6947

Effect of Cavity Ventilation on Moisture in Walls and Roofs

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ABSTRACT

Moisture damage in walls and roofs is often associated with air leakage. Many believe that installing vents prevents moisture problems; venting roofs is common building practice, and providing ventilation openings at top and bottom wall plates is accepted practice in U.S. mobile home manufacturing.

This paper presents a discussion of the effect of airtightness and vents on moisture and airflow in walls typical of U.S. mobile home construction. We used measured airtightness data for wall components to calculate airflows, moisture flows, and wetting or drying potentials for U.S. cold winter conditions. Vents can significantly increase air leakage through the wall. If the airflow is exfiltrative, more wetting may occur during winter in vented walls than in unvented walls. There is no guarantee that vents will provide enough ventilation with outdoor air to offset this increase in wetting. Thus, we conclude that installing vents in walls is not a reliable moisture control strategy. In addition, vents degrade thermal performance and increase construction cost. An effective air barrier and vapor retarder should provide more reliable moisture control and superior thermal performance.

Similar conclusions can be drawn for cathedral ceilings, although we believe field studies of unvented cathedral ceilings are warranted. We do not recommend change in the current practice of providing attic ventilation at this time.

INTRODUCTION

Installing vents in attics, cathedral ceilings, and flat roofs is widely accepted in the U.S. building industry and building codes as a necessary measure to prevent moisture problems. To a lesser extent, installing vents has also been adopted as a method to relieve moisture problems in wood frame walls of manufactured houses (U.S. Department of Housing and Urban Development 1990). The rationale for adding vents is simple: ventilation provides a mechanism for removing moisture that enters the attic or cavity from the conditioned space or elsewhere. Thus, ventilation is thought to increase the ability of the cavity to dry. Installing vents in an unheated attic is relatively easy and straightforward, but installing vents in walls or cathedral ceilings is more difficult and costly and causes a greater loss of insulating value. Cavity ventilation is sometimes recommended to dry wet building materials. This is, of course, unneccessary if dry building materials are used. To dry wet materials, strategies other than installing permanent vents should be considered.

Field moisture studies showed that moisture problems in walls and roofs often correlate with air leaks (Platts 1987; Tsongas and Nelson 1991). Installing ventilation openings to the wall or roof cavity may increase the air leakage through the wall, thereby increasing rather than decreasing the potential for moisture problems. This may explain the lack of consistent experimental confirmation of roof or wall vent effectiveness. At least in one instance, wall cavity ventilation appeared ineffective at reducing moisture levels in the sheathing (Sherwood 1983). The effectiveness of vents depends on the balance between the drying potential of ventilation air and the wetting potential of any additional moist air leakage.

This paper discusses the merits of wall and roof cavity ventilation, illustrating it with an example of wall ventilation in manufactured houses. We present simple equations to calculate approximate drying or wetting potential in a cavity as a function of cavity ventilation rate and exfiltrative or infiltrative airflow.

THEORY

The purpose of cavity vents is to create or increase a drying potential in the cavity. This section describes a simple analytical procedure for estimating the wetting or drying potential at a selected location within a wall or roof. In addition to thermal conduction and water vapor diffusion, the procedure also takes airflows into account.

An earlier paper introduced a simple equation to calculate the temperature and net vapor flux at a selected location in a multi'layered wall (TenWolde 1985). The temperature at that location can be calculated with

$$t = t_i-(t_i-t_o)\frac{e^{Ax}-1}{e^{A}-1} \tag{1}$$

Equation 1 assumes steady-state. one-dimensional heat flow. The nomenclature section of this paper lists the terms, symbols, and units used in all equations.

The approximate net vapor flux is

$$w = \frac{B}{R_v}\left\{\frac{(p_i-p_s)e^{By}}{e^{By}-1}-\frac{(p_s-p_o)}{e^{B(1-y)}-1}\right\} \tag{2}$$

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If positive, w represents the rate of wetting at that particular location, and if negative, w represents the rate of drying, assuming there is free water at that location. Equations 1 and 2 account for the effect of steady-state, one-dimensional thermal conduction, water vapor diffusion, and airflow through the wall from the inside to the outside (exfiltration) or in the reverse direction (infiltration) (Figure 1). Latent heat, hygroscopic effects, thermal storage, and liquid moisture flow are ignored.

