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Reference Publication: James B. Cummings and Charles R. Withers, Jr.. "Unbalanced Return Air in Residences: Causes, Consequences, and Solutions". ASHRAE Transactions Vol 112, Part 1, January 2006.

Unbalanced Return Air in Residences: Causes, Consequences, and Solutions

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FSEC-RR-140-06

Key Words

Residential Buildings, Ducts, Air Distribution Equipment, Air Handlers, Building Envelope

Abstract

Field research performed in 70 central Florida homes found that return grills are almost always located in the central zone of the house, and that individual rooms rarely have ducted return air or return transfer pathways. When interior doors were closed, the closed rooms went to +0.0249 inches of water gauge (in w.g.) (+6.2 pascals (Pa)) wrt outdoors (wrt = with respect to), and the central zone went to -0.0116 in w.g. (−2.9 Pa) wrt outdoors. Room pressures as high as +0.150 in w.g. (+37.3 Pa) and central zone pressure as low as -0.059 in w.g. (-14.7 Pa) wrt outdoors were found. These pressures create exfiltration from the closed rooms and infiltration in the central zone. With the air handler operating, the house infiltration rates increased, on average, from 0.46 to 0.60 air changes per hour when all interior doors were closed. According to homeowner reports, interior doors are closed 11% of the time, on average. These pressures and increased infiltration rates impact indoor air quality, indoor relative humidity, energy use, peak electrical demand, comfort, and system sizing.

Background

In many parts of the country, supply air is delivered to individual rooms, but return air is located only or primarily in the central zone. In some building codes, return air is a requirement. The Florida Building Code, for example, requires that return air transfers be provided in both residential and commercial buildings so that pressure differentials across interior partitions may not exceed 0.01 in w.g. (2.5 Pa) (Florida Building Code, Mechanical Volume, May 2001, Section 601.4, Balanced Return Air.)

The absence of return air in closeable spaces causes positive pressure in the closed rooms and negative pressure in the central zone. 1 These positive and negative pressure fields create a number of unwanted impacts. In a study of 12 homes, it was found that infiltration rates increased from 0.26 ach with the air handler OFF, to 0.58 ach with the air handler ON, to 0.99 ach with all interior doors closed (air handler ON). 2

Negative pressure also creates potential IAQ consequences. Contaminants in the soil (e.g., radon), sewer gases in poorly trapped drain lines, and air contaminants (e.g., pesticides, mold odors, chemicals, auto exhaust, dust) in unconditioned zones such as crawl spaces and garages can be drawn into the conditioned space. Negative pressure can also produce combustion venting problems. At approximately -0.02 to -0.04 in w.g. (−5 to −10 Pa) wrt out, most atmospherically vented combustion devices experience problems with spillage (partial venting) and backdrafting (no venting due to complete reversal of vent flow) 3. Fireplaces can experience spillage and backdrafting at even lower pressure differentials. At pressures in the range of -0.06 to -0.08 in w.g. (−15 to −20 Pa) wrt out, high velocity backdrafting can restrict the entry of air into the combustion chamber of atmospherically vented gas water heaters, limiting the availability of oxygen for combustion, and creating the potential for very high carbon monoxide production. At pressures in the range of -0.08 to −0.12 in w.g. (−20 to −30 Pa) wrt out, high velocity backdrafting can cause a reversal of flow in the flue (the vent inside the combustion appliance). This reversal of flow is strong enough to push flame out of the combustion chamber in a process referred to as flame rollout. These combustion system impacts can create serious dangers for both home and occupants.

A Canadian Housing Mortgage Corporation study of backdrafting in atmospherically vented combustion devices concluded that spaces containing these combustion devices should not be depressurized by more than 0.012 in w.g. (3 Pa) to 0.02 in w.g. (5 Pa) wrt outdoors, depending upon the type of combustion appliance. 4 Furthermore, space depressurization in buildings in hot and humid climates can result in considerable moisture problems in wall cavities and in the conditioned space.

