TECHNICAL NOTE
NO. 9

Small Homes Council--Building Research Council, University of Illinois at Urbana-Champaign

CONSTRUCTION FOR ATTIC VENTILATION

Volume 71, Number 70; January 23, 1974. Published twelve times each month by the University of Illinois. Entered as second-class matter December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Office of publication, 1002 West Green Street, Urbana, Illinois 61801.

Fifty Cents
VENTILATION AIR FLOW

Why ventilate an attic in the summer? Two reasons for summer attic ventilation are 1) to reduce the heat gain through the ceiling, and 2) to reduce the heat gain to cooling ducts installed in the attic.

Summer attic ventilation was a part of the cooperative investigation in Warm Air Research Residence No. 2 during the summer of 1956. The study was undertaken to investigate: 1) the reduction in attic temperatures that could be accomplished through attic ventilation, and 2) the effect of this temperature reduction on the ceiling heat gain.

The attic fan was installed in the gable-end of the attic. Weather-tight louvers, which were opened by the force of the air leaving the fan, were included as a part of the fan installation. Attic vents were located in the soffit of the roof overhang and also in the gable end of the attic.

Residence No. 2 was a well-constructed, one-story house with a large amount of glass area and a full basement. The residence had a floor area of 1,040 sq. ft. The side-walls and ceiling were insulated with 3 1/2" (full thick) mineral wool. All windows on the south side of the residence were shaded from direct sunlight by the roof overhang. Blinds were kept drawn on all windows exposed to direct sunlight.

The calculated heat gain of the residence was 22,500 Btuh. The ceiling heat gain was calculated as 4,160 Btuh which was 24 per cent of the total heat gain.

The lower curve in Figure 1 shows the effect of the ventilation airflow rate on the average attic air temperature. The average attic air temperature is an average of the temperatures recorded over a period of several hours. The curve shows that the average temperature is decrease as the ventilation airflow rate is increased. The curve begins to level off as the airflow rate approaches 1.5 cfm per sq ft. If the curve were extended beyond 2.0 cfm per sq ft, it would become almost horizontal. This trend of the curve indicates that ventilation airflow rates above 2.0 cfm per sq ft will cause no further reduction in average attic air temperatures.

Figure 1. Effect of ventilation airflow rate on maximum and average attic air temperatures.

With the proper placement of attic vents and the proper sizing of the vents, an airflow rate of 1.0 cfm per sq ft may be obtained without the use of a fan. If airflow rates greater than 1.0 cfm per sq ft are required, a fan must be used to prevent the attic vent area from becoming excessively large.

Figure 2 shows the installation and instrumentation details of the residence attic fan. The fan was equipped with a 24" blade which was driven by a 1/2 hp motor.

A SUMMARY OF ATTIC VENTILATION IN RESEARCH RESIDENCE No. 2

Edward J. Brown
Research Associate in Mechanical Engineering

How hot is an attic and how much reduction of attic temperature may be accomplished with attic ventilation? Figure 1 shows the effect of several attic ventilation airflow rates on the maximum and average attic air temperatures. The vertical scale indicates attic air temperatures in deg. F. The horizontal scale is the ventilation airflow rate divided by the ceiling area. The upper curve shows the effect of the ventilation airflow rate on the maximum attic temperature on a day when the outside temperature was 95°F. The small circles on the curve indicate the airflow rates for which temperatures were recorded. The airflow rates were 0.2, 0.6, 1.0 and 1.5 cfm per sq ft of ceiling area. The first point (0.2 cfm/ft²) indicates the airflow rate which was obtained with natural ventilation—that is, without the use of the attic fan. The curve shows that, with use of the fan and an airflow rate of 0.6 cfm per sq ft, the attic temperature was reduced from 127°F to 121°F. With an airflow rate of 1.0 cfm per sq ft, the temperature was reduced to 115°F. With an airflow rate of 2.0 cfm per sq ft, the temperature was reduced to 107°F.

Research described in this article was conducted under terms of a cooperative agreement between the University of Illinois and the National Warm Air Heating and Air Conditioning Association under the direction of Donald R. Bahnfleth. Investigation by Rama Rao and J. R. Wright.
Normally an attic fan is not furnished with a duct; however, the duct was necessary in this case to facilitate the measurement of the air-flow rate. The fan was thermostatically controlled to go on when the attic temperature reached 85°F and to shut off when the attic temperature dropped to 75°F. A limit switch was set to shut off the fan if the air temperature reached 85°F and to shut off when the attic temperature dropped to 75°F. This was a safety feature to stop air circulation in case of fire.

