MECHANICAL AIR DISTRIBUTION AND INTERACTING RELATIONSHIPS

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ABSTRACT

It has been determined from extensive testing conducted between May 1987 and May 1988, in the hot and humid climate of central Florida, that pressure differences within the envelope of residential housing exists. These can range from near neutral to pressures, either positive or negative, as great as 0.24" w.c. (60 pascals). Reasons sighted and discussed in this paper include duct system design, duct system failure, airtightness of the residence and human interactions. This testing further reveals that one of the largest driving forces in air change rates can be attributed to mechanically induced infiltration and exfiltration. Airtightness can also drastically affect this pressure difference within the envelope.

In conclusion, the effects of these pressure differentials on energy consumption, indoor air quality, comfort, and degradation of building materials will be discussed. Possible solutions and practical field test protocol to correct these ill effects both in new and existing residential housing will be covered.

FINDINGS

The axiom, "the whole is the sum of all the parts", rings true in both new and retrofit construction. As residential housing becomes tighter it is becoming imperative that a house be viewed as a system. Extensive residential airtightness testing* was conducted between May 1987 and May 1988, on 371 single family homes, ranging from 1 year to 50+ years old. An estimated infiltration rate (ACH-50 / 20) from .35 to 1.95 was recorded (figure 1); 11.6% of these homes were mobile homes, 11.6% were frame construction and the remaining 76.9% were concrete block structures (figure 2). It has been determined that pressure differences within the building envelope* and across interior partitions of residential housing exists. The extent of airtightness of a residence can drastically effect this pressure difference within the building envelope. This testing has further revealed that one of the largest driving forces of air change rates in residential housing can be directly attributed to the operation of forced air ventilation 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 (i.e. homeowner

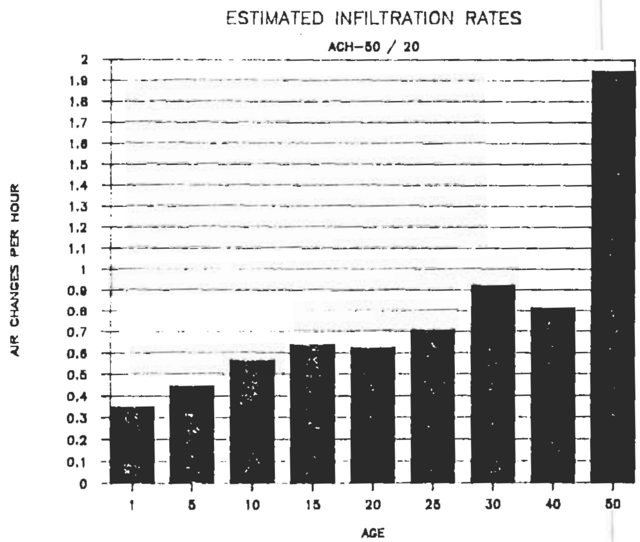


Figure 1
Estimated infiltration rate by age

health to the possible extent of illness, grave sickness and even death).

Over the period of this testing a procedure for mechanical air distribution systems inspection and interaction monitoring was developed (Appendix A). This procedure was implemented because over 90% of central Florida homes have duct systems* outside the building envelope. Prior to the

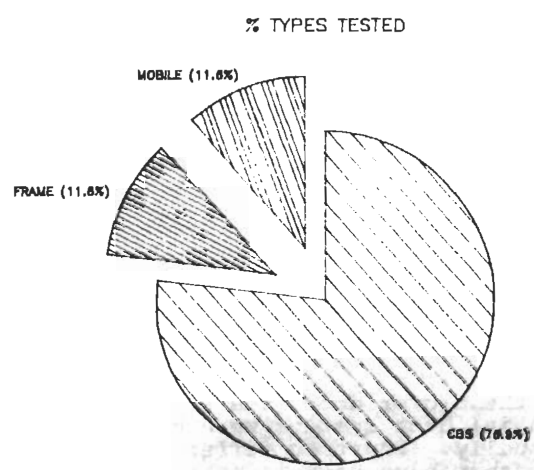
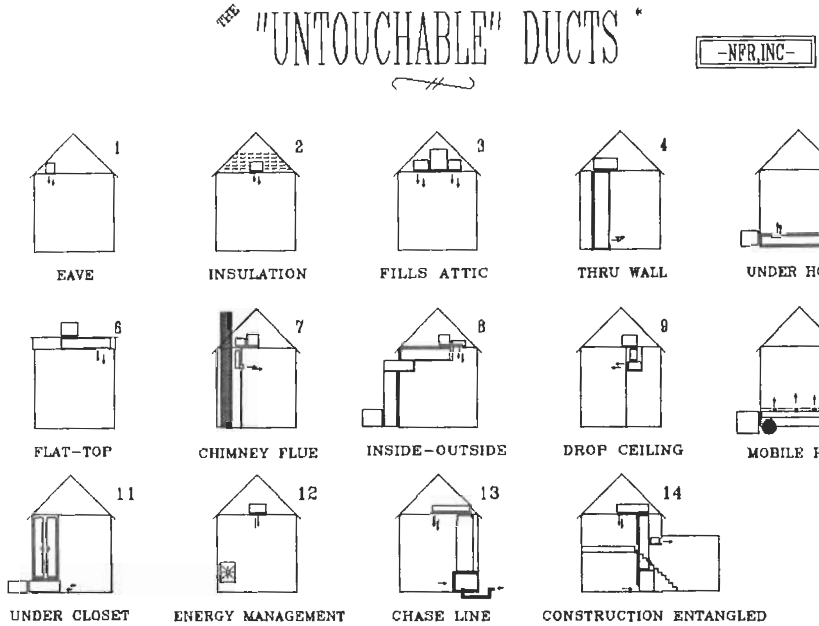