Unbalanced Return Air Field Data

Field research was performed on 70 homes in central Florida. These homes were built in the 1980s, were less than five years old at the time of testing, and were on average 1699 ft 2 (158 m 2) in size. Testing was done to characterize pressure differentials with the interior doors closed and the air handler operating. House pressure was measured in the following manner. A tube (1/8 th i.d.) with a static pressure probe was run from approximately 50 feet (15 m) outside the house to indoors, locating the exterior tube terminus away from buildings, vegetation, or other obstructions to avoid pressure fields from wind “shadows”. A manometer with resolution of 0.0004 in w.g. (0.1 Pa) and rated accuracy of +/- 1% of reading or 0.0008 in w.g. (0.2 Pa) whichever is larger, was used to measure the pressure of the central zone of the house wrt outdoors. Because of fluctuations in pressure caused by wind, the recorded measurement was the result of time-averaged readings over a 30 to 60 second period. The same manometer was then used to measure the pressure differential from the central zone of the house to each closed room.

Figure 1 shows the pressure in the central zone of the house wrt outdoors with all interior doors closed. Sixty-four of 70 homes had negative pressure in the central zone while six of the 70 houses show positive pressure in the central zone wrt outdoors. The explanation for central zone positive pressure is that in these six cases, return leakage was elevating house pressure more than the unbalanced return air was lowering the central zone pressure. On average the central zone was -0.0116 in w.g. (–2.9 Pa) wrt outdoors. As a point of reference, these 70 houses were at an average pressure of +0.0032 in w.g. (+0.8 Pa) wrt outdoors when the air handler was operating and interior doors were open. Therefore, the central zone pressure declined by 0.0148 in w.g. (3.7 Pa) due to door closure.

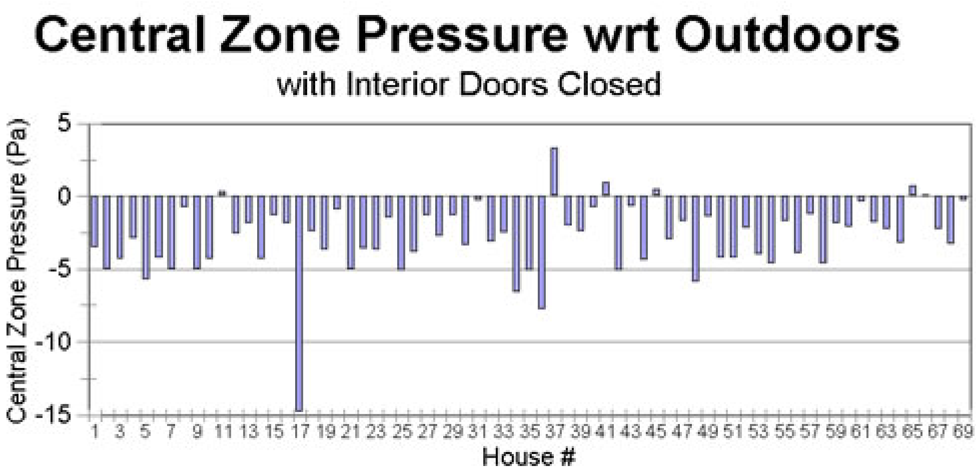

Figure 1.
Measured pressure (wrt out) in central zone of house with all interior doors closed.

In general, returns were located only in the central zone. In 59 homes, there was only one return grill. In nine homes, there were two return grills. In two homes, there were three return grills. However, these returns were all located in the central zone, with the exception of one house that had a return in the master bedroom suite. In 11 homes, there was a second AC system each with a single return.

