Practical Implications of the Elimination of Natural Attic Ventilation in Mixed Climates

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ABSTRACT

Many attics are retrofitted with additional ventilation, primarily ridge ventilation, when the roof covering is replaced. The driving forces for this action are usually the presence of mold, wet insulation, wet or weakened wood, or the premature aging of the roof coverings. A protocol for determining the effects of the added ventilation is developed. Several occupied whole buildings are surveyed to determine the reasons the ventilation was added and to establish a base for determining the outcome of the additional ventilation.

INTRODUCTION

Attic ventilation has been studied in many model buildings and, in some cases, unoccupied homes. (Rose 1994; TenWoulde and Rose 1999; Parker and Sherwin 1998; Fulger 1999) This study departs from this norm to develop a protocol for obtaining attic moisture data in occupied homes. The study also looks at the reasons for roof replacement. The relationship of attic ventilation and premature shingle roof replacement is probed.

Attic ventilation has become controversial in the last few years as some of the data from laboratory, small scale, and unoccupied building tests have indicated that ventilation of attics may result in a net increase in energy costs and may not be effective in removing moisture (Rose 1995). Studies in certain climates have been applied to the entire housing stock, which may not be appropriate in other climatic zones.

In contrast to the research reports, roofing industry consultants and home inspectors are finding that lack of code-required ventilation is resulting in significant moisture accumulation in attics. Mold, rot, mildew, wet insulation, high-energy bills, and significant sheathing replacement during re-roofing evidence this moisture accumulation (Tsongas 1994). In addition, there have been anecdotal reports that this lack of ventilation is resulting in premature replacement of asphalt shingles. This has created a major industry in the sale of ridge vent systems and other ventilation appliances.

Moisture pick up in attic spaces is often a relatively slow process. In order for the wood in attics to become saturated, the relative humidity must be high over several months (Lstiburek and Carmody 1991; ASHRAE 1997). However, the diurnal cycle results in high and low relative humidity each day. In most areas there are seasonal cycles of high and low humidity. It is, then, the relatively high humidity that eventually results in problems. Although trends can be noted in a year, or during an experiment in the lab, there are so many factors that affect occupied buildings that most research tends only to be forensic when significant damage is noted. Looking at an inventory of houses of relatively the same age, comparing them to houses of similar age and similar climatic exposure, would provide a base for future understanding and research. A route to finding that is proposed in this study.

The opportune time to examine the attic spaces of occupied homes is when the house is sold, and it is being inspected for mortgage and insurance purposes or when re-roofing decisions are being made. In both cases the conditions are likely to be changed. When home ownership changes occur, and no other house modifications occur, changes in attic moisture can be attributed to lifestyle changes. In contrast, when the roof is

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replaced and the ventilation modified, most changes in moisture levels in the attic can be attributed to the ventilation change.

Overlying the changes in occupancy or ventilation are the seasonal changes that result in moisture changes in the attic. Seasonal changes also result in different timings for peak relative humidity and moisture content in attics. Maritime climates tend to have peak moisture contents in spring and fall, whereas midwestern and northern severe or moderate climates show peak attic moisture in winter. Arid climates are not expected to have attic moisture problems due to the dry seasons. Hot, humid climates experience significant moisture pick up in structures during their peak high humidity seasons (Powell 1994).

Research facilities can instrument buildings and examine the changes based on the diurnal as well as the seasonal cycles. Having a few opportunities to visit occupied homes will result in data that are affected by the season and the time of day. The challenge is to get useful data that reflect the true moisture and temperature conditions in attics. This study will present a form for collecting the data. An analysis of the data that accounts for seasonal variation is developed.

REASONS FOR ATTIC VENTILATION

Attic ventilation is installed in most new construction to prevent moisture buildup and to reduce the cooling load. Other beneficial effects are reduction or elimination of ice damming, prevention of mold development, and creation of a hostile environment for unwanted arthropods. Dry wood does not rot. Dry insulation provides better heat transmission resistance. Attic ventilation also provides an additional factor of safety in building construction. Although there may be specific designs that eliminate ventilation, most residential housing in the United States and Canada is designed for inclusion of code-required ventilation. When this ventilation is not installed in these homes, problems develop that can be serious structurally, such as warping and rotting of structural members (Treschsel 1994), and can affect the health of the occupants. Both mold and arthropods are typically found in moist environments (ASHRAE 2000; Romero and Brenner 1998). In addition, both the Canadian and United States model building codes require attic ventilation for all climates (ICC 2000a, 2000b).

