"MAD-AIR"

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ABSTRACT

Forced air heating and air conditioning duct systems in residential housing have been largely overlooked in house diagnostics. Even the building is itself a part of the overall air distribution system. When a duct system fails, it can have some serious effects on the home. Proper air flow within the conditioned space is as important as the air flow within the duct line. Failure of a duct system or even the closing of the interior doors can create pressure differentials both within and across the building envelope when the heating and air conditioning fan is in operation. These failures may cause increased energy usage, poor indoor air quality and even promote multiple moisture problems.

In the pursuit of the high quality, tight, super insulated, and energy efficient home, we might have built in problems that can be so elusive and hidden that the best of builders only come away with stress-related illness rather than the answer that spells RELIEF.

Air flow in, through and around a house is an important concern in the building we call home. To enhance air flow and change the various conditions or properties of the air, a variety of mechanical means are employed. These range from simple bathroom vent fans designed to remove excessive moisture to

The building profession has become a very specialized industry with each sub-contractor doing a specific function. Here is where our problem starts, a basic axiom is partially forgotten. "The whole is equal to the sum of all its parts." As homes are made more energy efficient, one of the first areas of attack is in that of an infiltration barrier. Now the highly efficient HVAC system needs only to deal with the air encased within the house. According to the builder, designer, architect, the computer calculations and models, and the HVAC contractor -- all is well; the house will stay comfortable at an affordable price. But, the new homeowner complains of the lack of comfort in certain bedrooms and the utility bill is higher than predicted or expected, and mildew is appearing. The problem might easily be diagnosed as "MAD-AIR".

"MAD-AIR" (Mechanical Air Distribution And Interacting Relationships) is easily defined as air flow across a barrier created by a pressure difference induced by a mechanical device. This flow of air has the potential of drastically influencing the inside environment in the areas of comfort, energy use and indoor air quality. It can also be the source of condensation in partitions and attics causing rot and mildew in all parts of the home. The most common and dominant cause of "MAD-AIR" is the HVAC system fan. Let's consider a typical house which has been built to current energy efficient standards. This house is a typical ranch style, 3 bedroom 2 bath home with central heating and air conditioning. The duct system is located in the attic. There is a single return inlet located in the hallway near the center of the home. Because of the concern of the builder, he has the house tested with a blower door to determine its airtightness and it is found to be fairly tight (let's assume 4 airchanges per hour at 0.2 w.c. (50 Pascals) or approximately 0.2 air changes naturally). The insulation was installed according to current standards and practices and appears to be alright. The HVAC system is a highly efficient system with a cooling EER rating of 10 and has a super efficient natural gas heating. It is important to remember that quality and all current building practices and codes have been addressed and met or exceeded.

The new homeowner has moved in and is an average consumer who tries to maintain a comfortable house environment of 78 degrees during the summer and 72 degrees during the winter months. But a problem arises, he finds that there are some comfort problems in the master bedroom, mildew is appearing and the utility bill is about 25% higher than what he expected. The builder is called and a solution is sought after. The first person called in is the HVAC contractor -- something is wrong with your system. The homeowner is complaining and you need to get it fixed. With

doing something wrong.

Let's look at the problem again. First, we must look at the house and its occupants as a system. All parts of the system must be working in harmony or problems will arise. After quizzing the homeowner, we find that they leave their bedroom doors closed most of the time for privacy. At this point, part of the problem comes to light. The house was designed with all the interior doors opened -- not closed. When the interior doors are closed (with a single return inlet system), the main body of the house will become depressurized and the bedroom areas will pressurize. The comfort complaits associated with the master bedroom can now be partially understood. Closing bedroom doors is somewhat like closing the register, only a small portion of the air designed to *enter* that room actually does. Its like trying to blow air into a bottle. Very little air can be forced in because there is no exit for the incoming air. Not only does the temperature rise or fall in that room because of lack of heated or cooled air, but humidity will also rise because of the people in that room. To compensate for the lack of comfort, the thermostat is adjusted a few degrees by the homeower. Therefore that friendly central heating

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and air conditioning system is running a little longer than was originally expected. If the lack of comfort is not bad enought, this pressurization in the bedroom causes exfiltration. This loss in winter can cause condensation to form, inducing severe damage to insulation and materials in exterior walls and attic, where the warm, moist air can be forced into contact with cooler surfaces that are below the dew point temperature. These conditions also become great breeding grounds for mold and mildew.

It sounds like we might have determined the problem...but something else is going on. While the bedrooms are being pressurized by the system, the main body of the house is being depressurized. This depressurization is caused by the HVAC system starving for the air it delivered to the bedrooms and lost through exfiltration that cannot get back to the return register. Now the HVAC system is pulling outside air into the house through all the various nooks and crannies. In the heating season, if the gas furnace is not totally uncoupled from the house, (this means the furnace must not be able to interact with the inside air of the home in any way) then we can actually pull flue gases from the flue and distribute them throughout the house. While being depressurized, attic air (and its contaminants) are being pulled in, around and through any penetration of the ceiling, ie., electrical boxes, lights, vents, etc. This will not only affect the interior temperatures, but in the cooling season will also increase the latent load of the house by drawing in the higher humidity from outside (especially in the hot, humid South). This humid air will probably come into contact with a cooler surface and if dew point temperatures are reached, then moisture/mildew problems will surface. And last, but not least consider the hottest scare in the building industry -- RADON. Radon gas moves through construction by pressure differential. If radon exists and the house (or a portion of it) is at a lower pressure, then all the pieces are in place for an elevated radon count. The friendly HVAC system is distributing the problem throughout the house.