Figure 2
Construction Types Tested

Proceedings of the Sixth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, TX, October 3-4, 1989



THE 'UNTOUCHABLE' DUCTS

1..THE EAVE DUCT - NORMALLY THIS DUCT IS TOUCHING BOTH THE RAFTER AND CEILING JOISTS.

2..THE INSULATION DUCT - A DUCT THAT IS BURIED OR NEARLY BURIED IN THE ATTIC'S INSULATION.

3..THE FILLS ATTIC DUCT - EXISTS IN LOW PITCH ROOF HOMES AND ACCESS TO ATTIC IMPOSSIBLE WITHOUT DUCT DESTRUCTION.

4..THE THRU WALL DUCT - A DUCT THAT DISAPPEARS INTO A WALL CAVITY AND REAPPEARS EITHER ABOVE OR BELOW THE POINT OF ENTRY.

5..THE UNDER HOUSE DUCT - ONE THAT TRAVELS A LENGTH THRU AN INACCESSIBLE CRAWLSPACE UNDERNEATH THE STRUCTURE.

6..THE FLAT-TOP DUCT - WITH A FLAT-TOP ROOF, THIS DUCT DISAPPEARS INTO THE RAFTER CAVITY.

7..THE CHIMNEY FLUE DUCT - ONE OF TWO TYPES, EITHER THE ONLY ACCESS IS WITH A LONG LADDER (HARD TO MANEUVER IN AN ATTIC) OR THE CAVITY IS FILLED WITH CHIMNEY AND DUCT.

8..THE INSIDE-OUTSIDE DUCT - NORMALLY BLOCKED FROM VIEW AS THE DUCT MOVES FROM ONE SIDE TO THE OTHER.

9..THE DROP CEILING DUCT - MANY TIMES THIS DUCT IS COMPLETELY HIDDEN AS IT DROPS INTO A SOFFIT.

10..THE MOBILE HOME DUCT - THIS DUCT IS WITHIN THE ENVELOPE AND HIDDEN BY FLOORING ABOVE AND A FLEX PAN WITH INSULATION BELOW.

11..THE UNDER CLOSET DUCT - USUALLY FOUND IN OLDER HOMES WHERE THE CLOSET FLOORING BETWEEN END BEDROOMS HIDES THIS FELLOW.

12..THE ENERGY MANAGEMENT DUCT - THIS IS A DEAD DUCT DUE TO UTILITY CONSERVATION TURN-OFFS.

13..THE CHASE LINE DUCT - A LITTLE DUCT THAT TRAVELS FROM INSIDE THE RETURN BOX TO THE *HOT*, HUMID OUTSIDE.

14..THE CONSTRUCTION ENTANGLED DUCT - A RARE DUCT THAT IS INTIMATELY ENTWINED WITH THE STRUCTURE.

Figure 3
Duct Systems Difficult to Inspect

use of the blower door, the only way residential duct systems were being checked was visually. Fourteen different types of duct systems have been identified that could not be inspected by normal visual inspection procedures (figure 3). A blower door can increase the quality of inspections by actually testing the integrity of the duct system and to increase the ability to diagnose energy ills in residential housing.

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 outside and inside of the building envelope caused only by the air handler fan* of the air conditioner/heater, it became apparent that a house could operate in one of three pressure modes... neutral, positive or negative, with all interior doors open. A neutral condition indicated the existence of a "standard"* properly operating system (figure 4) or equal supply* and return* duct system leaks or that the house might be too loose to be measured either positive or negative. In this group of 101 houses tested for "MAD-AIR", 21 of the neutral pressure houses we tested fell in these categories: 5 were operating properly, 2 had equal duct leaks, and 11 were too loose to measure and 3 had undetermined causes of neutral pressures (figure 5). If the house was operating positive this could indicate a return duct system leak, where the return was drawing air from outside, garage, attic or soil in contact with the floor system of slab. We tested 18 houses that fell in this area and 100% of these homes had return system leaks (figure 5). While if the house was operating negative, then this could indicate that there might be supply duct system leaks. We tested 17 homes like this and 80% of these residents had supply leaks (figure 5).