The appropriate value of the dimensionless thermal resistance x depends on location L in the wall and the thermal properties of the materials:

$$x = \frac{1}{R_t}\int_0^L (1/k)\,d\ell \tag{3}$$

The value of x varies between 0 (inside surface) and 1 (outside surface). The dimensionless vapor diffusion resistance y depends on the vapor diffusion properties of the materials:

$$y = \frac{1}{R_t}\int_0^L (a/\mu)\,d\ell \tag{4}$$

In SI units, a = 1; in I-P units, a = 12.

If thermal and moisture properties are assumed to be isotropic in each of the wall materials, x and y can be calculated with a simple summation of resistances of the individual materials. Because we are usually interested in the thermal moisture conditions at the interface between two different materials, Equations 3 and 4 can also be written as

$$x_n = x_{n-1} + D_n/(k_n \cdot R_t) \tag{5}$$

$$y_n = y_{n-1} + D_n/(\mu_n \cdot R_v) \tag{6}$$

The objective of cavity ventilation is to have outdoor air enter the cavity and exit again to the outside (Figure 2). Effects of cavity ventilation can be approximated with equivalent resistances parallel to the vapor diffusion and thermal resistance of the exterior sheathing and siding. This assumes that the ventilation air does not significantly penetrate the cavity insulation (Figure 3). The net additional heat flow from the cavity resulting from ventilation is

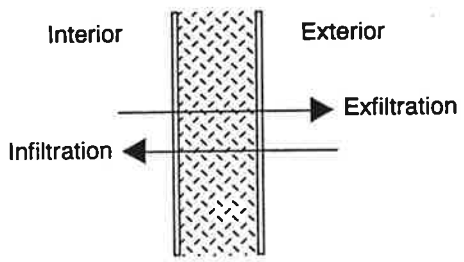


Figure 1 *Infiltration and exfiltration of wall cavity.*

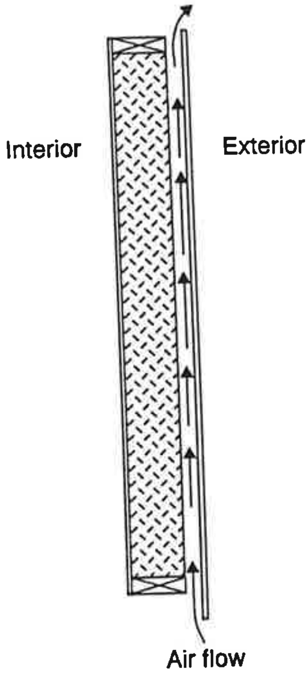


Figure 2 *Circulation of exterior air through wall cavity.*

$$q_{vent} = Q \cdot \rho \cdot c_p \cdot \Delta t \tag{7}$$

The equivalent parallel thermal resistance representing the ventilation heat flow is

$$R_{t,par} = S \cdot \Delta t / q_{vent} = S/(Q \cdot \rho \cdot C_p) \tag{8}$$

Similarly, the net vapor flow resulting from ventilation can be approximately represented by an equivalent vapor diffusion resistance in parallel to the vapor diffusion resistance of the exterior materials of the wall:

$$R_{v,par} = S \cdot \Delta p / w'_{vent} = S/(Q \cdot \rho \cdot c) \tag{9}$$

In SI units, c = 6.14 Pa^{-1}; in I-P units, c = 145 grain/lb·in. Hg. The total equivalent thermal or vapor diffusion resistance across the exterior can now be represented with

$$R_{e,ext} = R_{par} \cdot R_{ext} / (R_{par} + R_{ext}) \tag{10}$$

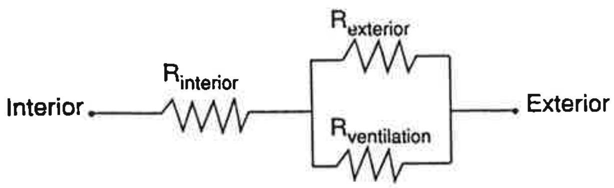
where

R_{ext} = resistance of the exterior siding and sheathing,
R_{par} = parallel resistance.

