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A Case Study of Unintended Consequences

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According to the Law of Unintended Consequences, every action has more than one effect and these effects always include some that are unforeseen. Indoor Environmental Technologies recently encountered an example of this law as it applies to modifications made to buildings to increase their energy efficiency.

The following changes interacted to create what IET has dubbed Cold Attic Syndrome.

• Modifications made to reduce heat gain through the attic.

• Modifications to the HVAC system to increase its energy efficiency and ability to control humidity.

This article discusses how these energy-efficiency designs and improvements were employed in the home and how their interaction created significant moisture and mold-growth problems.

Reducing Heat Gain Through the Attic

The case-study home is located on the Gulf Coast waterfront, where humidity levels are high most of the year, especially from June to September. During these months, the dew-point temperature in the outside air averages above 70 F and occasionally climbs above 80 F. These dew-point temperatures equate to 110 grains per pound and 156 gpp specific humidity, respectively.

Since indoor temperature is usually recommended to be set at 78 F and indoor dew point should be maintained below about 60 F, maintaining comfortable indoor conditions in the Florida environment without using excessive energy is challenging.

In most of Florida, air temperatures rarely exceed 95 F. Heat gain through walls is not as high as in areas like the desert Southwest, where temperatures routinely go much higher. However, the Florida sun is intense, resulting in high radiant heat gain to the structure. Most of this radiant heat load is absorbed by the roof, which heats the materials and air in the attic, which in turn transfers the heat through the ceiling to the occupied space below. Attic temperatures in Florida often exceed 135 F.

Several approaches have been tried to minimize solar heat gain and therefore the energy needed to maintain comfortable temperatures:

1. Ventilation reduces attic heat by exhausting hot air and pulling in cooler outside air. This can be done passively, by use of soffit and ridge vents, or actively with electric fans.

2. Insulation effectively slows heat gain from the attic or roof to the occupied space. There are two locations where insulation can be installed – on the underside of the roof and on top of the ceiling. When installed at the roof line, the attic must be of an unventilated type, which, as we will show, has other advantages.

When insulation is installed on top of the ceiling, the temperature in the attic itself is not lowered, but heat transfer from the attic into the occupied space is reduced.

3. Radiant heat gain can also be reduced by modifying roof or attic construction methods. For instance, using tiles rather than shingles reduces attic temperatures, particularly when barrel tiles, which provide an insulating air space between the tile and the roof deck, are used. Using reflective or light-colored roofing materials also reduces absorption of radiant heat. A separate radiant barrier can also be installed in the roof or attic.

Increasing the HVAC System's Energy Efficiency and Ability to Control Humidity

There are numerous ways to accomplish this. The particular systems chosen for the home in this case study used several approaches, including two-speed motors for both the air handler fan and compressor. With proper controls, these systems have the potential to efficiently remove both heat and humidity over a larger percentage of the operation cycle and also to effectively remove humidity during periods when the heat load on the structure is reduced during cooler periods.

A side effect of these more efficient systems is that the air leaving the coils and traveling through the ducts is often at least several degrees colder than in more "traditional" systems, is colder through a longer percentage of the operational cycle and the system, properly sized and controlled, runs for a greater percentage of the day. These characteristics all contribute to greater energy efficiency and humidity removal, but, as an unintended consequence, the outer surfaces of the HVAC ducts become colder and remain cold longer. This surface temperature drops low enough to cause condensation. While the ducts are insulated, the temperature of the air inside the ducts still eventually affects the temperature of the exterior surface of the duct.

Case Study

The home in question was first occupied in the last week of July, 2007. About a month later, the owners discovered significant condensation occurring on HVAC duct-system components in the attic. Building materials were getting wet and mold growth was starting. IET was retained to investigate and make recommendations to correct the situation.

The home is a 7,000 square foot, three-story concrete-block structure in a waterfront location on the Florida Gulf Coast. The moisture problems were discovered in the attic above the third floor, where the air handler and ducts for the HVAC system conditioning the third floor are located.

Heat gain through the attic into the occupied space was reduced by:

- Roofing with light-color barrel tiles;
- Ventilation through soffit and ridge vents. However, the ridge vents were never actually installed, leaving only the soffit vents to provide ventilation;
- A foil radiant barrier on the underside of the top chord of the roof trusses;
- R30 fiberglass batt insulation installed on top of the ceiling, with the vapor barrier facing up.