When specifying an attic fan, it is quite important to indicate the resistance to air flow which the fan must overcome. Resistance to air flow is expressed in terms of inches of water. An attic fan must deliver the required air-flow rate against a static pressure of 0.10 inches of water. The static pressure 0.10 inches of water is equivalent to the resistance set up by the vent screens and turning of the air streams as the air flows through the attic.

How much vent area is required for attic ventilation with a fan? The required area is approximately 4 sq ft per 1000 sq ft of ceiling area. This is approximately the same as the FHA minimum vent area for winter attic ventilation. Natural attic ventilation requires considerably more vent area. The following article will give examples of the area required for natural ventilation.

The reduction of attic air temperature is accompanied by a reduction in ceiling heat gain. Figure 3 shows the reduction in ceiling heat gain which was accomplished by attic ventilation in Residence No. 2. The left side of the figure indicates 4 air-flow rates. Reading from top to bottom, these correspond to 0.2, 0.6, 1.0 and 1.5 cfm per sq ft of ceiling area. A bar accompanies each air-flow rate. The horizontal scale indicates ceiling heat gain in thousands of Btu per hour on a design day. (Sunny day, 95°F outdoor air temperature.) On the right of the figure are shown the heat gains as a percentage of the heat gain with natural ventilation (0.2 cfm per sq ft). The bar graph shows that the heat gain is reduced by 14 per cent with an air-flow rate of 0.6 cfm per sq ft. The gain is reduced by approximately 26 per cent with an air-flow rate of 1.0 cfm per sq ft. An air-flow rate of 1.5 cfm per sq ft reduced the heat gain by about 43 per cent, and it could be reasonably projected that the gain could be reduced to 50 per cent with an air-flow rate of 2.0 cfm per sq ft.

The ceiling heat gain of the residence was 24 per cent of the total heat gain; therefore, reducing the ceiling heat gain by 50 per cent reduced the total gain by only 12 per cent. In the case of Residence No. 2, attic ventilation could reduce the size of the cooling unit requirement by about ¾ ton. (One ton is equal to 12,000 Btu/h.) Or this could be expressed as a reduction of ¾ ton per 1000 sq ft of ceiling area, with an air-flow rate of 2.0 cfm per sq ft and with 3 1/2 inches of mineral wool ceiling insulation.

Ceiling heat gains can also be reduced by the addition of insulation in the attic. A comparison of the effects of attic insulation and attic ventilation on ceiling heat gain is given in Figure 4. Three groups of bar graphs are shown, one set for each of three insulation thicknesses. Four air-flow rates are shown for each insulation thickness. The horizontal scale shows the ceiling heat gain in thousands of Btu per hour. The numbers on the right of the figure indicate the relative heat gains as percentages of the heat gain with no insulation and with natural attic ventilation (0.2 cfm per sq ft). The lower bar in each insulation thickness group is equal to 57 per cent of the length of the upper bar in the same group. The increase in air-flow rate from 0.2 cfm per sq ft to 1.5 cfm per sq ft had the following effects: with no insulation, the heat gain was reduced by 43 per cent; with 2 inches of insulation, the heat gain was reduced by 16 per cent; and with 3 1/2 inches of insulation, the heat gain was reduced by 12 per cent.

The upper bars for 0 and 2 inches of insulation show that 2 inches of insulation reduced the ceiling heat gain by more than 62 per cent. This indicates that attic ventilation should not be used as a substitute for insulation. Attic ventilation may be used to advantage to further reduce the ceiling heat gain after insulation has been added. If a fan is used for attic ventilation, it may also be used for night-air cooling.
The optimum attic ventilation air-flow rate is 2.0 cfm per sq ft of ceiling area, which may be accomplished with an attic fan. Air-flow rates of 1.0 cfm per sq ft are attainable with natural ventilation.

An air-flow rate of 2.0 cfm per sq ft can reduce cooling unit requirements by approximately ¼ ton per 1000 sq ft of ceiling area. In a large house, this could make a difference of as much as one ton of cooling unit capacity.