The focus of much research and this study is moisture accumulation in the attic. With moisture the focus, the documented cooling benefits of attics are ignored. (Parker and Sherwin 1998; Petrie et al. 1998) The benefits of ventilation are found with most levels of insulation and whenever cooling is required.

Ventilation as Required by the Building Codes

The *International Building Code* (IBC) and the *International Residential Code* (IRC) require the net free attic ventilation at a ratio of 1/150. This ratio can be reduced to 1/300 if a vapor barrier of 1 perm or less is installed on the warm "ceiling" side of the insulation, and there are eave or cornice vents providing at least 50% of the ventilation (IBC) or 20% of the ventilation (IRC).

Conditions for Mold Growth

Mold exists everywhere but will grow only when some conditions are met. General conditions for mold growth include: average monthly surface humidity greater than 80% (70% danger zone). Mold growth can occur in temperatures of 40ºF+ and is usually stopped from growing at temperatures greater than120ºF, although exact high-temperature limitations vary by species and are not clearly defined. Wood decay occurs at fiber saturation of 30% or more and temperatures of 50ºF to 100ºF. Spot measurements of wood moisture should be less than 20% equilibrium moisture content (EMC). The EMC at 68ºF and 45% RH is 8.5%. In summer conditions of 75ºF and 70% RH, EMC is about 13% (ASHRAE 1997a).

COLLECTING THE DATA

A form was developed to collect the data to determine if there are problems in attics, to get the data beyond the anecdotal stage, and to attempt to trace the causes of problems. The following discussion covers the sections of the form and the importance of the data in each section.

Evidence of Concern

Mold. Any attic that has mold is of concern. The mold may be able to enter the occupied space through breaks in the air or vapor barrier. It is these same breaks that are likely to be the source of moisture that leads to mold. Therefore, when mold is detected in the attic, the key source of moisture entering the attic should be sought and eliminated. Elimination in cool or mixed climates is most likely to take the route of stopping the air, and the moisture it is carrying, from getting into the attic. In hot climates the high attic temperatures reduce the potential for mold formation. Mold has been found where the surface temperature of mold-supporting media such as wood or papers is maintained at temperatures below the maximum survival temperature of the molds. This can occur at air leakage or thermal breaks in cooling duct insulation and/or on the drywall surface beneath the insulation blanket. Sweating pipes are also a source of moisture, which may be trapped under insulation. Primary prevention is elimination of cold spots by insulating ducts and pipes and sealing cooling ducts.

The amount of moisture in the attic in heating conditions is related to the relative humidity of the occupied space below. Open air paths or direct venting can significantly increase the attic moisture content. It may also be related to the crawl space or basement area (Britton 1949). Our study, however, found little correlation of attic moisture and wet basements or crawl spaces in mixed climates.

Crawl Spaces. The moisture in the crawl space can be reduced by placing a vapor retarder over the soil and making sure it is well sealed at all joints and perimeters. Improving drainage to make sure all water runs away from the structure may also be required. Adding a vapor retarder over the soil in a crawl space is a minimal cost item. A vapor retarder should always be present and should be added when not present.

Basements. Basements may have high humidity because of high moisture in the surrounding soil. Proper drainage away from the structure is the first step in reducing the moisture load. Sump pumps that properly discharge water to a sewer can help alleviate moisture in a basement. Correct design requires drainable soils under the basement slab and as back-fill. This does not always occur.

Occupancy. The number of occupants significantly affects the humidity in the living areas. Generally as the number of occupants increases, the humidity increases, which changes the vapor drive balance between the occupied area and the attic. If there is an air path between the occupied space and attic, that increase in humidity is driven into the attic in heating configurations and can be reversed if the building is being cooled and there is high exterior humidity. Because the use of water can be very different in houses with similar numbers of occupants, the number of occupants may not be directly correlated to attic humidity.

Some of the excess moisture due to occupancy, such as direct ventilation of dryers and vent fans from bathrooms, can easily be corrected with direct venting to the exterior. There is, however, little that can be done about long showers, hot baths, and the respiration/perspiration of many bodies if direct venting or air exchange is not in place. Many middle and cold climate houses have humidifiers to keep a comfortable moisture level (30% to 60%). This moisture level may create high relative humidity if there is air leakage into the attic space. The moisture will be generated. It will need to find a way out and will take the path of least resistance.