See Figure 1 for a diagram illustrating the attic and HVAC layout.

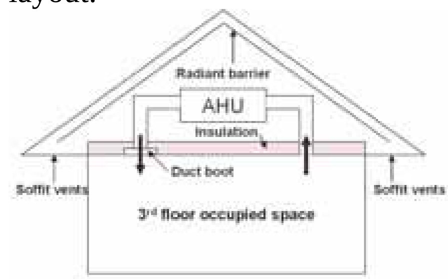

Figure 1: Diagram of attic and HVAC system components at time of inspection.

These methods were highly successful at reducing attic temperatures. During a week of temperature-humidity data logging, air temperature in the attic tracked outside air temperature closely, never exceeding it by more than two degrees. During this week, the peak temperature in the attic was 93 F and the low temperature was 85°F. Because the attic was ventilated, attic dew-point temperatures also tracked outside conditions closely, varying between 69 F and 81°F.

As discussed above, the HVAC system used in this home tends to keep colder air moving through the ducts for longer periods than many other systems. This results in the surface temperature of the duct boots (the insulated box above the ceiling that connects the fl ex duct to the vent) being colder for longer than with other systems. Exacerbating the situation, a layer of R-30 fiberglass batt insulation above the boots means that boot surfaces are well-insulated from even the modest attic air temperature. During the week we monitored conditions, the surface temperature of the duct boot varied from 63 F to 72 F.

Fiberglass insulation is highly permeable. This allows humid attic air to easily penetrate through it, where it comes into contact with the surface of the duct boot. Although there is a vapor barrier on the upper side of each strip of insulation, its effectiveness is limited because the vapor barrier is not continuous. During the week of data logging, the surface temperature of the duct boots was almost continuously below the dew-point temperature of the attic air, resulting in a significant amount of condensation, which then ran down onto the ceiling drywall. *(See Figure 2 below)*

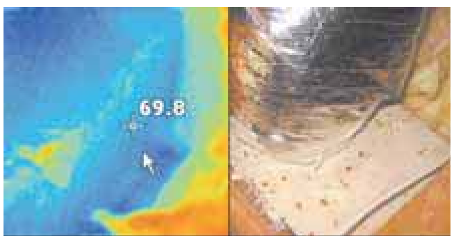

Figure 2: Thermal image (left) and visible light image of duct boot under insulation. Note surface temperature reading on thermal image.

Condensation also occurred during this period on flex-duct insulation where it attaches to the duct-board supply plenum. The attachment was made with a clamp installed over the outer jacket, compressing the insulation. As a result, the insulation lost effectiveness and the surface temperature of the duct at this point reached condensing levels for much of the period during which we logged conditions. *(See Figure 3 below)*

Figure 3: Thermal image (left) and visible light image of plenum to flex duct connection. Note significantly colder surfaces where duct insulation is compressed.

Results of Investigation

IET found that the low attic temperature, the colder-than-usual air in the ducts and the high humidity of the attic air interacted to produce significant condensation on duct-system components not adequately insulated for the conditions. Condensation was especially severe on the 14 duct boots located on the third floor. Given sufficient time, this condensation would result in extensive mold growth on drywall and other materials around the affected areas.

Options for Correction

Two approaches were considered:

1. Significantly increase the surface temperature of the affected duct components.
2. Reduce the humidity of the air contacting the affected duct materials.

Approach 1 can be achieved by significantly raising the temperature of the air passing through the ducts. However, this would require major modifications to the HVAC system, which the homeowners wanted to avoid. Such modifications would also be likely to reduce the energy efficiency of the system.

Another way to implement Approach 1 is to add sufficient insulation to the affected duct components. Due to the difficulty of access to all affected points in the complex attic, this option was also rejected.

To implement Approach 2, the attic must be isolated from the outside air, the source of the humidity. IET's research found extensive documentation showing unventilated attics to often be more efficient in hot/humid climates when properly designed and constructed. Unventilated attic systems have been controversial in Florida, but, after a 10-year battle, the local code authorities have recently agreed to allow unventilated attics without a variance.