Pressure in each of the closed rooms was measured. While the central zone goes to negative pressure, the closed rooms generally go to positive pressure. Figure 2 shows pressure in the master bedroom with all interior doors closed and air handler(s) ON. Note that the master bedroom of House #45 was at negative pressure. In this house, a return was also located in the master bedroom suite. This return was drawing 515 cubic feet per minute (cfm) (243 l/s) while supply air to the master bedroom suite totaled 270 cfm (127 l/s). The net return air of 245 cfm (116 l/s) (return air minus supply air) from the room caused the room to be depressurized to -0.0241 in w.g. (-6.0 Pa) wrt outdoors when all interior doors were closed and the air handler was ON.

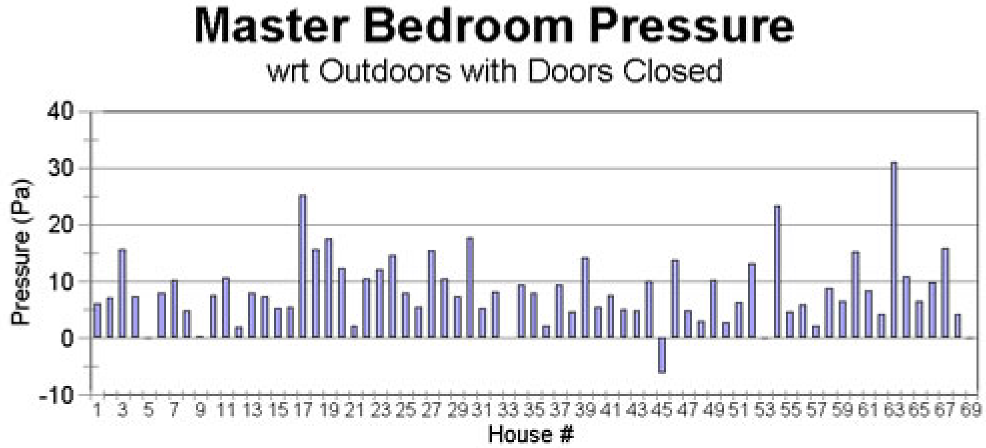

Figure 2.
Measured pressure (wrt out) in closed master bedroom with all interior doors closed.

Figure 3 shows the average pressure in three bedrooms (including the master bedroom) wrt outdoors. On average, the closed rooms are 0.0249 in w.g. (+6.2 Pa) wrt outdoors and 0.0365 in w.g. (+9.1 Pa) wrt the hallway. There is considerable variability in room pressure from one house to another, and even from one room to another within a single house. Consider four closed rooms in house #36, a two-story house. Two closed rooms were at 0.129 in w.g. (+32.2 Pa) and 0.150 in w.g. (+37.3 Pa) wrt outdoors, while two other rooms were at 0.008 in w.g. (+2.0 Pa) and 0.014 in w.g. (+3.5 Pa) wrt outdoors. The rooms with large positive pressure had 209 cfm (99 l/s) and 245 cfm (116 l/s) of supply air, respectively. The rooms with small positive pressure had 59 cfm (28 l/s) and 47 cfm (22 l/s) of supply air, respectively. The amount of pressure in a specific room is a function of the net air flow rate to that room, the amount of door undercut and other pathways back to the central zone, and the airtightness of the room to outdoors (including attic, etc.). None of these houses had intentional return transfers from the closed rooms, except for door undercut.

Consider house #17. This house has an airtightness of 5.5 ACH50 (air changes per hour at 50 Pa), somewhat tighter than the average of 7.2 ACH50 for the entire 70-house sample. Total supply air to the master bedroom suite was a very large 557 cfm (263 l/s) and closing only the master bedroom door caused the remainder of the house to become -0.028 in w.g. (–7.0 Pa) wrt outdoors. When all interior doors were closed, the central zone pressure became -0.059 in w.g. (–14.7 Pa).