Homes were also tested with the bedroom and bath doors closed during the test. This typically caused the house to operate with negative pressures in the main body* of the dwelling and positive in the bedroom areas

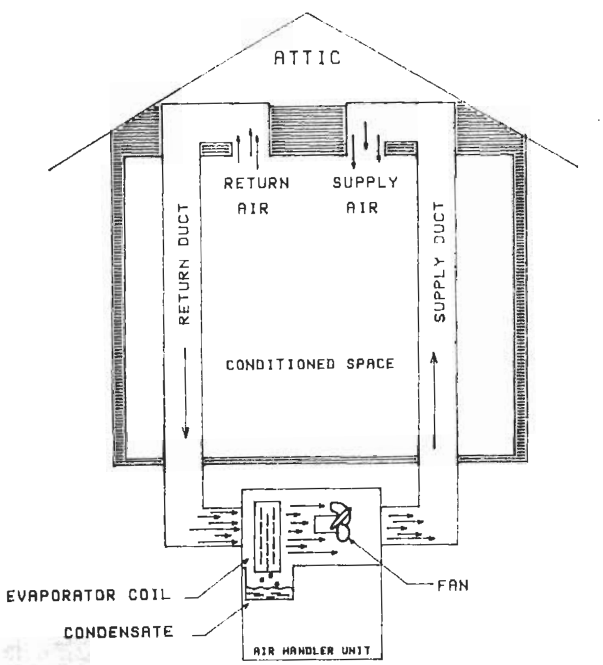


Figure 4
Simplified Single Return System

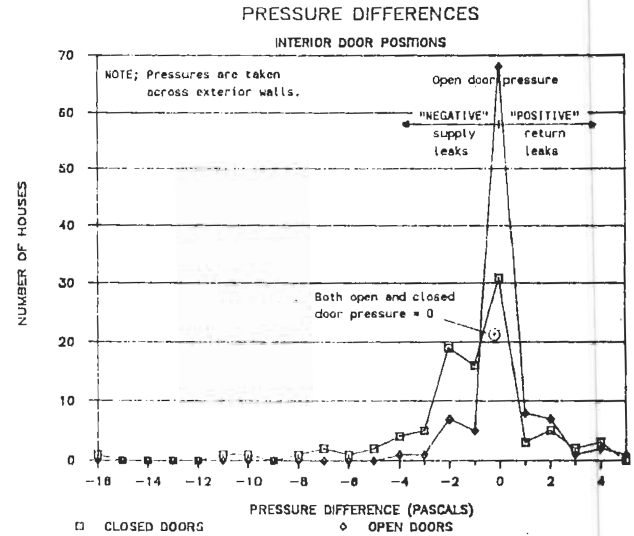


Figure 5
Pressures Differences Across Envelope

while the air handler fan was in operation (figure 6). We soon found that not only duct system failure could affect the air pressure difference in homes but that four more factors must be taken into account...

1.) duct system design
2.) homeowner interaction with the system
3.) how tight the house is and
4.) cleanliness of the blower, filter and evaporator coil.

This combination can cause air pressure differences within the house from room to room, or body of rooms to the main body of the residence. Duct system failure on the supply side of the system looses 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 gains outside air and results in positive pressures in the home. All of our duct system tests and inspections (371 houses) using the blower door, smoke guns charged with titanium tetrachloride and physical checks revealed that 100% of the systems were found to have varying leaks. Most of these leaks were measurable using the blower door and others only by the use of a smoke gun and physical inspection.

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 can not easily get back to the air handler if the doors or air registers are closed. Fifty-six homes tested with the HVAC blower on and doors closed registered negative pressures from -0.004" to -0.032"w.c. (-1 to -8 pascals) and 100% of these homes were single returned (figure 5). Pressures beyond -0.032"w.c. (-8 pascals) were found in three homes. One was related to error in