Roof Type, Performance, and Condition. In studies in the western provinces of Canada and surveys across the U.S. building tightness was a significant variable. Most new construction was more airtight than construction more than 20 years old (Sherman and Dickerhoff 1998). Requests to those constructing the buildings to make them more airtight did not result in significant differences in airtightness. The attics were found to have significantly increased air changes as the wind speed increased moderately. These air changes were also affected by the degree of exposure to the prevailing wind. Deliberately closed attics had 0.5 to 5 air changes per hour in wind speeds of 11 mph (5 meters per second). At the same time ventilated attics had from 2 to 14 air changes per hour (Fulger 1999). This indicates that houses with the same level of designed attic ventilation could have significantly different moisture levels in the attic due to their exposure to wind. Of course an attic with an air barrier would perform differently than one without. Current studies have not pinpointed the construction details that result in more air changes in the attic.

Increasing the air changes is likely to reduce the moisture in the attic in most climates. During the day the temperature of the attic will be elevated significantly above ambient unless a white or light-colored roof or shading is present. The hotter air will have a relative humidity lower than the ambient relative humidity and therefore be able to carry more moisture out of the building without wetting the structure if more air changes can occur (Parker and Sherwin 1998).

This study is focused on attics beneath asphalt shingle roofs. Tile and metal roofs are expected to have differing amounts of air changes. Both types can be more open than shingles and some types of metal roofs can limit air exchange.

The condition of asphalt roofs is not likely to influence the air changes or the moisture in the attic, unless they are leaking. Most homeowners replace their shingle roofs before the roofs leak. Replacements are usually precipitated by, or are in conjunction with, other aesthetic changes. The shingles may, however, be near the end of their functional lives and have poor aesthetics.

The aging of asphalt shingles is increased by the time they spend at high temperature and exposure to ultraviolet light radiation. Some studies show that shingles over unventilated or poorly ventilated roofs can have daily maximum temperatures 4.8ºF to 18ºF (3ºC to 10ºC) greater than over well-vented roofs (Parker and Sherwin 1998). However, the focus on the peak temperature misses the point that chemical deterioration is both a function of time and temperature. In a Florida study the mid-attic temperature of an attic with 1/150 ventilation was 110ºF (43ºC) or hotter for 2.5 hours, whereas the mid-attic temperature of an attic with 1/300 ventilation was 110ºF (43ºC) or hotter for 7 hours. Each roof had similar shingles, exposure, and interior conditions. The attic with the 1/300 ventilation had a peak temperature of 136ºF (58ºC) and the attic with 1/150 ventilation had a peak of 122ºF (50ºC). Although the temperatures directly beneath the shingles were not reported, there clearly is significant cooling to the shingles over the 1/150 ventilated attic when compared to shingles over the 1/300 attic.

Arrhenius demonstrated that molecular activity approximately doubles for each 18ºF (10ºC) increase in temperature. Decomposition or shingle degradation is largely an oxidation reaction. The rate of decomposition is expected to follow the laws of chemical reactions as described by Arrhenius. As the increase in molecular activity leads to degradation, it's obvious that the shingles over the 1/300 roof will not last as long (*Chemical Engineers Handbook* 1973).

Ventilation Area. The code requires, and all studies report, more effective ventilation when the ventilation is balanced. The goal is to have 50% of the ventilation air arrive at the base of the attic and have that air removed at the peak. When the attic is being heated by the sun, the increased air temperature at the top of the attic allows for more moisture in the air; therefore, all entering air will leave carrying out moisture. This does not occur when the attic space is colder than the outside air. However, during the heating season the air over the insulation will also be warmer than the entering air and again the ability of warm air to carry more moisture will help carry the moisture out. This of course would be negative if there is warm moist air entering from the occupied space.

From the above discussion of air changes it is obvious that ventilation area is most important when the wind is not blowing. If an 11 mph (5 meters per second) wind is blowing, the attic is likely to have sufficient ventilation to remove all of the unwanted moisture accumulated from the occupied spaces. Future studies should evaluate ventilation and moisture pick up verses mean wind speed.

Moisture Measurement Points. This study selected the ceiling joist, the roof rafter, and the sheathing. Earlier studies pointed out significant differences in the moisture level of the sheathing and the structural wood. In cold or mixed climates, moisture frequently condenses on the sheathing and can wick into the wood sheathing. If the humidity in the attic space is high and remains so, the structural wood can pick up excessive moisture as well. Sheathing moisture, however, remains an early warning of the moisture in the building.

The moisture in the wood is compared to the equilibrium moisture content (EMC) for the measured humidity. Wood that is more moist than the projected EMC for a measured humidity is considered damp. Wood that has a moisture content greater than 20% is considered wet, and wood with a moisture content of greater than 30% is severely wet (ASHRAE 1997a). To determine if the structural wood or sheathing wood in an attic is wet, the surface moisture of the wood, that is, the moisture in the first 3 mm, was measured using a moisture probe.

