# Air Handler Fan: A Driving Force for Air Infiltration

by John J. Tooley, Jr. and Neil A. Moyer

***Does the house you just weatherized, audited, or bought have "leak around the collar"? Its central air system's air handler may move as much as 2,000 cubic feet of air per minute, driving air through any leaks in the ducts. Leaky ducts or not, though, the air handler can create inefficient and possibly dangerous pressure differences from room to room.***

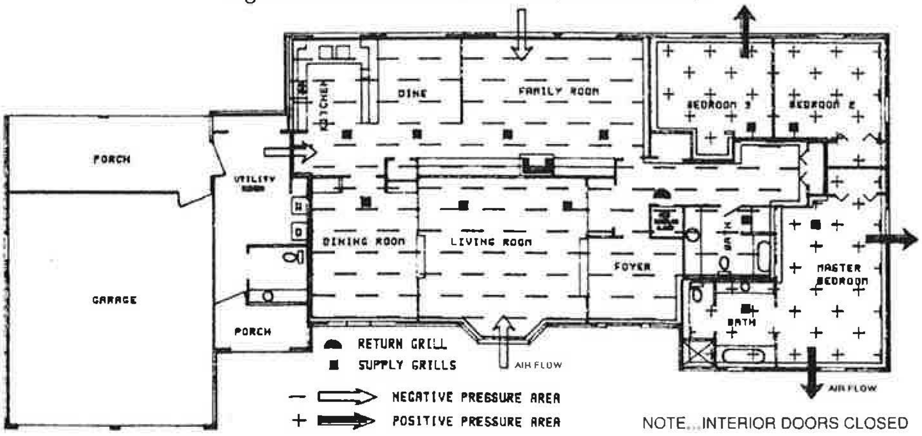
Our company, Natural Florida Retrofit, Inc., has been conducting airtightness tests with a calibrated blower door for several years. One day we tested a house in which the bedroom doors had been inadvertently left closed during the test. The house was a typical Florida three-bedroom concrete block structure. It had central heating and air conditioning with a single return duct in the hallway (Figure 1). The supply duct system was located in the attic and was in very good condition. We performed an airtightness test and determined that the structure was fairly tight—8.0 air changes per hour (ACH) at 50 Pascals or 0.2" water column of pressure.

We found that under normal conditions the house had negative pressure relative to the outdoors. This in itself is not unusual. We had already discovered that some houses had pressure differences *within* the building envelope, across interior partitions of single-family homes—a substantial problem in its own right, which we will talk about more later.

But this house was different. Unlike other houses with negative pressures, it had no leaks in the duct system. What was sucking the air out of the house? The only thing different about this house was the position of the bedroom doors—they were closed. Could it be the closed doors caused the house to operate with negative pressures in the main body of the dwelling and with positive pressures in the bedrooms, where there were no return grills? Yes, it turned out, whenever the air handler fan was on and the doors were closed, air could not return to the air handler from the bedrooms fast enough to balance the pressure. To test the effect of door closing, we performed tracer gas tests in 12 houses having a naturally occurring average infiltration rate of 0.26 ACH. When we closed the interior doors of these homes, infiltration rates jumped to an average of 0.99 ACH.[1]

We soon realized that not only leaky ducts affect air pressure differences and infiltration rates in homes, but that four other factors can be involved: 1) duct system design, 2) resident interaction with the system (e.g., door closing), 3) house tightness, and 4) cleanliness of the blower, filter, and evaporator coil. These factors can cause air pressure differences within the house, from room to room or from the rooms to the main body of the residence. Duct system failure on the supply side of the

**Figure 1. Pressure differences (doors closed).**

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system loses conditioned air to the outside. This causes the return to starve for air, resulting in negative pressures in the home as the air handler seeks to replace the lost air. Failure on the return side of the system pulls in outside air and results in positive pressures in the home. All of our other duct system tests and inspection—using a blower door, smoke guns charged with titanium tetrachloride, and physical checks—revealed that 100% of the systems (371) were leaky to varying degrees. Most of these leaks were detectable using the blower door and others merely by use of a smoke gun and visual inspection.