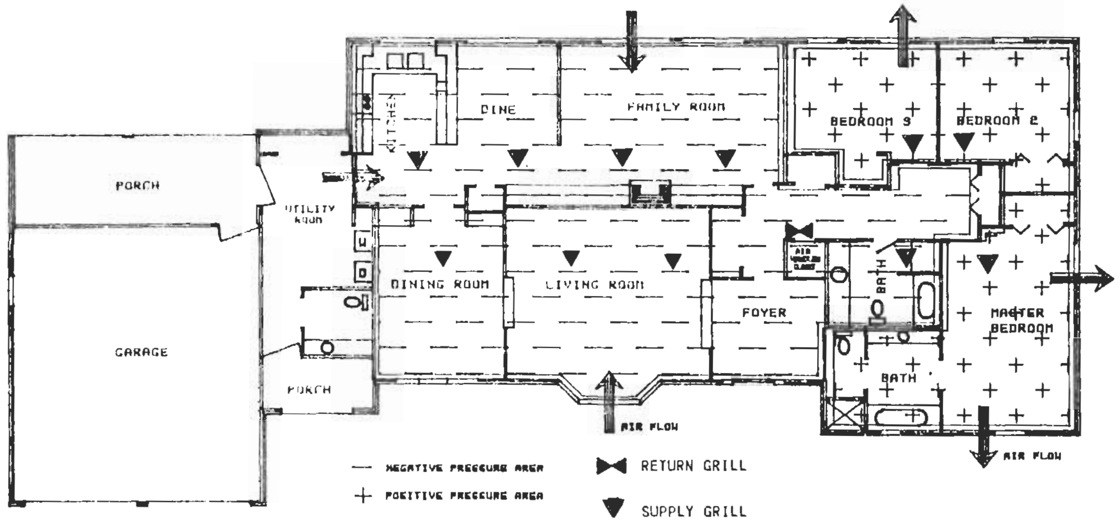


Figure 6
"MAD-AIR" in Action...Doors Closed

duct design of a zoned house (-0.244"w.c. (61 pascals)) and the other two had large supply system leaks. Multi-return systems allow easy air return to the air handler across the entire home as long as there is a return located in the main body of the home and in each bedroom. Sixteen multi-return homes were tested and ten registered a no pressure difference with doors open and doors closed and the air handler on. The other six homes had supply or return system leaks that caused either negative or positive pressures. Homeowner interaction with the system by closing of doors for privacy or air registers with the desire not to heat or cool a room can cause the home to operate with pressure differences across interior and exterior partitions. Across our testing of 101 homes for "MAD-AIR", it became difficult to measure pressure differences across the exterior partition when the house was much looser than 12 ACH at 0.2"w.c. (50 pascals). However, when the home was found to have an ACH/50 of 12 and tighter the pressure differences were easily discernible. Of the 371 homes tested for airtightness in central Florida and 216 of these fell in this range or tighter (figure 7). The tighter the house the more drastic the pressures across exterior and interior partitions. Cleanliness of the blower, filter and evaporator coils also was found to be a contributor to the degree of pressure differences. This was due the lack of air flow through the air handler caused by dirt on the blower, filter or evaporator coils. One house tested with a very dirty air filter showed a one pascal increase in pressure across the exterior partition and a two pascal increase across the interior partitions when just the air filter was changed.

Duct system design, duct system failure, human interaction with the house, and cleanliness of the system can cause the main body or room or body of rooms of a house to operate negative. In a hot and humid climate this would be one of the last things we would want to happen from an energy consumption, indoor air quality and health and last but not least comfort point of view. Across all our testing the above four mentioned causes, pointed to one of the largest driving forces in air change rates in residential housing in central Florida: the mechanical air distribution system. It

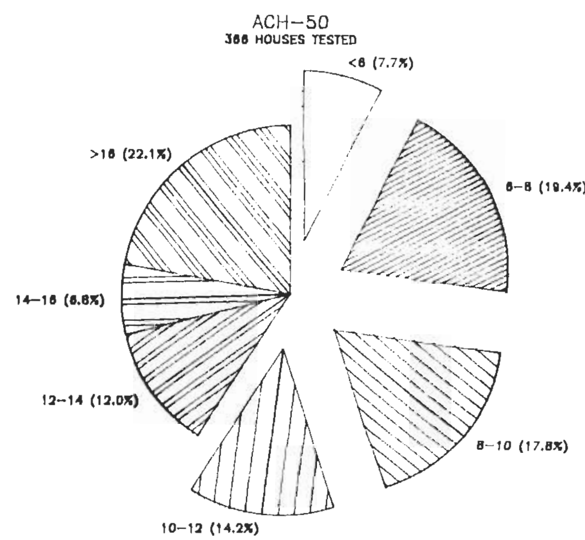


Figure 7
Range of Tightness using Blower Door

cannot be emphasize enough, "the tighter the house the more drastic the pressure differences within the residence."

ENERGY CONSUMPTION

The higher the negative and positive pressures within the house, the higher the occurrence of excessive energy consumption complaints by the homeowner 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. 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; ie, hot air rising. 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 it's 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 in many cases not considered as a major cause of infiltration and exfiltration. This fan has the capability of becoming the dominating force, pulling outside air in and pushing the inside air out of the conditioned space*. "Central Air Conditioner Impact upon Infiltration Rates in Florida Homes" written by Jim Cummings of the Florida Solar Energy Center, (where he tested nine residences) and a paper presented at the 1984 ASTM symposium on Measured Air Leakage of Buildings, "Parameters Affecting Air Infiltration and Airtightness in Thirty-One East Tennessee Homes", written by Gammage, Hawthorne and White both reported a marked difference in the infiltration rate depending on whether or not the central air handler fan was on. Both projects used a tracer gas dilution technique and tested with air handler on and off. Cummings recorded both ambient temperatures and wind speed and neither could account for the major difference in infiltration resulting from the HVAC blower being on. This adverse condition causes hot, humid air to be mixed with the conditioned air within the building envelope. 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 percentage of the remaining 80 to 84% from the attic. This leakage becomes complex even in the most standard* constructed house.