The total equivalent resistance of the wall is

$$R_e = R_{int} + R_{e,ext} \tag{11}$$

Temperatures and wetting or drying conditions can now be calculated using the equivalent values for x, y, and resistances. These equations can be easily implemented in a computer spreadsheet program.



$R_{interior} = R_{gypsum} + R_{insulation}$

$R_{exterior} = R_{siding}$ or $R_{sheathing} + R_{siding}$

Figure 3 *Model for heat or vapor transfer through wall.*

An example using Equations 8 and 9 also offers immediate insight into the relative magnitude of the effect of ventilation on moisture performance when compared to thermal performance. Ventilation of a wood stud wall cavity, 0.4 by 2.4 m (16 in. by 8 ft), with outdoor air at a rate of 1 air change per hour (ach) would have the thermal effect of a parallel equivalent thermal resistance of about 35 $m^2 \cdot K/W$ (200 $h \cdot ft^2 \cdot °F/Btu$). This is a very large resistance compared to typical thermal resistances of sheathing and siding materials, and this level of ventilation therefore has a negligible effect on thermal performance, if the ventilation air does not significantly penetrate the cavity insulation. However, the parallel equivalent vapor flow resistance is about 5.6 10^9 m/s (0.32 1/perm), which is within the range of typical vapor flow resistances for sheathing and siding materials. Thus, vapor flow is likely to be significantly affected by ventilation.

The ratio of the equivalent thermal resistance and the vapor diffusion resistance is independent of the ventilation rate:

$$\frac{R_{t,e}}{R_{v,e}} = \frac{C}{C_p} = \frac{0.0038 s^2 \cdot °C}{N} \qquad (12)$$

or in the British units,

$$\frac{604 \text{ grains} \cdot °F}{\text{Btu} \cdot \text{in. Hg}} .$$

Thus, the conclusion from the example can be generalized: ventilation of wall or roof cavities usually has a much greater effect on moisture performance than on thermal performance.

WALL CAVITY VENTILATION

We used the equations in the "Theory" section to determine the effects of cavity ventilation on drying and wetting of walls typical of manufactured housing. We used the results of air pressurization tests on several test walls to calculate the exfiltrative or infiltrative airflows into the cavity at a standard pressure difference of 4 Pa (0.016 in. of water) across the wall. Following is a short description of the walls and the test procedure.

Airtightness Measurements

We determined the airflow characteristics of two pairs of similar test walls, all with a standard duplex electrical outlet (Table 1). The walls had nominal 2 by 6 in. (standard 38 by 140 mm) wood framing, 0.41 m (16 in.) on center, and were 2.1 m (7 ft) high. On the interior, 11-mm (7/16-in.) gypsum board with vinyl finish was fastened with drywall screws. The vinyl finish qualified as a vapor retarder. We caulked the joint between the framing and gypsum board to ensure that all airflow between the cavity and the interior would be through the electrical outlet. We installed 13-mm (0.5-in.) painted waferboard siding on the exterior. In two walls (2HB and 2LB), ventilation spacers approximately 6 mm (0.25 in.) thick were installed between the plate and the siding at the top and bottom to provide cavity ventilation. In the other two walls (1HB and 1LB), the siding was nailed directly to the framing. The wall cavities all contained R-19 glass fiber insulation with kraft paper facing. There was no air space between the insulation and the siding in any of the walls.

We measured airtightness of the walls with a test procedure derived from ASTM Standard Method E 783-84 (ASTM 1984). We used a blower to pressurize or depressurize a specially constructed box with an open face designed to tightly fit against the interior gypsum board over the electrical outlet (Figure 4). To ensure a tight fit, the edge of the open face of the box had a foam gasket; air leakage through the gasket was negligible.

The following were important features of the test procedure.

