MECHANICAL AIR DISTRIBUTION INTERACTIONS WITH THE HOUSE SYSTEM IN HOT AND HUMID CLIMATES

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ABSTRACT

A large and growing body of research has proven that there are important and often dangerous interactions taking place in homes across America. The key element in all of these findings is a new understanding of the pressure differences and the resulting air flows that are occurring in our homes. These powerful driving forces or pressures are caused by the fans in HVAC systems and venting appliances. Other contributory factors are todays tight building envelopes, door closure and badly leaking forced air duct systems.

We now know that on average 25%-40% of the air handler fan flow is either coming from, or being lost to, areas outside of the thermal envelope by residential duct systems. My experience in testing and repairing over 1,000 homes in Austin, Texas has confirmed these findings. It has also been shown in tracer gas testing that in most homes the air change rate of the home will double or triple when the HVAC system is in operation thus introducing large amounts of moisture and heat into the house. Another surprising fact is the fact that interior closing doors can cause combustion appliances to experience backdrafting of their combustion by products into the home.

This paper will present a review of the basic principles of Mechanical Air Distribution And Interacting Relationships.

THE HOUSE IS A SYSTEM

The syndrome is commonly called MAD AIR for Mechanical Air Distribution And Interacting Relationships. It encompasses a multitude of interactions and consequences that threaten the health and safety of our families, the structural integrity of our homes, as well as increasing utility bills by billions of dollars annually. The key components of MAD AIR are the air distribution system, the structure, the appliances in the conditioned space and the actions of the occupants. These so called "sub systems" in fact comprise a single system that in many ways we are just beginning to study and understand.

It is an unfortunate truth that our approach to home building and design in America has been one that narrowly focused each individual on only the single aspect or system that they felt responsible for. Each firm, each professional, each sub contractor involved in the process gives their input and moves on. No one sees it as their responsibility to look at the house as a whole. The architect designs the house, but doesn't leave enough room for the ducts or consider in the design how the supply air will return to the HVAC unit. The HVAC sub-contractor installs the HVAC system, but doesn't test the house to determine if his unit will cause dangerous pressure differences in the various zones of the home.

One reason that this problem is now coming to light is the fact that we are building our homes much more air tight than we did in the recent past. This tighter construction has changed everything about the way the systems in a home interact. An old leaky home, like a tire with a large hole in it, was almost impossible to either pressurize or depressurize. Air moved easily into and out of the home. It was uncomfortable, but it didn't create zones of different pressures and it is these pressures that drive all of the other problems.

Today, we triple seal all of our new construction. Like a new tire, internal pressures can be created by very little air movement into or out of the home. In fact, when we tighten an older home's envelope and don't address the pressure balance within the new envelope we often create a dangerous situation where one didn't exist before. While it's true that ducts have always leaked and didn't cause this set of problems before, we have now changed key components in the house system and therefore have in fact a totally new reality to deal with. The key point to understand is that since the house is a system, considering only one part of the system will give you a false answer.

PRESSURES ARE THE PROBLEM

Duct leakage has been shown to be the primary driving force behind the infiltration of outside air in American homes. That's right. Wind and stack pressures finish a distant second to the pressures caused by the mechanical system. Studies done at the Florida Solar and Energy Center revealed that the air change rate of homes increased by 200%-300%

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when the air distribution system fan was operating. Since the return leak introduces additional air to the conditioned space it will in fact pressurize the house. This positive pressure drives out conditioned air and replaces it with a mixture of outdoor ambient air and attic air.

Recent tests have indicated that commercial duct systems suffer from the same problems. In terms of energy loss and poor indoor air quality, perhaps even more so because they operate at much higher pressures.

RETURN LEAKS

In hot and humid climates, duct leakage in the return side of a system will also increase the latent load on a residence dramatically. One reason for this is the fact that in most cases return plenums are not sealed air tight by the residential HVAC contractor. Tracer gas testing has shown that 70% of the leakage into return ducts comes from the attic. Return leakage rates of 15% are very common. If that air flow is 135 degree attic air with a 55% relative humidity it will degrade the efficiency of a three ton unit to only 22,000 BTU's and drop the SEER from 10 to 7.2.