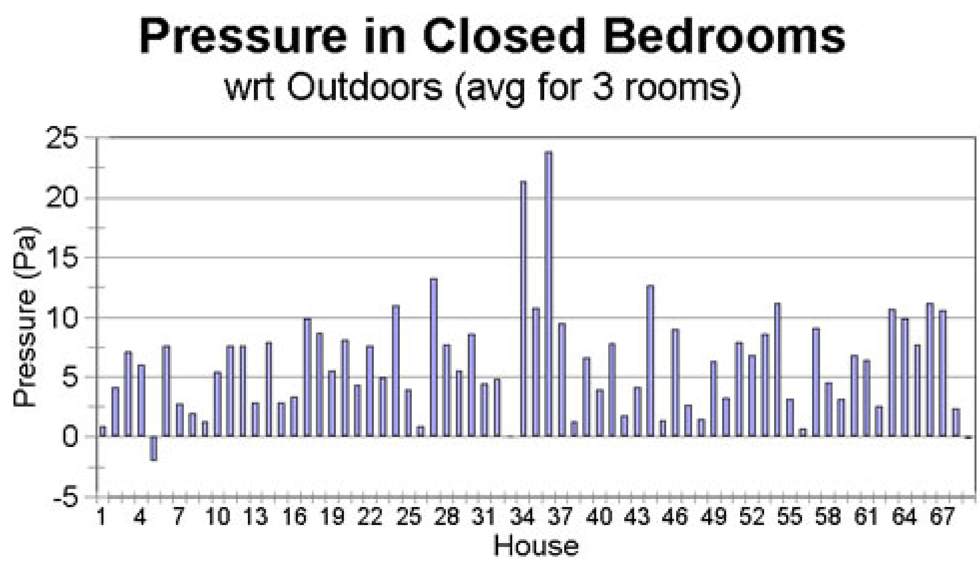

Figure 3.
Average pressure (wrt out) in three bedrooms (including master bedroom) with all interior doors closed.

Implications of Pressure Differentials

There are several consequences of the pressure differentials produced by unbalanced return air. First, the positive pressure in the closed rooms increases exfiltration of air from those rooms to outdoors. Second, the increased positive pressure in a closed room causes a reduction in the supply airflow rate into that room. Third, this increase in room pressure causes increased supply duct leakage. This occurs because the pressure in the supply duct may increase by 10 to 50%, depending upon the room pressure. For example, if the room pressure increases 0.04 in w.g. (10 Pa) wrt outdoors, then the pressure in the supply duct serving that room will increase by a similar amount. This can be a very significant increase because normal pressures in branch supply ducts in residences (based on the authors' field measurements) are often in the range of 0.02 in w.g. (5 Pa) to 0.06 in w.g. (15 Pa). In fact, static pressure in supply boots is often less than 0.008 in w.g. (2 Pa) under normal operaton, and may in some cases be negative (a result of venturi effect as high velocity air shoots into the boot). The authors have observed air being drawn into leaks in supply boots.

The negative pressure in the central zone increases infiltration of air from unconditioned spaces (outdoors, attic, garage, crawl space, etc.) into the conditioned space. Tracer gas testing was done to characterize the infiltration rate of 50 of these 70 homes. With the air handler (and all other HVAC equipment) turned off, the average infiltration rate was 0.21 air changes per hour (ach). With the air handler running continuously, the house infiltration rate increased to 0.46 ach. When the interior doors were also closed, the house infiltration rate increased to 0.60 ach. Infiltration rates were measured by means of tracer gas decay. Sulfur hexafluoride was mixed throughout the house, and the concentration of tracer gas was measured at multiple locations throughout the home at time intervals. The infiltration rate was calculate based on the equation

$$ach = 60/N * \ln(C_i/C_f)$$

where N is the number of minutes of the test, C_i is the initial tracer gas concentration, and C_f is the concentration at the end of the test period. Wind speed was measured in an open area of the yard by a cup anemometer standing 6 ft high, connected to a datalogger. Outdoor temperature was recorded. On average, wind speed was 3.8 miles per hour and outdoor temperature was 85.4 °F (29.7 °C).