1. Air pressure differentials across the outlet and across the insulation and waferboard siding were measured simultaneously and individually.
2. These pressure differences were measured at a sequence of different airflow rates through the wall. Because of the careful caulking of the seam between the gypsum board and the wood members, we assumed that the airflow rates through the outlet and the exterior membrane were equal.
3. The pressure differences ranged from 0 to 150 Pa (0 to 0.6 in. of water) across the tighter membrane.

The pressurization data were collected as part of a field study that will be reported at a later date. We fitted the results for each wall membrane to a power equation

$$q_{air} = K \cdot p_{air}^{b} \qquad (13)$$

and calculated effective leakage area (ELA) at a reference pressure of 4 pa (0.016 in. of water) We also calculated the ELA of the entire wall from the individual pressure-flow relationships. The results are shown in Table 1. Whereas the average ELA of the unvented walls was 2.5 10^{-5} m^2 (0.039 in^2), the average for the vented walls was 7.7 10^{-5} m2 (0.12 in^2). This means that at 4 pa (0.06 in. of water) air pressure difference, the infiltrative or exfiltrative airflow was about 65 10^{-6} m^3/s (8.3 ft^3/h) through the unvented wall and 202 10^{-6} m^3/s (25.7 ft^3/h) through the vented wall, a three-fold increase.

TABLE 1
Effective Leakage Area (ELA) of Walls*

Ventilation	Wall Type		Pressure Direction (10^{-5} m^2 [in^2]) Positive	Negative	Average
No Vents	1LB	Outlet	9.8 (0.152)	12.8 (0.198)	11.3 (0.175)
		Exterior	3.4 (0.053)	4.5 (0.070)	3.9 (0.060)
		Total wall	2.9 (0.045)	4.1 (0.064)	3.5 (0.054)
	1HB	Outlet	6.2 (0.096)	5.9 (0.091)	6.0 (0.093)
		Exterior	1.6 (0.025)	1.9 (0.029)	1.7 (0.026)
		Total wall	1.4 (0.022)	1.6 (0.025)	1.5 (0.023)
Vents	2LB	Outlet	7.8 (0.121)	8.3 (0.129)	8.1 (0.126)
		Exterior	47.1 (0.730)	54.7 (0.848)	50.9 (0.789)
		Total wall	7.1 (0.110)	7.6 (0.118)	7.4 (0.115)
	2HB	Outlet	8.7 (0.135)	7.5 (0.116)	8.1 (0.126)
		Exterior	106 (1.643)	169 (2.619)	138 (2.139)
		Total wall	8.6 (0.133)	7.5 (0.116)	8.0 (0.124)

*Reference pressure 4 Pa (0.016 in. of water).

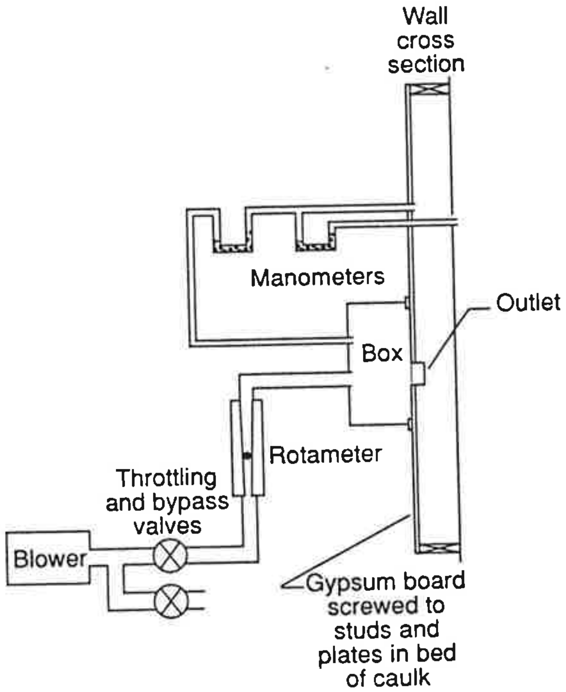


Figure 4 *Apparatus used to measure airtightness of walls with electrical outlets (box shown was pressurized).*