An attic fan should be large enough to operate at a speed which will not create a noise problem. The fan should deliver the required air-flow rate against a static pressure of 0.10 inches of water, with a vent area of 4 sq ft per 1000 sq ft of ceiling area.

**Figure 4. Comparison of attic ventilation with insulation as means of reducing ceiling heat gain.**

<table>
<thead>
<tr>
<th>CEILING INSUL RATE, INCHES</th>
<th>VENT RATE, CFM</th>
<th>CEILING HEAT GAIN (CEILING AREA 1040 SQ FT), THOUSANDS BTUH</th>
<th>RELATIVE GAIN, PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>NAT</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>625</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1030</td>
<td>742</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1560</td>
<td>573</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>NAT</td>
<td>376</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>625</td>
<td>324</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1030</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1560</td>
<td>21.6</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>NAT</td>
<td>28.4</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>625</td>
<td>24.4</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>1030</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>1560</td>
<td>16.3</td>
<td></td>
</tr>
</tbody>
</table>
REDUCING ATTIC TEMPERATURE BY NATURAL VENTILATION

William H. Kapple
Research Associate Professor of Architecture, Small Homes Council

You have just read about the need for attic ventilation in order to reduce heat gain through the ceiling of the house. In the attic ventilation described, electric fans were used.

We conducted a separate study to determine whether or not it will be practical to reduce the attic temperature significantly by natural ventilation without the use of any fan. Our analysis showed that although gravity air flow, with large vents, will not cool to the same extent as a large fan, it will reduce the attic temperature significantly if the vents are large enough and well placed. Based on the temperature recorded in the research dwelling, it was decided that attic temperature, which built up to 130°F. with an outside temperature of 95°F., could be reduced to 115°F. by natural ventilation alone.

Attic Ventilation for Moisture Control

Most of you are familiar with the current requirements of the Federal Housing Administration and of a great many building codes concerning attic ventilation. These regulations specify that attic vents in houses with a vapor barrier in the ceiling shall have a free area equal to $1/300$ of the attic area. To compensate for the 8 x 8 mesh screen (64 openings per square inch) which is also required, the screened opening must be 25 per cent larger. If screened and louvered openings are used for the vent, the size of the louver must be 125 percent larger than the specified free area. Hence, in a 1,000 sq. ft. house, the attic vents required to satisfy the needs for moisture control must have a free area of $3 \frac{1}{3}$ square feet, a screened area of $4 \frac{1}{4}$ square feet, and a louvered area with screens of $7 \frac{1}{2}$ square feet. This means that a louver of $3 \frac{3}{4}$ square feet is required in each gable of such a house.

Attic Ventilation for Summer Comfort

In order to significantly reduce the attic temperature by gravity air flow, the vent area must be at least 6 times the area required by current codes. Actually, the amount of vent space required depends upon the difference in height from the inlet to the outlet. In other words, if one half of the vents are low in the eave and the other half high in the attic near the ridge, the air flow would be far better than if all of the vents were high. The greater the difference in height from the low inlet vents to the high outlet vents, the greater the gravity air flow. It is necessary to rely on gravity air flow rather than the greater air flow caused by wind because the prime need for ventilation is seldom during periods when the wind is blowing. Instead, it occurs when there is no wind to force the air into and out of the attic. For this reason, daytime attic cooling without a fan is almost entirely dependent upon gravity flow of air which requires a significant difference in the height of inlet and outlet vents.

In a house with a 6-foot difference in inlet and outlet heights, the free area will have to be $1/300$ of the attic area. If, for instance, one half of the vent is a screened inlet vent and the other half of the vent is a louvered and screened outlet vent located high in the attic, a 1,000-sq.-ft. house will require a screened inlet of 12 square feet and two louvered outlets of 11 square feet each. Actually, such large louvers are impractical for this purpose because they cannot be economically built to control rain and snow infiltration. You must use other types of attic vents if they are to be large enough to significantly cool an attic in the summer. Furthermore, if the difference in height from the inlet to the outlet is less than 6 feet, larger vents will be required. In other words, the lower the stack height, the larger the vent required. Just as a tall chimney has a much better drawing power than a short chimney, so a tall attic with inlet vents low and outlet vents high has a much better gravity airflow capacity than a low attic.