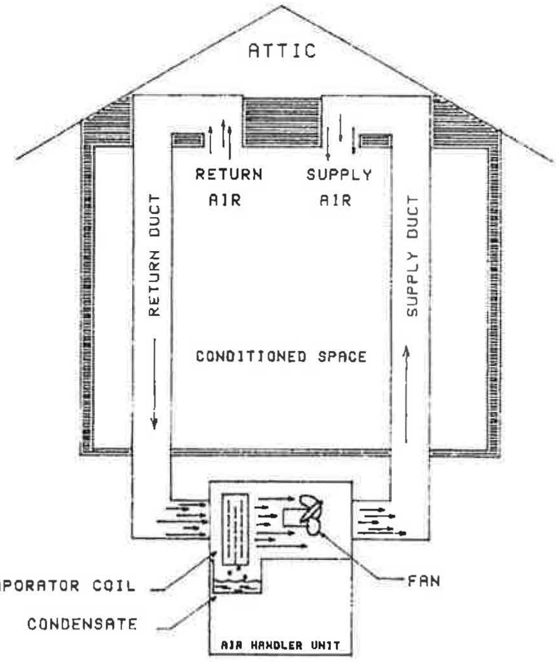



**Figure 2. Simplified Single Return Duct System**

In a duct system design containing a single return, starvation of air to the system is easily achieved. The air supplied to the rooms without the return cannot easily get back to the air handler if the doors or air register are closed. Fifty-six homes tested with the HVAC blower on and doors closed registered negative pressures from -1 to -8 Pascals, and all of these homes had single returns (Figure 2). Pressures lower than -8 Pa were found in three homes. One was related to errors in duct design of a zoned house (-61 Pa) and the other two had large supply system leaks. Multireturn systems allow easy air return from the entire home to the air handler as long as there is a return located in the main body of the home and in each room with a closable door. Of 16 multireturn homes we tested, ten showed no difference in pressure between when the doors were open and when they were closed. The other six homes had supply or return system leaks that caused either negative or positive pressures. Once again, we concluded that resident interaction with the system (by closing doors for privacy or air registers with

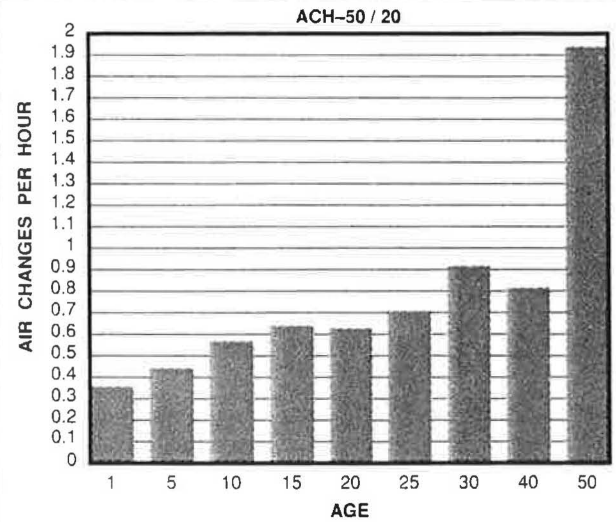



**Figure 3. Estimated infiltration rate by age.**

the desire not to heat or cool a room) can cause some homes to operate with pressure differences across interior and exterior partitions.

Altogether, between May 1987 and May 1988 we studied 371 single-family homes ranging from 1 year to more than 50 years old. We estimated infiltration rates (see Figure 3) from 0.35 to 1.95 ACH (using ACH-50/20). Of these houses, 11.6% were mobile homes, 11.5% were frame construction, and the remaining 76.9% were concrete block structures (Figure 4).

We found that the extent of airtightness of a residence can drastically effect the pressure differences from room to room within the building envelope. We also found that one of the largest driving forces of air change rates in residential buildings can be directly attributed to the operation of forced-air distribution systems. These factors can be major contributors to: 1) excessive energy consumption, 2) poor thermal comfort, 3) degradation of building materials, and 4) indoor air quality problems, including carbon monoxide poisoning.