Wetting and Drying

The equations in the "Theory" section were used to estimate the potential net effect of cavity ventilation on wetting or drying conditions in the cavity of the walls described. We chose an indoor condition of 21.1°C (70°F) and 50% relative humidity (RH) and a winter outdoor condition of -6.7°C (20°F) and 50% RH and calculated the net vapor flux to the back of the waferboard siding, the wettest expected location in the wall during winter. The thermal conductivity values and permeance data listed in Table 2 were used. We examined the effect of infiltrative and exfiltrative airflow on the net vapor flux, assuming a constant 4 Pa (0.016 in. of water) air pressure across the walls. The net vapor flux was calculated assuming various levels of outdoor air circulation in the cavities with vents (cavity ventilation). We also included a wall of identical construction without an electrical outlet in our analysis, assuming no significant exfiltrative or infiltrative airflow through that wall. Comparing this wall with the other two walls revealed the effect of air leakage through an outlet on the wetting or drying potential.

The results are shown in Figure 5. Positive values indicate wetting conditions at the back of the siding; negative values indicate drying conditions. The wall with an outlet but no cavity vents experiences some wetting at a rate of 0.47 10^{-6} kg/m^2·s (2.4 grain/h·ft^2) with air exfiltration and slight drying at 0.11 10^{-6} kg/m^2·s (0.6 grain/h·ft^2) with the same amount of air infiltration.

The results for the walls with an electrical outlet clearly show that adding vents does not always increase the drying potential in the wall and could actually result in a substantial increase in wetting of the siding. The wetting or drying potential depends on the direction and magnitude of the airflow through the wall and the degree to which the vents allow outside air to circulate through the cavity (cavity ventilation). When the pressure differential induces infiltration through the wall, drying conditions prevail at the back of the siding, even without cavity ventilation. Thus, with infiltrative air pressure there is no need for vents. The vents cause an increase in infiltration, which results in an increase in the drying potential from O.11 10^{-6} kg/m^2·s (0.6 grain/h·ft^2) to 0.35 10^{-6} kg/m^2·s (1.8 grain/h·ft^2). Cavity ventilation further increases the drying rate. However, when the 4 Pa air pressure differential is in the opposite direction, the wall with vents experiences more air exfiltration, causing a three-fold increase in wetting if there is no effective cavity ventilation. The wetting potential decreases

TABLE 2
Thermal Resistance and Water Vapor Permeance of Materials in the Walls

Wall Material	Thermal Resistance ($m^2 \cdot K/W$ [$h \cdot ft^2 \cdot °F/Btu$])	Water Vapor Permeance (10^{-9} s/m [perm])
Air film	0.12 (0.68)	22. (380)
Vinyl-covered gypsum board, 11 mm	0.053 (0.3)	0.03 (0.5)
Kraft paper	0	0.06 (1)
Fiberglass, 0.14 m	3.35 (19)	1. (20)
Painted waferboard, 13 mm	0.088 (0.5)	0.1 (2)
Air film	0.03 (0.17)	200. (3,500)

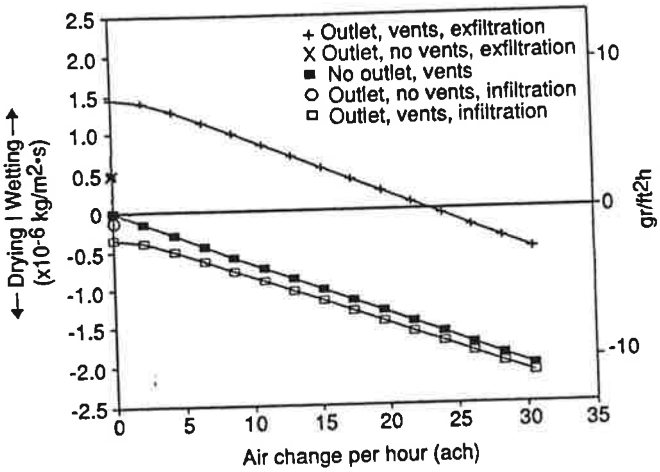


Figure 5 *Influence of vents, electrical outlets, and airflow on wetting and drying potential in wood-frame wall during winter.*

if the vents simultaneously provide cavity ventilation. However, there is no improvement compared to the wall without vents unless the vents provide cavity ventilation of over 15 ach, and drying will not occur with less than 23 ach.