All residences tested had return leaks in varying degrees, pulling air from the attic, garage and outside depending upon the location of the air handler. Example: systems with return plenums are in most cases framed into interior and exterior walls with lumber at 19% or greater moisture content. As the system operates, it dries the wood to around 9% or less which causes shrinkage and leaves cracks that become air

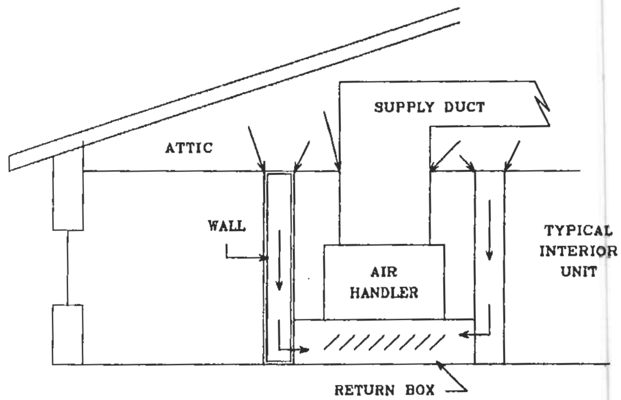
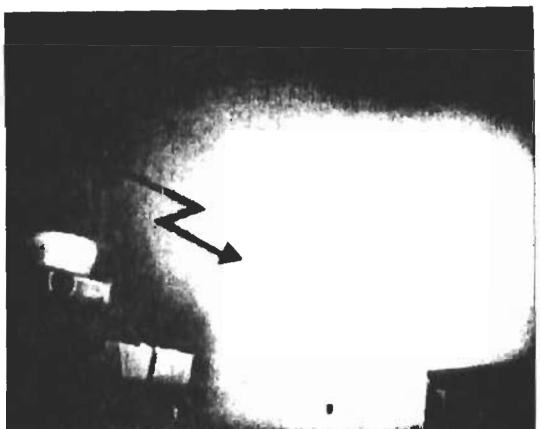


Figure 8
Air Path Created by Shrinking Materials

entry points from the attic and garage to the air conditioning system (figures 8 and 9). Supply leaks were less pronounced, but were found in each house in varying degrees also. The connection between duct and sheetrock was found to leak most. When registers and doors were closed, this connection was found to leak more than if the register or door were left open. These are only two of many examples found during our testing. House to attic leaks caused by doors or registers being closed causes a negative pressure at electric outlets and pulls attic air whether wiring holes were sealed or not. Top plates of walls also shrink from drying leaving air entry points. Plumbing entry, lights, attic access, and base trim held up off of the floor and not sealed to the floor or wall are all just a few of the leaks found to come from the attic (figures 8 and 9). Attic temperatures can easily reach 130+ degrees F with humidity levels equal to or greater than the outside ambient air. Many homes had dryer, kitchen and bathroom vent fans exhausting directly into the attic. Confirmation of this attic-to-house air leakage with the use of an infrared camera and can easily understand the homeowner reports of unusual energy consumption (figure 9). The impact to peak cooling and heating electrical demand to the utilities will be even larger as the peak temperatures outside and in the attic are at their worst when the HVAC equipment is operating at its' utmost.

At the 1987 Affordable Comfort Conference held in Pittsburgh, Pa., Arthur H. Rosenfeld, Professor of Physics, UCB, Director, Center For Building Science, Applied Science Division, Lawrence Berkley Laboratory, University of California, Berkley, California, stated "with the research and development of the fluorescent light bulb, 50% of America's lighting energy can be saved which equals 50 power plants." How many more power plants could be saved on a state and national level if we research and develop ways and means to eliminate or

Air handler unit sitting on return plenum located in garage.



Utility room wall with air handler located on other side of wall.

Thermogram of utility room wall showing hot attic air being pulled down wall.

Figure 9
Thermogram of "MAD-AIR"
Created by Leaking Return Plenum

reduce this excessive energy use caused by mechanical air distribution and interacting relationships. All over the hot and humid South, air conditioners and heat pumps are being replaced on existing homes having the aforementioned problems. Here in central Florida, large numbers of all electric homes are under construction and will most likely have the same dilemma.

COMFORT

Comfort in these homes is another important issue. The causes of poor thermal comfort are usually considered to be solar gain through a window, lack of insulation over a room or the whole house, improperly sized air conditioning units, air conditioners not serviced properly, or poor air distribution ("the room is the farthest from the air handling unit.") Unfortunately, many a homeowner has tried to remedy one or more to the above problems and found no relief. Rooms with no return air system and a closed door can not cool or heat efficiently and are very uncomfortable both in summer and winter. Pressure differences within a residence are also, as mentioned before, the cause of large intakes of both sensible* and latent* heat. This infiltration is known to be an enemy of human comfort, showing itself as a cold draft or unwanted heat and higher interior humidity. It especially shows up in the summer with an attempt to overpower the infiltration load by lowering the thermostat setting. The usual result is a cool and clammy house because of the inability of the air conditioner to adequately dehumidify the incoming air.