Over the period of this testing, we developed a procedure for mechanical air distribution system inspection and interaction monitoring (see box). We implemented

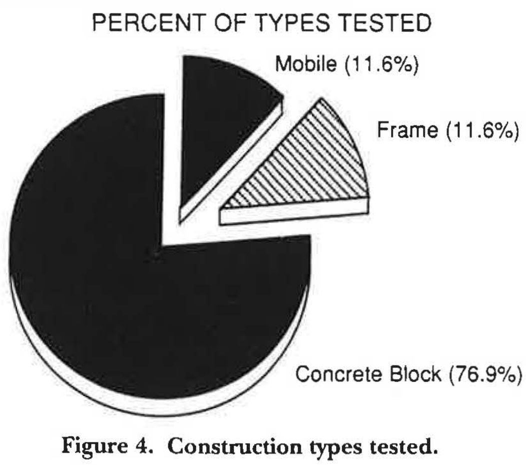



**Figure 4. Construction types tested.**

## Procedure to Test House for Fan-Caused Pressure Problems

1. Prepare building for blower door test. Install blower door, same as for airtightness test.
2. Turn on the HVAC fan with all interior doors open.
3. Take pressure reading across exterior envelope.
6. Take pressure reading across all interior bedroom/ bath doors.
7. Open all interior doors.
8. Turn off HVAC fan.
9. Pressurize the building with the blower door.
10. Check each grill with smokestick (note all leaks).
11. Turn off blower door.
12. Turn on HVAC fan.
13. Take pressure reading across return register (with filter in place).
14. Turn off HVAC.
15. Depressurize the whole house to the same pressure found at the return. Note the amount of air coming out of the return.

*Editor's note: On windy test days Natural Florida Retrofit used the garage as a buffer. We do not recommend this practice.*

this procedure because most central Florida homes have duct systems outside the building envelope. Prior to the use of the blower door, our company had conducted hundreds of visual duct system inspections through a conservation program with one of the local utilities, Florida Power Corp. We had identified 14 different types of duct systems that could not be inspected by normal visual inspection procedures. Then we purchased a blower door to increase the quality of our inspections. With it we could actually test the integrity of the duct system and its effect on the whole house.

We began to see an interior air pressure difference occurring in a large number of the homes we tested. By measuring the pressure differences between the inside and outside of the building envelope caused only by the HVAC fan, it became apparent that a house could operate in one of three pressure modes: neutral, positive, or negative. In a sub-group of 101 houses tested for what we came to call "mechanical air distribution and interacting relationships," or "MAD-AIR," 21 neutral-pressure houses fell into the following categories: five were operating properly, two had equal duct leaks in the return and supply ducts, 11 of the houses were too leaky to measure properly, and three had undetermined causes of neutral pressures (Figures 5 and 6). If the house had an overall positive pressure, this could indicate a return duct leak, or more leakiness in the return than in the supply. We tested 18 houses that fell into this category and all of them had return system leaks.

Throughout this study of the 101 homes, it was difficult to measure pressure differences across the exterior partition when the house was much leakier than 12 ACH at 50 Pa. However, in tighter homes, pressure differences were easily discernible. In the larger study, we had estimated 216 of the original 371 homes would fall into this range (at a natural air change rate of 0.6 ACH-50/20 or tighter). The tighter the house, the more drastic the pressure differences across exterior and interior partitions. Cleanliness of the blower, filter, and evaporator coils also contributed to the degree of pressure difference. This was due to the lack of air flow throughout the air handler caused by dirt on the blower, filter, or evaporator coils. One house, which had a very dirty air filter, showed a 1 Pa increase in pressure across the exterior partition and a 2 Pa increase across the interior partitions from merely changing the air filter.

Duct system design, duct system failure, human interaction with the house, airtightness, and cleanliness of the system can cause the main body or rooms of a house to operate under negative pressure. In a hot and humid climate, this is one of the worst things that can happen in terms of energy consumption, indoor air quality, and comfort.