Air and Vapor Barriers. Most Midwestern houses do not have vapor barriers between the interior and attics. Although the design is for airtightness between the interior and the attics, the airtightness is achieved by sealing the drywall and the addition of corner moldings. This study did not involve any leakage rate testing. Leakage is only estimated by examining the obvious locations for air leakage such as penetrations and ceiling wall interface joints. The treatment of these penetrations has been found to be inadequate in many previous studies (Buska et al. 1998). Settling and building shifts also lead to openings and air movement from the interior to the attic.

The dry wall ceilings minimally restrict water vapor diffusion. The latex paint, however, adds considerably to the resistance to the passage of moisture (Ojanen et al. 1994). In addition, blanket insulation with facers directly over the ceiling retards the vapor flow. The moisture flow through the ceiling materials is usually not considered a major contributor to the moisture in the attic. However, if the relative humidity is significantly different, enough vapor pressure differential can develop to move significant volumes of water vapor from the occupied space to the attic. If there is no mechanism to remove the water vapor, it will build up and condense on any cold surface.

Attic Ductwork. Ducts in the attic can be a significant source of air to the attic. They can also remove air if they are on the return side. Ducts will exchange heat with the attic. They may affect the stratification of air in the attic and can be locations for condensation during summer cooling. Surface condensation can drip and wet ceilings or wood supports. Leaking ducts in unconditioned space can be significant contributors to building energy requirements (Petrie et al. 1998).

Attic Insulation. Attic insulation will greatly affect the temperature in the attic and the ability of the attic to gain or remove moisture. Lowered attic temperatures in winter due to increased insulation result in significantly lower moisture carrying capacity of the air. It is also likely that the temperature at the sheathing will fall below the dew point when the attic is cooler. If the air is humid, condensation on the sheathing will occur, which can lead to high moisture in the wood if the action is repetitious. Greater attic insulation levels will result in higher attic temperatures in the summer, as the attic is decoupled from the interior. The higher temperature air will carry more moisture and will aid in drying the attic if adequate ventilation is provided.

Climate Type. If most of the air entering a building is dry, the potential for negative moisture effects of lack of ventilation are low; if, however, the air entering the facility is moist, most building products will be significantly challenged.

Heating and Cooling Degree-Days. This information is added to help categorize the buildings. There are significantly different phenomena associated with the amount of heat or cooling added to the building.

Aging. It has been found difficult to build houses with consistently high levels of airtightness. The ceiling attic interface is often found to be compromised during construction, and the aging of the structure opens more passageways for air to migrate to the attic space (Fulger 1999; Sherman and Dickerhoff 1998).

Attic ventilation has been shown to be a needed safety valve for the moisture that accumulates. Ventilation also provides significant cooling for the attic space. It has provided the release that keeps paint from peeling, wood from rotting, and insulation from becoming wet and loosing its R-Value.

Tools

The tools required to complete these measurements are quite simple and are readily available from many sources. The two key instruments are a reliable device for measuring relative humidity and a typical capacitance measuring device for determining wood moisture. A camera is the best way to record the presence of mold. A bright light is also critical for attics and crawl spaces.

THE SELECTED DATA

The data were collected with the help of a residential roofer and a home inspector. The initial data presented below were from houses in the central Ohio area, collected with the expectation that we would be able to do followup studies with these homes. This has not yet been completed and more homes are being considered. The homes provided by the residential roofers were in the 12- to 25-year age range and the median to

TABLE 1
Residential Roofing Contractor

Shingled Roof Data	10 roofs May, June -00
Roofs replaced for aesthetic reasons	60%
Roofs replaced for deterioration	40%
Roofs replaced for leaks	20%
Mold in attic	40%
Wet wood in attic	70% (Greater than 20% moisture in wood sheathing)
No ventilation added	0%
Ridge ventilation added	100%
Other ventilation added	20%
Average age of roof replaced	13 years (Range 8 to 23 years)
Typical insulation thickness	9 inches, 230 mm
Zip codes served	43081,43082, 43085

TABLE 2
Home Inspector Data

Shingled Roof Data	50 Houses inspected May -00-May -01
Replace roofs for aesthetic reasons	6%
Replace roofs for deterioration	32%
Replace roofs for leaks	18%
Mold in attic	4%
Wet wood in attic	34%
Add attic ventilation	34%
Redirect bathroom or other vents	20%
Existing ventilation ratio	>60% = 1/300 or more
Average age of roof needing replacement	>10 years Range 8 –25 years
Typical attic insulation thickness	6 inches, range 0–10 inches, 15 mm
Zip codes served	18 zip codes

higher price range ($140,000 to $450,000). The owners had signed a contract for re-roofing at the time of inspection.