INDOOR AIR QUALITY

Indoor air quality and homeowner health are also directly linked to a house or parts of a house operating with negative and positive pressures. All over central Florida, homes have combustion devices coupled* to the residence within the conditioned space. Negative pressures can cause back drafting* from furnaces, gas water heaters, wood stoves and fireplaces; pulling the noxious flue gases into the home, which are then picked up by the return duct system. These flue gases are then distributed evenly across the home by the air distribution system, unnoticed by the homeowner and family. Commonly used exhaust devices such as bath vent fans, range hoods, clothes dryers, etc. also cause house depressurization*. Our testing has not addressed the effects of these fans since much research has already been done by other agencies on these devices and their interaction with the house. However, it is most important to consider the effect of these fans when analyzing the problem of back drafting. "The major short-term hazard from chimney spillage* is carbon monoxide, a particularly dangerous gas. It has no smell or color and is difficult to detect. Only a small difference exist between concentrations that are harmless and levels that can leave you unconscious or dead..."

Progressive Builder, December 1986. ASHRAE's INDOOR AIR QUALITY, Position Paper, approved by ASHRAE Board of Directors August 11, 1987, states, "Carbon monoxide combines with hemoglobin to form carboxyhemo-globin, resulting in a decrease in oxygen carrying capacity of the blood. This results in complaints of fatigue, shortness of breath, headache, nausea, and at high levels death." "About half the fatal poisonings in the United States are attributed to carbon monoxide and many sublethal poisons by this gas are unrecognized." [CARBON MONOXIDE POISONING, The New England Journal and Medicine, by Arthur J. McBay, February, 1965.] I am sure we all would agree that residential housing is much tighter today than in 1965 when this article was written.

Early last year several counties in central Florida were put on alert for having high concentrations of radon. Infiltration causes radon gas to enter through cracks in the floor slab and hollow concrete block walls, etc. This has been cited many times by research papers, TV and the local news papers alerting the public of its' danger and need for detection and mitigation*. Indoor radon concentration is believed to be the greatest "natural" radiation hazard to the general public. The test results of this project indicate that if a home has radon problems, they might very well be worsened by an air distribution system that is pulling this deadly gas into our homes. "Negative air pressure over the portion of the structure with soil contact results in a pressure driven transport of radon and other soil gases into the house." RADON MITIGATION IN TEN CLINTON, NEW JERSEY HOMES: A CASE HISTORY, by Michael Osborne, Terry Brennan and Linda Michaels. "Energy Design Update", May 1987, reported that Charles Kunz, Wadsworht Center for Laboratory Research, NYS Dept. of Health, Albany, NY used perfluorocarbon tracer (PFT) gas emitters buried in the ground near 60 homes in four different regions of New York as part of a research project to characterize the mechanism and rate of radon entry into homes there in New York. The finding was that on the average, 55% of the tracer gas emitted into the soil found it's way back into the homes. "Energy Design Update" went on to ask a very important question, "should we be considering other potentially harmful substances that are applied to lawns and gardens or washed into septic tank leach fields around houses?". "New Shelter" magazine, Healthy Home section, Aug 1986, Chemical Lawns, written by Carrie Kent and Greg Jenson, stated, "Questions surrounding some lawn service center mainly on the insecticides and herbicides used to combat pest and weed problems. Some of these chemicals may be unhealthful and even brief exposure to others can make some people and animals extremely ill." In the same article "New Shelter" reported that Carolyn Gorman of the Environmental Health Center of Dallas, Texas, says she's seeing an increasing number of patients made sick by exposure to pesticides and herbicides. "Some are sensitive to very weak solutions," she says, adding that children, elderly people, asthmatics, those with chronic lung and heart conditions and those who suffer from allergies are most susceptible.

In a tight house where the above mentioned flues and slab/wall cracks are being vacuumed, drawing in radon, flue gases and other chemicals could be the cause of severe illness and in some cases possibly death. Airtightness across the nation, across our state, our county, and our cities has become a large issue and is encouraged by all conservation programs at all levels. The results of this testing very well could be saying to fix one problem might be causing larger energy and health problems.

The tighter the house, the higher the occurrence of interior moisture and mildew problems. If a tighter house is depressurized, we now have high temperatures and high humidity infiltrating into the home. This warm moist air is now contacting much cooler surfaces, many of which are below the dew point temperature. The result could be moisture and mildew. "High humidity can support the growth of pathogenic or allergenic organism. Examples include certain species of fungi, associated mycotoxins, and dust mites." ASHRAE Standard 62-1981R, Ventilation for Acceptable Indoor Air Quality.

CONCLUSION

In conclusion, "curing one problem without creating another is a continuing challenge to the building science community." We all should take notice of this wise statement by Joseph W. Lstiburek, M. Eng., P. Eng., Building Engineering Corp., Ontario, Canada. Having tested and inspected 371 homes and duct systems during this project, the results seem clear that research in the area of interacting relationships with the air conditioning system, to include return and supply duct system design and construction is a must have item. This research could very easily reduce the need for future utility plants here in the hot and humid South and across the nation as well. Of the 101 homes tested for "MAD-AIR", only five homes were considered to have had no notable problems. This leaves us to conclude that across the housing stock in general, this is a problem in need of attention.