The added infiltration increases heating and cooling loads, and during hot and humid weather indoor relative humidity (RH) as well. Additionally, the negative pressure can draw humid air into exterior wall cavities, creating a high moisture content microclimate inside these wall cavities. Furthermore, negative pressure can also draw air down interior partition walls from the attic, creating a moist microclimate in these interior walls as well. If outdoor dew point temperatures are say 75 °F (23.9 °C). (as is the case in Florida and other Gulf of Mexico coastal areas through much of the summer), then surface RH in the wall cavities can be at or near 100% if indoor temperature is about 75 °F (23.9 °C). This can lead to condensation (if the thermostat is set low enough) or high material moisture content as a result of adsorption of water vapor into these materials. The consequence can be mold growth.

In five of the 70 homes, central zone depressurization was greater than -0.02 in w.g. (-5 Pa) which is sufficient to create spillage and backdrafting problems with fireplaces and atmospherically vented combustion appliances. In one of those 5 cases, space depressurization reached -0.059 in w.g. (–14.7 Pa) which is sufficient to produce backdrafting and perhaps even elevated carbon monoxide production. Fireplaces and atmospherically vented combustion appliances located in the central zone, or in utility rooms or mechanical rooms attached to the conditioned space, may be vulnerable to venting and other combustion safety problems.

Types of Unbalanced Return Air

The most common form of unbalanced return air occurs when there are supply registers but no returns located in a space that can be closed off from the central zone (where the returns are located). The closed door represents a restriction in airflow from supply to return. A second form of unbalanced return air occurs when there is a mismatch between return and supply air to a space that can be closed. In the master bedroom of house #45, as previously discussed, the return was oversized by a factor of approximately two causing the closed room to become -0.024 in w.g. (–6.0 Pa) wrt out.

A third form of unbalanced return air occurs when supply air is provided to a remote location. This could occur, for example, when supply air is provided to a workshop located in a separate building (shed), and no return is provided. The workshop could also be located inside the house structure but with access only from the garage. In this case there is no doorway for air to return to the house. In other cases, the garage may be conditioned by the central system that serves the house, and of course there would be (and should be) no return air from the garage. (If a garage is to be conditioned, it should be served by a system separate from those that serve the occupied spaces of the residence.)

One example of a remote supply was found in this study, although other cases have been observed outside the study. House #50 has a single 11 x 31 ft (3.3 x 9.5 m) room upstairs with access only from the garage. Fifteen percent of 2040 cfm (963 l/s) supply air was being delivered to this space without provision for return to the system. This room was pressurized to 0.042 in w.g. (10.4 Pa) and the remainder of the house was depressurized to -0.0064 in w.g. (-1.6 Pa) wrt out.

An important implication of remote supplies is the substantial and persistent negative pressure that typically results in the remaining portion of the house. Because there is no doorway (or other pathway) from this room to the house, this pressure imbalance occurs at all times that the air handler is operating. It is this persistence of depressurization that can substantially increase cooling and heating loads (from increased infiltration) and cause water vapor condensation (and mold) problems in exterior walls during hot and humid weather.

Frequency of Unbalanced Return Air

Unbalanced return air occurs only when a restriction prevents the free flow of air from supply register to return grill. In most cases, this means that it occurs only when interior doors are closed and the air handler is operating. For remote supplies, however, with no possible return pathway, the unbalanced return air occurs whenever the air handler is operating.

In this 70-house study, the homeowner was asked to estimate the proportion of the time that each interior door (excluding bathrooms) was closed. The closed door percentages for individual doors were combined to obtain one closed door percentage for the house, as shown in Figure 4. There are large variations in reported door closure percentage from one house to another, with values as high as 70%+ in two houses and 0% in 29 homes. Eight homes have reported door closure of about 40%, which could mean all the doors are closed 40% of the day, or that 40% of the doors are closed all the time, or some combination thereof. On average, doors were reported (estimated) to be closed 11.2% of the time.