All of the attic space wood was probed with a moisture probe. If wet wood was found in any location, it was recorded as a wet attic. Any evidence of mold, identified with a bleach swab, was recorded as a moldy attic.

The larger database was from a home inspection company in north central Ohio. These homes were available for access when they were being inspected for a prospective buyer. Although they do not represent the total inventory of homes in the area, they represent homes that cover the market price range in the area. Because of the large area covered by the inspector reports, the houses are expected to be quite representative, a more general inventory with all ages of homes in the area. One minor bias in the home inspector data is that about 20% of the homes were unoccupied at the time of inspection and may have been for some time.

Wet wood as defined by the inspector was a sheathing moisture of greater than 20% as measured by a moisture probe. Attics that did not show moisture staining or other signs of moisture were not probed. Mold was 100% correlated with venting of a bathroom or other interior area directly into the attic in both the contractor and inspector data.

The residential roofing contractor data found 70% of the attics inspected had high moisture versus only 34% in the more general home inspector study. There could be several reasons for this differential in results that were not investigated to date and require further followup. It is suspected that more bathrooms are vented to the attic space in the central Ohio area and the insulation contractors are not diligent in keeping the soffit vents open. There may also be seasonality in the data with May being a time when the moisture level of homes is near its seasonal high in central Ohio.

DISCUSSION

A data collection system has been developed that will provide the essential data on how attics are performing. The technique evaluates the system at opportune times, such as re-roofing or home ownership transfer, and promises to provide data on the effectiveness of added ventilation. However, unless extensive and complete data from many areas of the country are obtained, there can be little long-term value concluded from the data. This study could be expanded to retrieving continuous data if appropriately funded. However, even with funding, the access to "normal" occupied homes is difficult.

Each of the surveyed characteristics has been studied in model buildings, and mathematical models have been developed for many of these characteristics and their influence on building performance.

The value of this study is that it provides a way to document conditions in homes after long-term occupancy. It is a method that will provide a database for future study and comparison. The major question remaining is how large the population of houses needs to be to provide an adequate database to make firm policy decisions. This is a step to get the data out of the anecdotal category and on a scientific basis where trends and facts can be determined.

CONCLUSIONS

Getting opportunities to inspect attics of occupied homes is difficult. Most opportunities occur when there are genuine problems and remedial action is required. Data based on problems are likely to skew the information and create questions of validity. It, however, is also valuable when properly documented to point out the problems that are occurring. Re-roofing often occurs when there are no attic problems. This provides an opportunity to get data from performing systems. Home inspectors have unique opportunities to get these data. However, it is not their prime goal when making the inspection and requires some additional incentive to get the data needed.

Filling the database with information that is reliable and meaningful is the first step. Secondly it must be determined if the data are universal or isolated. Occupied houses present varied loadings of moisture. This real-world situation has been shown to have significantly different air leakage than is found in lab huts. The detailing and large-scale movement of materials result in significant building-to-building variation that is not found in the small scale. The data from these studies should be useful to develop boundaries for future modeling.

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APPENDIX

Attic Ventilation Data Sheets

Visit Initial 3 Month 1 year	**Provide information in the space below** ____ ____________
Date	
Name	
Address	
City	
State	
Number of occupants	
Current roof age	
Current roof condition	
Roof color	
Reason for replacing roof Aesthetics Leaks	______________________________
Ventilation area Edge ventilation square inches Ridge ventilation square inches Peak ventilation square inches Total square inches Ventilation ratio	______________________________ ____ ____________ ______________________________
Ceiling joist moisture Left Side Center Right side	____ ____________
Sheathing moisture Left side Center Right side	____ ____________
Roof rafter moisture—near peak Left side Center Right side	____ ____________
Roof rafter moisture—near eave Left side Center Right side	____ ____________
Attic temperature and RH	Temperature Floor Peak RH
Ambient RH	
Roof slope	
Attic area	Width Length Height Area
Attic volume	
Air ducts	Length #Joints Insulated

Attic Ventilation Data Sheets (Continued)

Air barrier between occupied area and attic Condition	Yes_____ No_____ Good Compromised
Vapor barrier between occupied area and attic Condition	Yes ______ No _____ Good _____ Compromised _____
Attic insulation type	
Attic insulation thickness	
Estimated R-value	
Mold	Location
Occupied area below attic RH	Temperature RH
Crawl space or basement	Temperature RH Vapor Barrier present Yes No
House area	Length Width # Stories Total Square feet
House volume	Total cubic feet
Climate type	
Heating degree-days	
Cooling degree-days	