Here in Central Florida, we have a forgiving climate when it comes to overall airtightness. However, the location of the house leaks (attic, walls, doors, etc.) becomes a big issue here in the South. Unlike the northern section of the nation which must not have warm humid air entering the attic from the conditioned space in the winter, we in the South must not have hot humid air entering the conditioned space from the attic. Never before have we considered large amounts of very hostile hot and humid attic air entering our conditioned space via a driving force stronger than natural causes. This study seems to indicate that "MAD-AIR" should be the issue of tomorrow. With high tech products, new and innovative construction techniques and the concern for tighter, energy efficient houses, indoor air quality must be in the forefront in every phase of construction. This needs to be from the conception and design phase to the homeowner occupancy where the air conditioning system is first run. It is felt that this project demands attention to possible needs for research in all the above mentioned areas for solutions that will be compatible with the whole.

SOLUTIONS

We, of Natural Florida Retrofit, Inc. extend the following suggested solutions and submits them in full knowledge that they might not be complete in and of themselves, nor are they listed by priority.

1.) All combustion devices be uncoupled from the building envelope.

2.) Return plenums inside conditioned space must be sealed on all sides to eliminate communication with outside air through construction holes and cracks.

3.) Those systems having no return air ducts or plenum, such as those in mechanical closets, should be in closets that are completely sealed, i.e. the sheetrock wall bottom plate connection must be sealed to stop all communication with outside air.

4.) An energy retrofit code should be implemented to protect unaware homeowners. This code should include all energy retrofits of existing housing.

5.) All state and utility energy auditors should use "smoke guns" containing Titanium Tetrachloride or equivalent to assist in the diagnosis of a house as a system and its' problems.

6.) Duct system design needs research to eliminate homeowner interaction pressure differences.

7.) All new and retrofit air conditioning systems should be tested by the use of a calibrated blower door or tracer gas for mechanical air distribution and homeowner interaction to eliminate any pressure differences within the building envelope and a copy of the results be given to the homeowner and the county or city building inspection department.

8.) A set of standards for all levels of energy conservation retrofits, i.e., airtightening, insulation, air conditioning, etc., not in respect to the retrofit only, but in respect to the whole house and occupants' interaction.

ACKNOWLEDGEMENTS

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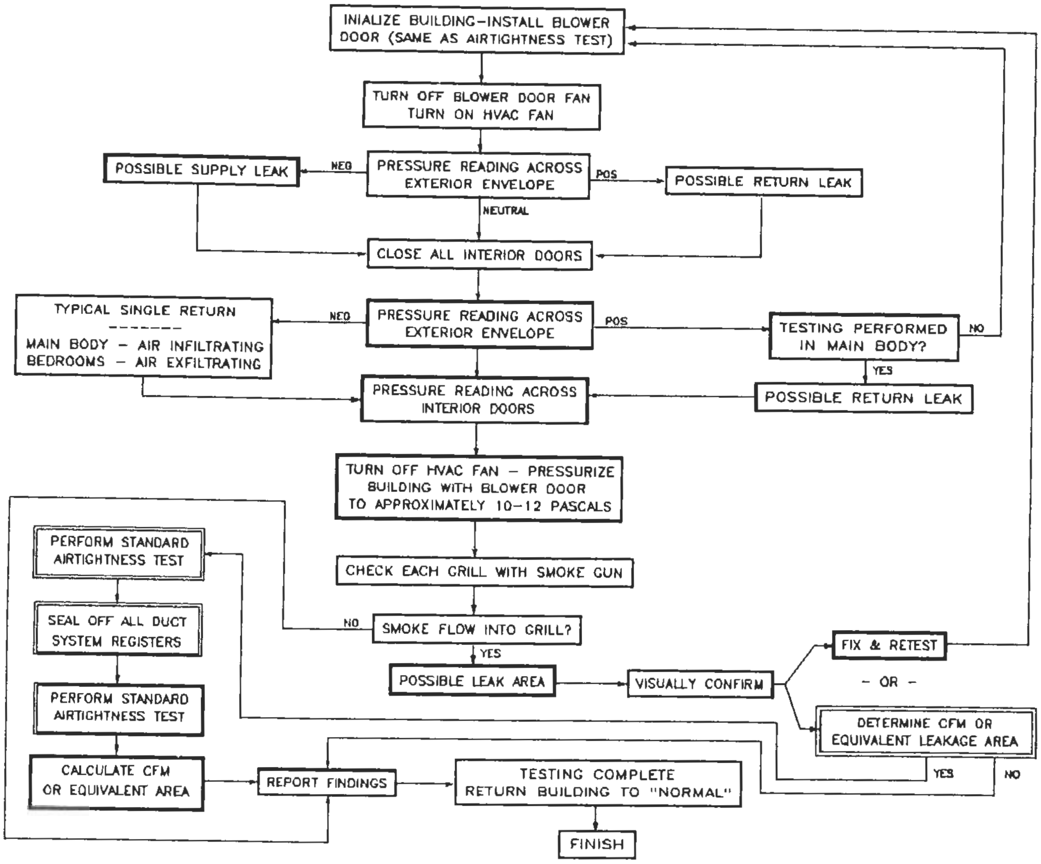
*...GLOSSARY OF TERMS...