## Energy Consumption

The higher the negative or positive pressures within the house, the higher the occurrence of excessive energy consumption complaints by the residents in our test group. This only stands to reason: a one-to-eight Pascal negative pressure causes all leaks in the main body of the house to draw air from outside, the attic, or garage. Positive pressure has an equal, if opposite, effect of causing exfiltration. Other research done on five Florida homes revealed the impact of increased infiltration, assessed by computer simulation using Thermal Analysis Research Program (TARP, from Florida Solar Energy Co.). A rise from 0.10 to 0.90 ACH, causes an annual cooling electricity use increase from 3,400 kWh to 4,500 kWh (31%). Also, the heating load is more sensitive to increased infiltration. It rises 127% when infiltration increases from 0.10 to 0.90 ACH, from 4.9 to 11.1 million Btu (5.2 to 11.7 GJ) per year.

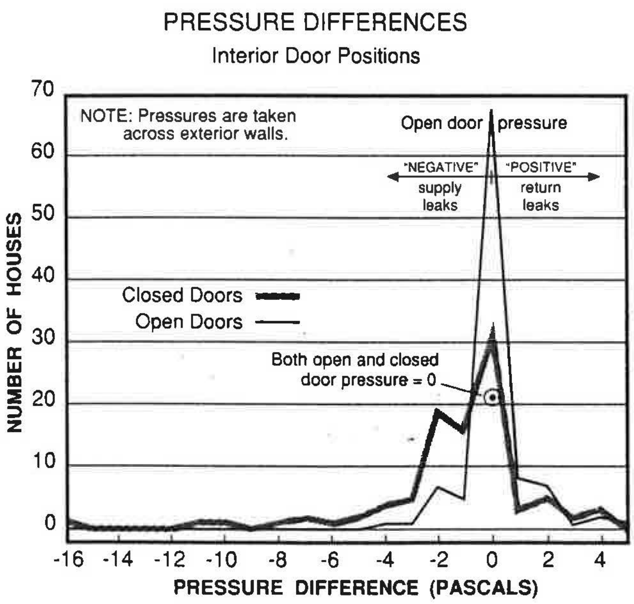



**Figure 5. Pressures across the exterior envelope**

# DUCTS

Infiltration and exfiltration are normally driven by two forces usually acting simultaneously. A temperature difference along a vertical plane causes the first force, stack effect, to be set in motion. As this air rises and escapes through holes in the ceiling area, it is replaced by outside air. The second driving force, wind, varies greatly in strength from one day to the next and even hour by hour. This driven air will find its way through even the most obscure passageways. Now a third force appears on the scene—mechanically induced pressure differences. Normally an air handler fan is overlooked and not considered as the major cause of infiltration and exfiltration it often is.

Two other studies of a total of 40 Florida[2] and Tennessee[3] homes reported a marked difference in the infiltration rate depending on whether or not the central air fan was on. Both projects used a tracer gas dilution technique and tested with the fan on and off. For the Florida study, Jim Cummings recorded both ambient temperatures and wind speed, and neither could account for the major difference in infiltration with the blower on. Our testing has shown that for a slab-on-grade home here in the central Florida area, approximately 16% to 20% of all air leakage comes from doors and windows and a very large portion of the remaining 80% to 84% is from the attic.

All residences tested had return leaks in varying degrees, pulling air from the attic, garage, or outside, depending upon the location of the air handler. For example, systems with return plenums in most cases have the plenum framed into interior and exterior walls, leaving major cracks. In addition, the framing is usually done with lumber at 19% or greater moisture content. Then, as the HVAC system operates, it dries the wood to around 9% or less, which causes shrinkage and creates more cracks (See Figure 7).