At present, the most effective way to insulate an unventilated attic seems to be spray-foam insulation applied to the underside of the roof system. This turns the attic into a semi-conditioned space inside the pressure envelope. Having the ducts inside the pressure envelope has the highly beneficial side effect of eliminating HVAC duct-system leakage as a contributor to negative-pressure issues in the occupied space. Negative pressure is a major cause of humidity problems in hot/humid climates. Spray foam insulates well and ensures thorough sealing against outside air penetration into the attic. For the case-study home, implementing this approach would require removing the radiant barrier and the batt insulation on the ceiling. *(See Figure 4 below)*

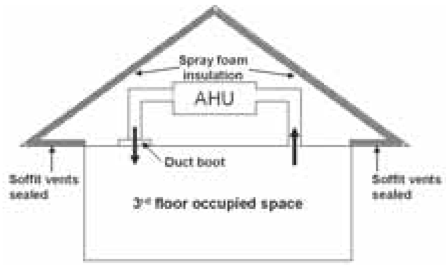

Figure 4: Diagram of modifications needed to seal attic and insulate at roof.

Application of the spray foam to the roof is a simple process when done during construction, but can be quite challenging when performed as a retrofit. Due to the complex nature of the attic in this home and the resultant difficult access to some sections, spray foam application to the underside of the roof was regretfully abandoned as an option, although it was recognized by all concerned as the best solution.

The remaining option, in simplified terms, has been described as "Seal the vents and stick a dehumidifier in the attic." This approach is not ideal. Even with soffit vents sealed, this attic was not designed to be air-tight, so humidity will continue to penetrate. The dehumidifier required to remove this humidity, when operating, adds to the energy usage of the home. The pressure envelope for the home remains at the ceiling, leaving the HVAC ducts in the attic outside the envelope. This means any HVAC-system leaks will contribute to negative pressure and humidity control issues in the occupied space.

However, "seal and dehumidify the attic" was a viable approach in this particular case, in which the owners wanted to avoid the disruption that would be caused by major modifications to the home. We expect this dehumidifier will operate primarily from June through September, when average dew point in the outside air is above 70 F, with less-frequent operation during spring and fall months. Dehumidifier run time will primarily be a function of how airtight the newly sealed attic will be, a factor which cannot be quantified in advance. See Figure 5 for an illustration of this approach.

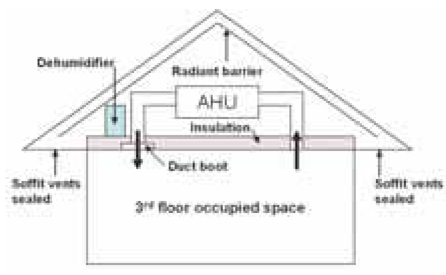

Figure 5: Diagram of modifications needed to "seal attic and install a dehumidifier."

Recommendations to the Client

IET's recommendations to the client were as follows:

1. Seal the soffit vents. This work can be performed from the outside, minimizing disruption for the residents. Also, seal other accessible openings between the attic and outside air.
2. Install an energy-efficient dehumidifier in the attic. Initially, set the humidistat at 65 percent. Ideally, the humidistat would be controlled by dew point rather than relative humidity. However, we have not yet located a reasonably priced humidistat of this type.
3. Flex duct connections to the duct board plenum were relatively accessible. Modify these connections to minimize compression of the insulation, allowing it to retain its R-value.
4. Monitor humidity conditions in the attic to ensure the dew point remains below 65 F. As experience is gained with the system, adjustments to the humidistat set point may be needed, with the goal of minimizing energy usage while still preventing condensation.

Preventing Cold Attic Syndrome in New Construction

Cold Attic Syndrome may develop in ventilated attics in hot/humid climates when one or more of these factors apply:

• Ambient temperatures in the attic are unusually low.
• The HVAC system produces colder-than-usual air and/or runs for longer periods than usual, resulting in colder surfaces on system component surfaces for longer periods.
• Permeable insulation is installed at the ceiling, insulating HVAC-system components from the heat of the attic, but still allowing humid air to contact these components.

In most cases, the most effective way to prevent Cold Attic Syndrome is to move the pressure and thermal envelope to the roof by building an unventilated attic and insulating the underside of the roof with spray foam. If a ventilated attic is desired, use more heavily insulated duct-system components and install any flex-duct components carefully to maintain their R-value.

All designs require careful consideration, or you may discover yet another application of the Law of Unintended Consequences!