Figure 5 also shows that with little or no cavity ventilation, the wetting potential on the back of the siding with air exfiltration is greater than the drying potential with the same rate of air infiltration. This difference between wetting and drying potentials increases dramatically with the addition of vents, unless the vents provide a significant amount of cavity ventilation. Thus, in order to maintain dry siding, infiltration must prevail over exfiltration most of the time, unless there is significant cavity ventilation. As we discuss later, neither significant cavity ventilation nor air infiltration can be guaranteed in practice.

Finally, Figure 5 shows that a wall with vents and without an electrical outlet behaves very similarly to a wall with vents, an outlet, and infiltrative airflow. We assumed that the vinyl-covered gypsum board without an outlet functions as an effective air barrier, preventing any significant exfiltration or infiltration. A significant wetting effect associated with an outlet only becomes apparent with exfiltrative airflow.

Interpretation of Results

Although vents in walls are intended to improve drying conditions in the cavity, our calculations indicate that vents may have the opposite effect. The effect of vents mainly depends on three parameters: the airtightness of the inside wall membrane, the direction of the dominant air pressure difference across the wall, and the amount of ventilation provided by the vents. We initially limit our discussion to winter heating conditions.

The results for the wall without an outlet show that if the inside membrane (gypsum board) is airtight and has a vapor retarder, the cavity and siding will experience drying conditions and should not exhibit moisture problems during winter. If the wall is constructed with wet materials, drying may not be adequate to dissipate the moisture, but wet building materials should be dried before installation or before closing the cavity. Thus, with an effective air barrier and vapor retarder on the warm side, vents should not be needed.

Without an effective air barrier, significant amounts of moisture may accumulate in the cavity because of exfiltration through the wall. As demonstrated with our example, vents may cause a significant increase in exfiltration and condensation if the exterior membrane is relatively airtight without the vents. Vents only encourage drying if enough outdoor air is circulated through the cavity to offset the negative effects of air exfiltration. Thus, the effectiveness of vents mostly depends on the balance between exfiltration and cavity ventilation.

The balance between exfiltration and cavity ventilation cannot be easily identified. With a vent at the top and bottom of the cavity, the amount of ventilation in each cavity depends on the air pressure difference between the two vents. These pressures and the resulting ventilation are difficult to quantify. Pressure differences from thermal stack pressure on the cold side of the wall cavity are likely to be small, in the range of 0 to 1 Pa (0 to 0.004 in. H_20) during winter. Wind pressure, indoor stack pressure, or pressure from an air distribution system could easily overwhelm this weak cavity stack pressure. Wall cavity ventilation is more likely governed by differences in wind pressures between the top and bottom of the wall, but these differences are not necessarily large enough to prevent a

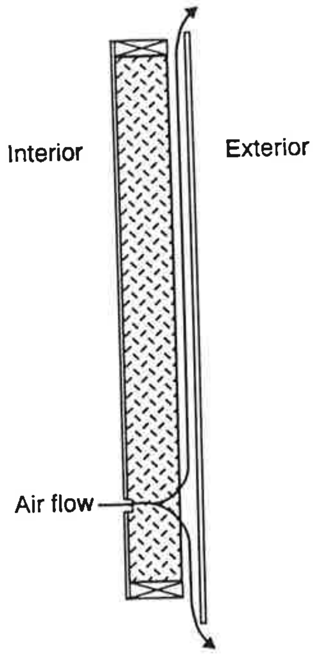


Figure 6 *Purely exfiltrative airflow in wall.*

purely exfiltrative air flow through both vents (Figure 6). Thus, there is no guarantee that vents will deliver adequate cavity ventilation for drying. In fact, there is a good possibility that vents will cause more wetting.

Modest air infiltration encourages drying, even without any exterior vents. Adding vents tends to increase infiltration and drying, but vents may permit so much cold air infiltration that it may seriously degrade the thermal performance of the wall and even induce condensation or mold growth on the interior wall surface.