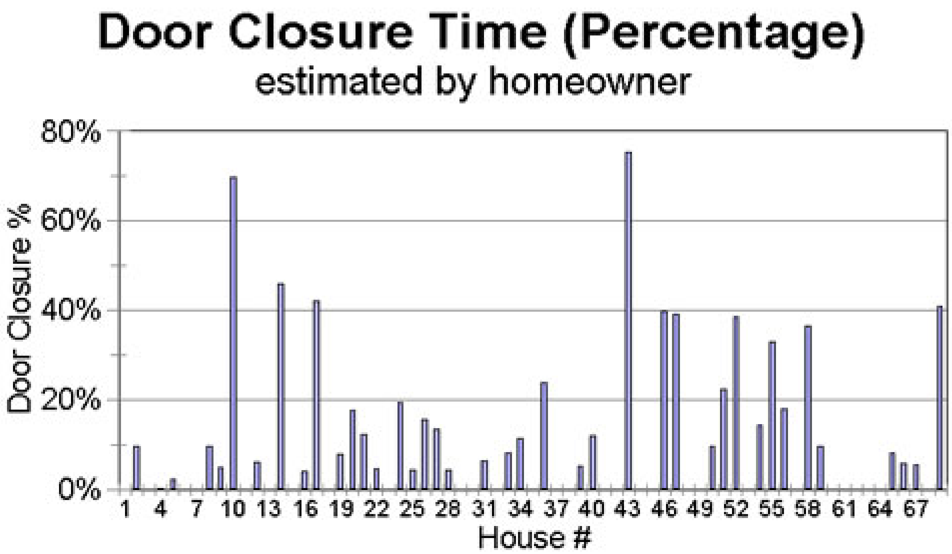

Figure 4.
Average door closure (percent of time closed) as estimated by homeowner.
Where a bar is not visible, the homeowner estimates that doors are always open.

There are lifestyle and stage-of-life variations in door closure. Some people prefer to keep doors closed and others do not. When children are young, doors may stay open much of the time, but during the teenage years, door closure may become more the rule than the exception. Furthermore, door closure patterns may change during special events, such as house parties or visits from relatives, or from one time of day to another – with more bedroom doors closed during the night.

The impact of door closure frequency is different for various potential energy and IAQ consequences. Total cooling and heating energy impact of door closure varies, in large part, proportionately with door closure. In other words, if more interior doors are closed more of the time, then cooling and heating loads from increased infiltration will increase. However, if doors are closed primarily during sleeping hours and open during the day, then the impacts on cooling energy use and peak demand will be limited. The impacts on heating energy use and heating system peak demand would, on the other hand, be maximized.

The potential for negative pressure to draw moisture and other contaminants into the house will depend largely on the door closure fraction. Intermittent space depressurization due to door closure is unlikely, in itself, to create moisture problems inside wall systems. The ability or inability of heating or cooling systems to meet space conditioning loads will not depend necessarily upon large door closure frequency, but rather on whether significant door closure occurs during peak load.

Consider a family that rarely closes interior doors except when they entertain. So when they invite a dozen friends over for a summer afternoon/evening party, and all the interior doors are kept closed, the increased infiltration created by door closure will add substantially to the cooling load. Because of the additional loads created by food preparation, increased entering and exiting of exterior doors, and the cooling load from the additional people, the cooling system will be at maximum stress. The door closure event is then creating increased cooling load at an inconvenient time because the homeowners do not want their guests to be uncomfortable. This may, in some cases, result in the AC contractor being informed that the system is undersized, which might lead to addition of additional cooling capacity in that home. Even if an AC change-out does not occur in this house, the AC contractor has gotten the message that the Manual J- sized AC system he installed is not large enough, and this will, along with the added loads associated with duct leakage, put pressure on him to oversize units in the future.