AIRHANDLER FAN: The fan that drives cooled or heated air into the home.
AIRTIGHTNESS TEST: A measurement process to determine a building's leakiness.
BACK DRAFTING: Chimney gases spilling into the home due to a greater negative pressure in the house than in the chimney.
BLOWER DOOR: An instrument used to measure the airtightness of a building.
CHIMNEY SPILLAGE: When the flue temperature is to low to afford proper drafting, same as back drafting.
COUPLED: Having the ability to interact with the air within the home.
CONDITIONED SPACE: Only the area that is lived in, that is the area that is heated or air conditioned.
DEPRESSURIZATION: When the pressure with the home is pulling air from outside of the building envelope, the area is in a lower pressure state.
DUCT SYSTEM: The combination of return and supply ducts. See return duct and supply duct.
ENVELOPE, BUILDING: Same as conditioned space.
LATENT HEAT: The energy exchanged as water changes from a vapor to a liquid without a change in temperature.
MAIN BODY: The area of the house excluding the rooms behind doors, ie the kitchen, living room, dining room, etc.
NEGATIVE PRESSURE: Same as depressurization.
PASCAL: A unit of pressure, 248 pascals equals 1 inch of water column or 50 pascals equals approximately a 20 mph wind hitting a surface.
PICOCURIE/LITER (pC/l): 1 picocurie per liter represents the decay of about 2 radon atoms in a quart of air.
POSITIVE PRESSURE: When the pressure within the house is blowing air from inside the building envelope to the outside, a high pressure exists.
RADON MITIGATION: The process by which the radon concentration is reduced within a building.
RETURN DUCT: The system that is constructed to return the flow of air from the house to the air handler unit for heating or cooling.
SENSIBLE HEAT: The energy exchanged while raising or lowering the temperature of air.
STANDARD: A house or system that has become a rule or model by which other things like it are to be compared.
SUPPLY DUCT: The system that is constructed to distribute cooled or heated air from the air handler unit to the various rooms.

"MAD-AIR" TESTING



1. INITIALIZE BUILDING - INSTALL BLOWER DOOR (SAME AS AIRTIGHTNESS TEST)
   NOTE: YOU CAN USE GARAGE AS A BUFFER ON WINDY DAYS. INSTALL BLOWER DOOR IN DOOR LEADING TO GARAGE. CLOSE LARGE GARAGE DOOR. IF THE AIR HANDLER IS IN THE GARAGE OPEN ATTIC ACCESS OR WINDOW REMOVING SCREEN, TO ALLOW FOR PRESSURIZATION/DEPRESSURIZATION CAUSED BY LEAKS AT THE AIR HANDLER.
2. TURN ON HVAC FAN (ALL INTERIOR DOORS OPEN)
3. TAKE PRESSURE READING ACROSS EXTERIOR ENVELOPE USING A MICROMANOMETER OR OTHER DEVICE CAPABLE OF READING TO 0.5 PASCAL.
   + = POSSIBLE RETURN LEAK
   - = POSSIBLE SUPPLY LEAK
4. CLOSE ALL INTERIOR DOORS.
5. TAKE PRESSURE READING ACROSS EXTERIOR ENVELOPE
6. TAKE PRESSURE READING ACROSS ALL INTERIOR BEDROOM/BATH DOORS.
7. OPEN ALL INTERIOR DOORS AND TURN OFF HVAC SYSTEM.
8. PRESSURIZE BLDG. WITH BLOWER DOOR (10-12 PA). USE THIS LOW PRESSURE TO MINIMIZE FORCING AIR ACROSS THE EVAPORATOR COIL.
9. CHECK EACH GRILL WITH SMOKE (NOTE ALL LEAK AREAS)
10. TURN OFF BLOWER DOOR
11. IF QUANTIFYING THE AMOUNT OF LEAKAGE IN EITHER CFM OR EQUIVALENT LEAK AREA (@ 50 PA), THEN COMPLETE THE FOLLOWING....
    A - PERFORM A STANDARD AIRTIGHTNESS TEST ON THE HOUSE.
    B - SEAL OFF ALL OF THE SUPPLY AND RETURN REGISTERS USING A SEALER SUCH AS PAINTERS PAPER AND MASKING TAPE.
    C - PERFORM A STANDARD AIRTIGHTNESS TEST ON THE HOUSE.
    D - CALCULATE THE CFM-50 AND/OR EQUIVALENT LEAK AREA-50 AS FOLLOWS.....

$$\text{DUCT LEAK}_{\text{CFM-50}} = \text{CFM-50}_{\text{OPEN}} - \text{CFM-50}_{\text{CLOSED}}$$

$$\text{DUCT LEAK}_{\text{EQL-50}} = \text{EQL-50}_{\text{OPEN}} - \text{EQL-50}_{\text{CLOSED}}$$

Appendix A

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