## *Supply Leaks*

Supply leaks were less pronounced, but were found in each house in varying degrees as well. Places where duct and sheet rock met leaked the most; closed registers and doors made these connections leak even more. House to attic leaks exacerbated by closed doors or registers created a negative pressure at electric outlets and pulled attic air in whether wiring holes were "sealed" or not. Top plates of walls also have cracks and shrink from drying. Plumbing entry, light fixtures, attic access, and unsealed base trim are just a few of the other leak sites we found in the attic. Attic temperatures can easily reach 130+ °F with humidity levels equal to or greater than the outside ambient air. Many homes had clothes dryers and kitchen and bathroom vent fans exhausting directly into the attic. We confirmed this attic-to-house air leakage with the use of an infrared camera and can easily understand the residents' reports of unusual energy consumption. If there are supply leaks as well, or if bedroom doors are closed, the main body of the home begins to operate under negative pressures. Many homes used more energy to compensate for infiltration than they saved with insulation.

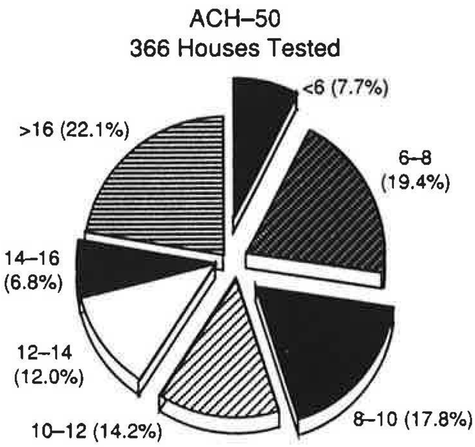



**Figure 6. Range of tightness using the blower door**

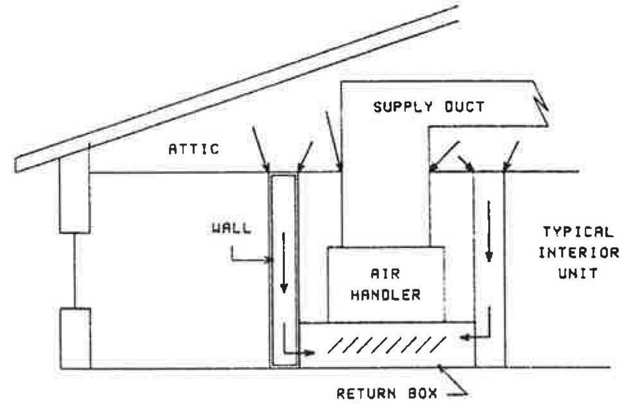



**Figure 7. Air path caused by shrinking construction materials**

## *Comfort and Indoor Air Quality*

Comfort in these homes is another important issue. The standard causes of poor thermal comfort are: solar gain through a window, lack of insulation, improperly sized HVAC, equipment not serviced properly, or weak air distribution ("the room farthest from the air conditioner just doesn't get cool"). Unfortunately, many a homeowner has tried to remedy one or more of the above problems and found no relief. Rooms with no return air system and a closed door will never cool or heat efficiently and are uncomfortable both in summer and winter. Pressure-induced infiltration, like any infiltration, reduces human comfort, whether via a cold draft or via unwanted heat and higher interior humidity. Often, raising or lowering the thermostat setting results in higher utility bills with little increase in comfort; the same house may sometimes be too hot in some rooms and too cold in others.

Indoor air quality and homeowner health are also directly linked to unequal pressures within a house. All over central Florida, homes have combustion devices coupled to the residence within the conditioned space. Negative pressures can cause excessive spillage or backdrafting from furnaces, gas water heaters, wood stoves, and fireplaces, and suck the noxious flue gases into the home. They are then picked up by the return duct system and circulated through the house. (See *HE*, Sept/Oct '89, p.6.)

Leaky ductwork and other faults in the air distribution system may pull outdoor air pollutants into the home. Our test results indicate that a minor radon problem can be exacerbated. Long-life pesticides for termites under the slab or crawl space may be drawn in, along with pesticides and herbicides around the edge of the foundation, as well as dryer exhaust vented into attics.