Unbalanced Return Air Solutions

The pressures and increased infiltration rates resulting from unbalanced return air can be eliminated or greatly reduced by providing properly sized return air transport pathways. These could be ducted returns or return transfers.

Ducted returns, of course, provide the potential for perfectly or nearly perfectly balanced airflows. In practice, of course, airflow balance is not likely to be perfect, but can, with a modest amount of attention, produce reasonably neutral pressures with doors closed. (The authors have relatively little experience with ducted return systems – to know how well balanced they typically are – because they are uncommon in central Florida.)

Alternatively, return air transfers can be provided to each closed room. This could include door undercuts, through-the-wall transfer grills, transoms, and jump ducts. By their very nature, transfers do not eliminate, but rather moderate pressure differentials. It is the positive pressure in the closed room, in fact, that drives the airflow through the transfer. Two questions then arise; what level of pressure differential is acceptable?, and what size transfers would be required to achieve this?

The State of Florida Mechanical Code has adopted 0.010 in w.g. (2.5 Pa) as the target pressure for both residences and commercial buildings. Specifically, this means that the pressure differential across closed interior doors and other interior partitions (including fire and smoke walls that subdivide ceiling spaces used as return plenums in commercial buildings) must not exceed 0.010 in w.g. (2.5 Pa).

Experiments were performed to examine the size of transfer openings required to meet this 0.010 in w.g. (2.5 Pa) requirement. In the case of an open hole in the wall with no grills, 54 square inches (0.0348 m 2) of opening were required per 100 cfm (47 l/s) to meet this requirement. When grilles were added to each side of the wall opening (slightly larger than the opening), the necessary hole size was 103 square inches (0.0665 m 2) per 100 cfm (47 l/s). When oversized grills were installed, the necessary hole size was reduced to 79 square inches (0.0510 m 2) per 100 cfm (47 l/s). (By oversized grills, the authors mean grills with net free area considerably greater than the cross-sectional area of the duct to which they are attached.) A 6 inch (0.15 m) diameter flex duct, located in an existing residence, attached to large grills on either side of the wall (each grille with 53 square inches net free area (0.0342 m 2)) was found to transfer 42 cfm (20 l/s) at 0.010 in w.g. (2.5 Pa). This is equivalent to 63 square inches (0.0406 m 2) per 100 cfm (47 l/s).

Conclusions

Unbalanced return air was found to be ubiquitous in central Florida homes. When interior doors are closed, there are substantial pressure differentials created in the residence. These increased pressure differentials across the building envelope increase the house infiltration rate, which may result in moisture and contaminant transport into the house. Tracer gas decay testing found the infiltration rate to increase by 33% when interior doors were closed and the air handler was operating.

In 64 of the 70 tested homes, closing of interior doors caused negative pressure in the central zone of the house wrt outdoors. This negative pressure has certain predictable results during hot and humid weather. Moisture laden air is drawn into exterior wall cavities. Additionally, the increased infiltration – all of which occurs in the central zone of the house – draws high moisture content air into the house. This increased infiltration can produce elevated indoor RH that can create adverse impacts on the moisture content of building materials and furnishings, potentially resulting in comfort problems and mold growth problems. It can also increase the potential for mold growth inside wall assemblies. This is especially true in homes where interior doors are kept closed a large fraction of the time, and in cases where remote supplies exist. In these homes, space depressurization occurs whenever the air handler operates.

Increased air infiltration and space depressurization can transport contaminants from soil, sewer lines, garage, attic, or crawl space, thereby degrading IAQ. Increased infiltration can also mean increased heating and cooling energy use and increased electric demand (impacting utility system demand and the need for new generation capacity). In some cases, comfort problems lead to complaints to the AC contractor, who in turn may be encouraged to install an oversized cooling system without addressing the unbalanced air problem.

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Acknowledgements

Return transfer experiments reported in the Unbalanced Return Air Solutions portion of this paper were performed by Neil Moyer and James B. Cummings.