Whew, what is the solution?? Hang in there, another problem may still remain hidden - duct system leaks. The house briefly described above was assumed to have had all the HVAC duct system properly constructed with no leakage in either the supply or the return section. To have an entirely leak-free system approaches the limits of impossibility, or so it might seem. However, if there is one sure thing -- mistakes will happen. This is especially true when the contractor is asked to install his duct system in, through and around some of the most elaborate construction entanglements of a house. The return plenums are framed into existing walls, which have many cracks, holes and chase lines. The supply lines pass through walls, floor/ceiling cavities and various other passageways. Now, if the home has a problem, these holes are well hidden by the finished walls. Consider for a moment the affect of a duct system or air distribution system (ADS), which has a return-side leak. This means that the system will be able to pull air from outside the house and cause pressurization of the house (figure #1). (Great for radon control...but might cause high utility bills, comfort problems and moisture/mildew woes!) Or

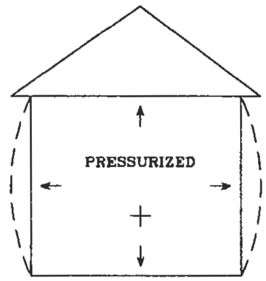

figure #1

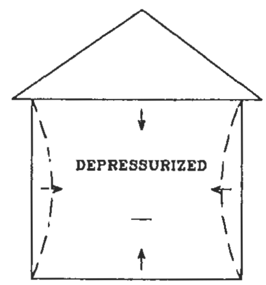

figure #2

consider the supply side leak of the ADS, these wil cause depressurization of the building (figure #2). (Now consider radon...and pesticides, etc.) But, most houses have a combination of leaks on both sides and depending on the accumulative size of leakage on either side will determine whether or not the building will be pressurized or depressurized. Of course, the amount of pressurization (or depressurization) is a function of many variables including the overall tightness of the house as well as the amount of duct system leakage. With either type of duct leak, problems arise in the form of moisture, mold/mildew, indoor air quality and of course, heating and cooling losses.

Enough is enough! I'm having nightmares, you say. It is because of these very problems with duct system integrity. and "MAD-AIR", that we have developed a test procedure. The equipment needed to perform such a test already exists... a blower door with pressure quages and a smoke gun. After preparing a house for an airtightness test, the air handler fan only is turned on. Observing the pressure change across an exterior wall will give an indication of how the ADS affects the house. The house will usually respond if there is leakage and the house is approximately 10 ACH-50 (air changes per hour at 50 pascals (0.2" w.c.)) or tighter. If there is a greater return-side leak, then the house will slightly pressurize and will slightly depressurize if the supply-side has a greater leakage. It should be emphasized that this is only an indicator of a possible problem and further investigation is a must. At this point, closing all interior doors will give a clue as to what effect occupant behavior has on the system. (Normally in a healthy single return house, the main body of the house will be depressurized when all interior doors are closed.)

It is also possible to get an approximate equivalent hole size of the entire ADS. First, an airtightness test of the entire house is performed with the blower door and from this an equivalent hole size is determined. Next, all the supply and return grills are completely sealed off to separate the ADS from the rest of the house. (We have found that plastic food wrap or painters paper with masking tape works well.) Another airtightness test is run and the difference in equivalent hole sizes is the equivalent hole size of the duct system. This is not the actual hole size of the system, but experientially, we have seen that the actual hole is approximately twice that of the equivalent size. After removing the sealant (ie., plastic wrap or paper), a smoke gun and the blower door can be used to identify the area(s) of leak. By slightly pressurizing the house to approximately 0.04"w.c. (10 pascals), note the flow of smoke at each register. The smoke will be aggressively dissipated when it is near a leak. After testing hundreds of homes, we have found that most have some degree of leakage in the duct system. Usually, this leakage is located at the return plenum and is very obsured...even with careful visual inspection. Only through the use of smoke guns and the blower, can these sometimes large leaks be found.

In conclusion, the ADS needs close attention both in the design stage and in the construction stage to ensure that the house will perform at its best. "MAD-AIR" and the headaches it produces can be a thing of the past. The solution comes from a gooding working knowledge of the interaction between all the systems, including the homeowner. Simple soulutions might vary from taking great care in the fabrication of duct systems to leaving all bedroom doors open to more expensive and fail-safe methods such as room-to-room air exchange vents to louvered interior doors or installing return air vents in each room that might be isolated from the main return.

Much of this testing was conducted between May 1987 and May 1988, in the hot and humid climate of central Florida. During this test period, we found that pressure differences within the envelope of the residential house. These ranged from near neutral to pressures, either positive or negative, as great as 0.24" w.c. (60 pascals). The various reasons included duct system design, duct system failure, airtightness of the home and human interactions. This testing further revealed that one of the largest driving forces in air change rates can be attributed to mechanically induced infiltration and exfiltration. Air tightness can also drastically affect this pressure difference within the building's envelope.

The effects of this pressure phenomenon on energy consumption, indoor air quality and health, and comfort are discussed in a paper "Mechanical Air Distribution and Interactinig Relationships" located in the Seminar Notes, 1989. Included are such items as 14 duct systems that cannot be visually inspected, a typical pressure differential graph of a single return HVAC system and thermographic evidence of a system dealing with a tremendous amount of hot attic air.