-only ventilation might exact less impact on energy and interior moisture conditions.

How does air infiltration from natural infiltration compare to the ASHRAE Standard 62.2 ventilation requirements?

During periods with no mechanical ventilation, the tight west home showed very low infiltration rates, even on windy days—often less than 0.06 ACH. The leakier east home, however, exhibited much higher infiltration rates, and during windy periods, it proved comparable over a daily time period to the ventilation prescribed by ASHRAE Standard 62-2. This was not true during periods of low wind, however; the building experienced air changes rates considerably lower than recommended by Standard 62-2. Meanwhile, the tight building with mechanical ventilation experienced less variation in the effective ventilation rate. The east home had infiltration rates that satisfied Standard 62-2 for some of the time and had an average infiltration rate of 58 CFM during a 9-day period, as shown in Section 4.4.

The tight west home with mechanical ventilation showed a more consistent level of effective ventilation averaging 73 CFM over an 8-day testing period. This period was less windy than the previously mentioned period and saw the east building, dependent only on natural ventilation, at well below Standard 62-2 levels,-with an average ventilation rate of 40 CFM.

According to these data, a leaky home experiences a significant amount of infiltration for a home compared to ASHRAE Standard 62-2 levels of ventilation, especially during windy periods. During the mechanical ventilation period, the leaky home experienced more than half the infiltration than the mechanically-ventilated home experienced.[5]

How does the level of moisture generation within a home affect its moisture levels and AC loads?

During summer months when a home's air conditioner is running regularly, differences in moisture generation seemed to have little impact on interior moisture levels and only moderate impact on energy use. The two test periods used to compare a standard moisture generation level and a reduced moisture generation level showed little difference between internal temperatures, humidities, and air conditioner power consumption. However, real differences in the impact of moisture generation were likely masked by increased air conditioner runtime during the period with higher moisture release, as this time came during a hotter part of the summer with greater air conditioner operation and hence moisture removal. The major change seen in the data was an increase in condensate collection from around 6.5 L/day with lower moisture generation to approximately 10.5 L/day with standard moisture generation. In the future, this influence could be isolated by introducing more moisture during a series of flip-flop tests that would likely show evidence of larger effect.

7.1   Key Findings/Lessons Learned

Overall, this study found that natural air infiltration from a relatively leaky home (~8 ACH50) does not cause a significant increase in cooling energy, but can cause some increase in moisture levels near the end of the summer season when sensible loads fall. It must be added that these

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[5] One caveat to the collected data is that the lab buildings, while similar to the distribution of leakage in most Florida buildings, may not be similar to other housing in the Southeast—particularly that with crawlspace floors. In Florida slab-on-grade homes, a majority of the leakage is shielded from the wind and located in the ceiling plane due to recessed lighting fixtures and bathroom and kitchen fans making up a preponderance of the leakage sites.

results are true, however, in locations such as Central Florida where the interior to exterior temperature differences under cooling are low and outdoor moisture levels are high. Such results provide further evidence that much of the moisture problem in residences in Central Florida likely occurs during winter when there are no sensible cooling loads and no humidity removal. Unlike natural infiltration in leaky homes, forced ventilation at ASHRAE Standard 62-2 levels caused increases to both moisture and energy use in homes. Cooling energy use increased by 27%–30% (5–7 kWh/day) and building moisture increased measurably, approaching and occasionally exceeding an interior RH of 60%.

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. However, mechanical ventilation is still seen as necessary because of the highly variable and often insufficient air ventilation rate provided by even a fairly leaky home in a hot-humid climate.

7.2   Future Work

The experience with the summer testing suggests that further experimentation be done in 2014 to examine the potential of enthalpy recovery ventilation systems to address moisture issues and provide more comparable energy performance. Also, as the buildings do not have interior walls or normal furnishings, there are questions about how these factors may influence moisture-related impacts. This should be examined in future testing.

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