The effect on the efficiency and capacity for heat pumps in the heating mode is even more dramatic. A 15% leak in the return plenum will cause a drop of 50% in efficiency. This is explained by the fact that the loss of efficiency isn't linear as it is with the air conditioner. When a heat pump can no longer meet the demand it falls back on strip heat resulting in a very large loss in system operating efficiency, not just longer run times.

Return leaks can also draw in gases like radon as well as pesticide and herbicide residues present in the soil around the home. A 1989 study at the Lawrence Berkeley Laboratories found that an air handler with a poorly sealed return plenum could exert a significant pull on the soil under a home. Using a blower door to depressurize a basement to -25 pascals, pressure readings were taken at one foot depths and at several points ranging from 1 foot to over 50 feet from the foundation. It was reported that the pressure difference created by the fan was still measurable at 30 feet from the foundation. A similar test conducted by a New York researcher found that over 50% of the tracer gas emitted three feet deep in the soil near a home passed through the air handler within one week.

SUPPLY LEAKS

Supply leaks will depressurize an entire home causing infiltration through the envelope and reduce the capacity and efficiency of the cooling system. Assuming 95 degree ambient air and 55% relative humidity a 15% loss in the supply ducts will degrade the capacity of the unit by as much as 50% and the SEER by over 30%. The reason for this is the manner in which the HVAC system and the home interact to create a cascade of effects. When the supply ducts leak, the unit becomes starved for return air. In effect the air handler and the leaking ducts are acting much like a blower door to depressurize the home. The first loss to the house system is obvious: the loss of the conditioned air out of the thermal envelope. The second loss is caused by the resulting increase in the infiltration rate of hot and humid air to make up for the duct leakage. A key concept to bear in mind is that for every cubic foot of air lost, one must be brought in to balance the scales.

We have learned through tracer gas studies and other methods that most homes experience an increase in their measured natural air infiltration of 200% - 500% each time the air handler is in operation. This effect again adds significantly to the loads, both sensible and latent, placed on the structure. You build a home with a tight envelope that allows only a 0.4 (40%) air change rate per hour. Every time that the air handler comes on the air change rate in that home will be driven up to 0.8 (80%) and possibly even 1.2 (120%) air changes per hour.

DON'T CLOSE THAT DOOR

Another culprit in the series of interactions is the closure of interior doors. For the HVAC system to operate properly, the supply air must be able to return freely to the unit. When the flow of return air is interrupted, system efficiency is lost and a series of detrimental side effects are introduced. Closing interior doors causes very large pressure imbalances in the home. The room behind the closed door becomes positively pressurized to as much as +70 pascals. The rest of the home falls to a negative pressure.

This causes the rate of outside air infiltration to increase dramatically. The air in the room with the closed door exfiltrates from the home carrying conditioned air to the outside. The rest of the home experiences increased infiltration of hot, humid outside air and some infiltration from the attic. This entire cause and effect loop has the unavoidable net impact of increasing relative humidity and energy consumption while decreasing the occupant comfort in the home.

In several studies it was found that the closing of one interior door caused infiltration rates to double. The closing of a second door tripled the infiltration rate and the closing of a third door increased air infiltration as much as seven fold.

Builders and architects can alleviate this problem in several ways. One solution is to provide some form of air bypass that would allow air to move freely from supply grilles to the return plenum. This would alleviate the pressure differences that provide the driving force for the air movement. These pressures could be mitigated by installing through-the-wall grilles or a short ducted bypass in the attic from inside the room to a register in a section of the home from which the air can flow unobstructed to the return plenum. Another solution would be to locate a return in each room. Even undercutting the bottom of the door as much as possible helps to minimize the negative impacts of this interaction.