Thus far we have limited our discussion to winter conditions. An increasing number of homes in the United States are air conditioned during all or part of the summer. Moisture entering the cavity with ventilation air may condense on the back of any vapor retarder on the air-conditioned interior, especially in humid summer climates. The risk of condensation is increased with any additional air infiltration through the wall assembly because of vents. Exfiltrating air does not pose a risk for wetting the exterior during summer.

In summary, during winter there is no guarantee that exterior vents in walls will deliver enough wall cavity ventilation for drying. In fact, there is a good possibility that vents will cause more wetting. Vents may also seriously degrade the thermal performance of the wall. In humid summer climates, vents may increase moisture levels in walls of air-conditioned homes.

VENTILATION OF CATHEDRAL CEILINGS AND FLAT ROOFS

In many respects, the situation for wood-frame cathedral ceilings and flat roofs is similar to that for walls, but there are important differences as well. Because the permeance of roofing and sheathing may be significantly lower than the permeance of siding and sheathing in most walls, water vapor diffusion through the top of the roof is likely to be smaller. This may cause a small wetting potential at the roof sheathing in the absence of any airflows. However, a very small amount of outdoor air ventilation (about 0.2 ach) offsets the effect of the lower permeance. Roofs generally receive more sun than do walls, which raises the average temperature of the roof sheathing and should further alleviate moisture problems. Another significant difference between wall cavities and cathedral ceiling cavities is in the dominant air pressure differences they are likely to experience and the amount of cavity ventilation they are likely to receive.

With vents at the bottom and top of each ceiling cavity, cavity ventilation may be thermally driven as well as wind driven. During the day, the thermal component in the ceiling cavity may be larger than that in walls because of solar heating of the cavity. The thermal component is larger in steep roofs than in low-pitched roofs and is virtually nonexistent in flat roofs. Wind often produces lower air pressure at the top than at the bottom of the roof, reinforcing the thermally driven ventilation, but vents must be installed at top and bottom to take advantage of this. Roof cavities with only a top or bottom vent will not receive much ventilation.

The stack effect in a house creates an exfiltrative air pressure at the ceiling during winter, and the resulting air leakage from below may offset any advantage gained from wind-driven cavity ventilation. In addition, the distance between the two vents is likely to be larger in roofs than in walls, reducing the chance for effective cavity ventilation. On balance, the conclusion is therefore the same for roofs and walls. There is no guarantee that vents will deliver enough ventilation for drying or, in fact, not cause more wetting.

Advocates of roof vents may argue that vents dissipate moisture from roof leaks, but vents are unlikely to induce enough drying to keep up with roof leaks, even when the vents are functioning properly. If the insulation has become saturated from leaks, it would be more effective to allow the roof to dry downward by temporarily removing part of the interior gypsum board and vapor retarder. Even more effective drying would be achieved by entirely removing the gypsum board and vapor retarder and replacing the insulation.

In addition to not guaranteeing drying conditions, vents can seriously degrade the thermal effectiveness of the insulation in ceilings. With a strong wind, the outdoor air sometimes penetrates deeply into the insulation, rendering the insulation ineffective. This is called windwashing. More importantly, ventilation requires an unobstructed air space between vents, which reduces the amount of insulation that can be installed in the ceiling. Without vents, this air space is not needed, and the entire cavity can be filled with insulation, increasing the R-value of the roof assembly.

Filling the entire cavity with insulation also would simplify construction of cathedral ceilings and conversion of existing attics into living space. Airtight construction combined with a vapor diffusion retarder should provide satisfactory moisture protection and superior thermal performance. The beneficial effects of solar radiation should further improve the moisture performance of such a system.

The arguments against vents in walls during summer also apply to cathedral ceilings and flat roofs. Drying conditions already tend to prevail in an unventilated roof. Vents may decrease the drying potential in roofs of air-conditioned homes. Cooling energy savings from filling the ventilation air space with additional insulation is likely to compensate for the modest cooling energy savings from ventilation.