Pressure differences can also create interior moisture and mildew problems. In hot and humid climates, if a tighter house is depressurized during the summer, warm and humid air infiltrates into the home and does not escape. When this warm, moist air contacts much cooler indoor surfaces, many below the dew-point temperature, the water vapor condenses. Just the reverse occurs with pressurization in the north during the winter. Warm, moist air from inside exfiltrates through the building materials of the envelope, and can cause condensation. Either way, the result can be moisture and mildew and even rot of building materials.[4]

Patricia Moriarty

**While you've got your hands on the ducts, why not insulate those running through unconditioned spaces?**

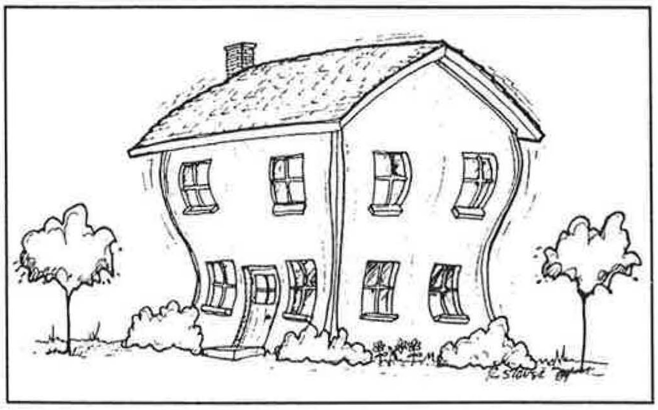
## Conclusion

We have tested and inspected 371 homes for pressure problems and found such problems in every single one. While losses vary too much for us to predict how much can be saved, it is safe to say that future research and retrofit work in this area could easily reduce overall energy use significantly.

Of the 101 homes tested for mechanically induced pressure problems, only five homes had no notable problems. We infer that a large proportion of centrally heated and cooled homes have such problems. It is clear that in future construction, builders should pay closer attention to the design of air distribution systems.

## Solutions

An air barrier for a house must meet four design conditions.



- The barrier must be air-impermeable.
- It must be able to resist the highest air pressure load.
- It must be continuous.
- It must be durable (have a long service life).

The same *must* also apply to the duct systems. We have measured pressure in residential ducts from 0 to 165 Pa (0.0-0.66" water column), which is equivalent to an approximately 0 to 30 mph wind blowing inside the duct. Undeniably, ducts need to form a continuous air barrier.

Fixing leaks in "untouchable ducts" is difficult at best and may require opening of walls, ceilings, and floors to seal (and in some cases replace). If a home's leaks reside in such inaccessible ductwork, the retrofit must always be planned with an eye to cost effectiveness, indoor air quality, and moisture problems. Fortunately, these homes are in the minority. Most homes can be repaired easily by sealing the break in the air barrier using a closure or combination of closures (e.g., high quality tapes, mastics and fiber-glass mesh, and clamps) described in the Sheet Metal and Air Conditioning Contractors National Association duct standards.[5]

New homes should be designed with returns in each room that has its own door. In some cases technicians have gone so far as to remove doors where pressurization appeared to be a safety hazard. And as always, it is important to clean the blower and coils, and to change the filter when dirty. ■

### Endnotes

Editor's note: Some of this material has also been published in the new newsletter, *Residential Energy Forum*, published by the North Carolina Alternaitve Energy Corporation. Summer 1989.


1. J. Cummings, and J. Tooley, 1989. Infiltration and pressure differences induced by forced air systems in Florida residences. Proceedings of ASHRAE Annual Meeting. Washington, D.C.: ASHRAE.
2. J. Cummings, 1988. Central air conditioner impact upon infiltration rate in Florida homes. Florida Solar Energy Center.
3. R. Gammage, A. Hawthorne and D. White, 1984. Parameters affecting air infiltration and airtightness in thirty-one east Tennessee homes.
4. "High humidity can support the growth of pathogenic or allergenic organisms. Examples include certain species of fungi, associated mycotoxins, and dust mites." ASHRAE Standard 62–1981R, Ventilation for Acceptable Indoor Air Quality.
5. SMACNA, Inc., HVAC Duct Construction Standards, Metal and Flexible, and Fibrous Glass Duct Construction Standard.