NEGATIVE PRESSURES SUCK

Leakage in the duct system can also result in sufficient depressurization of the home to cause combustion appliances within the thermal envelope to experience a reverse flow of combustion by-products into the living space. It is estimated that such back drafting of combustion gases results in hundreds of deaths each year. As builders in our region have begun to include fireplaces and gas appliances in almost every new home, this becomes an issue relevant to most home owners.

Testing in Canada has shown that most combustion appliances will backdraft at relatively low pressures. They have set what they call House Depressurization Limits or HDL's for most combustion appliances. The HDL for a water heater is -1 pascal and only -3 for a fireplace or a gas furnace. These pressures can easily be reached by duct leakage or door closure.

I have even seen the interactions of appliances, the air distribution system and the home result in flame rollout at the water heater and a house fire. The house depressurization limit (HDL) for a domestic water heater to experience flame rollout is -12.5 pascals. Above that pressure the flame may rollout and up the side of the appliance. I know of one case in Austin in which just this sort of situation resulted in a house fire.

The causal factor was a good faith effort by a contractor to air seal a home by weather-stripping and caulking the envelope. The gas water heater was in a utility room with a washer and dryer. The doors to the room had no thresholds and large openings under them. When the doors were weather-stripped, the make up air was cut off. When a dryer operates it exhausts 200 CFM from the house. This loss of air caused the room to depressurize to -15 pascals and the water heater experienced flame roll out. This situation is an example of the type of interaction that takes place when we alter one part of a building system and fail to fully appreciate and plan for the secondary impacts that are caused by that change. In this case a tighter building envelope created a dangerous situation.

MAD AIR DEMANDS ELECTRICITY

The impacts of these problems on the peak electrical demand placed on our utilities is very serious. A recent EPRI review concluded that duct leakage and other impacts related to the driving forces caused by the operation of the central HVAC system add from one to four kilowatts to the peak demand of the average home depending on the climate zone. The more severe the climate, the greater the increase in the demand.

One reason for this is the fact that all of these negative impacts are driven by the operation of the air handler. The greater the run time of the air handler, the more significant the various effects become. Another reason is that the greatest delta T between inside, attic and outside air occurs at the same time that the highest rate of air infiltration and exfiltration is being caused by the air handler.

Think about it. All of these events happen at the same time. The air handler runs more than at any other time, the structure experiences the highest rates of infiltration and exfiltration, the ambient temperature is at its hottest (or coldest), the HVAC system is experiencing its greatest degradation in efficiency and capacity, and the cooling (or heating) load is at its highest just when the utility system can least afford to have demand increased. Is there any doubt about why utilities concerned with reducing peak demand are now stressing sealing the duct system and addressing the whole house as a system?

CONCERNED ABOUT LIABILITY

Consider for a moment the liability associated with designing or building a home in which interactions between the home and the equipment are found to introduce carbon monoxide, large quantities of moisture, radon, allergens, or particulates into the home. Worse yet, what if this interaction causes health problems or a house fire. This is a set of potential problems that simply can't be ignored.

There have been successful lawsuits based on these scenarios. In fact, the number of such cases has been rising very rapidly in the last few years as knowledge of the effects of these pressures and the diagnostic techniques to find them has been spreading. I believe that because of what we have done and are continuing to do to the house/building system indoor air quality will be a major growth field for attorneys in the ninety's.

CONCLUSIONS

Professionals and firms associated with the construction industry would be wise to become aware of these interactions and learn how to keep these problems from occurring in the homes and commercial structures that they build. The solutions are simple and require no difficult or expensive changes in current practices.

I encourage all of you to introduce these concepts to the builders, air conditioning professionals, and architects in your markets. Support changes in your local building codes that are designed to address these problems. In some states, like Florida, and at least one major code writing body the Standard Code have already been amended to address these problems. The benefits to health, energy savings, comfort and structural integrity are great and the costs of inaction too high.

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