ATTIC VENTILATION

The thermal and moisture behavior of a wood-frame attic is different from that of a cathedral ceiling or a flat roof. First, attic endwalls are often not very airtight; this provides unintentional air leakage and ventilation to the attic, even without attic vents. Thus, air leakage through the ceiling probably is limited by the airtightness of the ceiling, and adding attic vents generally will not increase exfiltration through the ceiling as much as would adding vents in a cathedral ceiling. Thus, adding vents is less likely to lead to significant additional wetting of the roof sheathing during winter. Second, vents are more easily installed and can be installed without significant loss of thermal insulation in the ceiling. Third, attic vents are likely to provide more effective ventilation than cathedral ceiling vents because of the free interaction between all the vents in the attic. In summary, although attic vents may not be necessary, they are less likely to increase air exfiltration from the living space and wetting of the sheathing, are easy to install, and do not degrade the thermal insulation of the ceiling. Some windwashing may occur near the eave vents, but measures to protect the insulation can be taken to keep this to a minimum.

Current attic ventilation standards and guidelines are intended to prevent winter condensation and are not aimed at summer cooling. Generally, less attic ventilation is required for condensation control than for summer cooling. During summer, attic vents provide some cooling, but with sufficient ceiling insulation, the effect on cooling loads should be minor.

CONCLUSIONS

Our wall airtightness measurements indicate that installing exterior vents can significantly increase air leakage through a wood-frame wall. Most likely, exterior vents have a similar influence on airflow through a wood-frame cathedral ceiling. Our calculations show that if this increased airflow is exfiltrative, more wetting may occur during winter with vents than without vents. There is no guarantee that vents will provide enough circulation of outdoor air to offset this increase in wetting. Therefore, we conclude that installing vents in walls or cathedral ceilings is not a reliable moisture-control strategy, even though walls and roofs with vents may perform satisfactorily under many conditions. In addition, vents degrade thermal performance and increase construction cost. Instead, we believe that an effective air barrier and vapor retarder would provide sufficient and more reliable moisture control and would result in superior thermal performance. We further recommend evaluating the thermal and moisture performance of unvented cathedral ceilings under a range of actual service conditions.

Attic vents probably provide more effective ventilation than vents in walls or cathedral ceilings and are less likely to lower moisture and thermal building performance. Although we are not convinced of the necessity of attic vents for moisture control, we do not recommend any change in the current practice of providing attic ventilation.

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NOMENCLATURE

a	=	conversion constant
A	=	$\rho c_p v R_t$
b	=	exponent
B	=	$\rho c v R_v$
c	=	W/p, Pa^{-1} (grain/lb·in.Hg)
c_p	=	specific heat of air, kJ/kg·°C (Btu/lb·°F)
D	=	thickness of material layer, m (in.)
k	=	thermal conductivity, W/m·°C (Btu/h·ft·°F)
K	=	constant, m^3/s·Pa (ft^3/h·in.Hg)
ℓ	=	distance from inside surface of assembly, m (ft)
p	=	water vapor pressure, Pa (in.·Hg)
p_{air}	=	pressure differential, Pa (in. water)
R_t	=	thermal resistance of assembly, m^2·°C/W (h·ft^2·°F/Btu)
R_v	=	water vapor diffusion resistance of assembly, m/s (1/perm)
q	=	heat flow, W (Btu/h)
q_{air}	=	infiltrative or exfiltrative airflow, m^3/s (ft^3/h)
Q	=	ventilation airflow, m^3/s (ft^3/h)
S	=	surface area, m^2 (ft^2)
t	=	temperature, °C (°F)
v	=	air flux, m/s (ft/h)
w	=	net vapor flux, kg/m^2·s (grain/h·ft^2)
w'_v	=	net vapor flow, kg/s (grain/h)

W	=	humidity ratio
x	=	dimensionless thermal resistance
y	=	dimensionless vapor diffusion resistance
μ	=	water vapor permeability, s (perm·in.)
ρ	=	density of air, kg/m^3 (lb/ft^3)

Subscripts

c	=	cavity
e	=	equivalent
ext	=	exterior
i	=	inside
int	=	interior
n	=	pertaining to layer n
o	=	outside
par	=	parallel
s	=	saturation
t	=	thermal
v	=	water vapor diffusion
$vent$	=	ventilation

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