Table 1 shows that the minimum amount of free vent area required to keep an attic reasonably cool on a hot day must be 50 per cent larger if the stack is 3 feet high than if it is 6 feet. If the attic is only 2 feet high, you must provide a vent with 33.8 square feet of free area to get the same cooling effect that will be given by 19.4 square feet of free area when the stack is 6 feet high.

20% SMALLER OUTLET REQUIRES
60% LARGER INLET

Figure 1
Variation of Ratio of Inlet to Outlet

Even more vent area is required if the vent area of the outlet openings does not equal that of the inlets. For instance, a 20 per cent reduction in the outlet vent area will require a 60 per cent increase in the inlet vent area in order to provide the same gravity air-flow rate. (Figure 1.) Hence, a 1,000-sq.-ft. house with a 3-foot stack would require 21.6 instead of 13.7 square feet of inlet in order to get the same air flow when the outlet opening is reduced from 13.7 to 10.8 square feet. Maximum cooling effect is thus achieved if you provide equal inlet and outlet vents. If one must be larger than the other, there is very little value in making the larger one more than twice the smaller.

Gable Louver and Eave Soffitt Vent Design

If a gable louver is to be used as the outlet vent, it will be virtually impossible to install sufficient outlet vent to equal the area of the inlet vent. Even if the outlet vents are only one half of the size of the inlet vents (Figure 2), the gable louver will be extremely large. A house 25 feet wide with a 4-foot high ridge will have a stack height (namely, the difference in height of the inlet vents and outlet vents) of approximately 2'-8".1 The louver and soffit vent areas shown are interpolated from Table 1, Part B.

To provide the required 13 square feet of louver in each gable, the louver must be 12'-6" wide at the base and 2'-6" high. Such a louver is extremely large and would be subject to problems of rain and snow infiltration. It, therefore, is impractical.

Rake Soffit and Eave Soffit Vent Design

Let us next look at a technique which will make it possible to control rain and snow penetration. The ladder-panel gable overhang, shown at last year's short course, can be used to provide an outlet vent nearer to the upper part of the attic to replace the gable louver.2 (Figure 3.)

Continuous Ridge and Eave-Soffit Vent Design

Equal vents, high and low, in the attic can be easily provided with a continuous vent at the ridge and eaves. (Figure 4.) With the same roof slope, this type of vent system provides the greatest stack height and, therefore, requires the least vent area. Based on Table 2, Part B, only 30 square feet of screened vent is required,4 half high and half low. If two continuous slots 2 ½" wide are provided in the ridge vent, and a 2 ½" wide slot in each eave soffit, the attic can be well cooled by gravity flow. This will improve the summer comfort in the house but, as mentioned before, will require partial closure in winter-time.

Our first experience with the continuous ridge vent was the carpenter-built unit on our laboratory addition.

---

1 The effective height of a triangular louver is measured to a line dividing the upper and lower half of the triangle. The ratio of the height of the whole triangle to the height of the upper triangle is 1:V'0.5.
2 Small Homes Council Instruction Sheet No. 11, Gable Framing Using Ladder Panels on Roof Trusses. 50 cents.
3 Analysis indicates that it is best to locate the gable overhang vents in the upper half of the attic. The mid-point of these vents will be ¾ the height of the attic.
TABLE 1: FREE AREA OF ATTIC VENTS REQUIRED FOR SUMMER VENTILATION OF ATTIC SPACES

(Based upon equations and data in the ASHAE Guide, Chapter 11, 1958, and the results of a Study of Attic Ventilation in Research Residence No. 2)

Assumptions: Attic Area = 1000 sq. ft.
- Medium Dark Roof
- Outdoor Air Temperature = 95°F

**Part A: Area Required for Most Effective Attic Ventilation**

<table>
<thead>
<tr>
<th>Ventilation Rate (Q)</th>
<th>2000 cfm (2.0 cfm/sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resulting Attic Temperature</td>
<td>105°F</td>
</tr>
</tbody>
</table>

**Free Areas Required for Inlet and Outlet Openings (sq. ft.)**

<table>
<thead>
<tr>
<th>Difference in Height Between Inlet and Outlet Openings (in feet)</th>
<th>Free Areas Required for Inlet and Outlet Openings (sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When Openings of Equal Size</td>
</tr>
<tr>
<td></td>
<td>Inlet</td>
</tr>
<tr>
<td>3</td>
<td>38.6</td>
</tr>
<tr>
<td>4</td>
<td>33.4</td>
</tr>
<tr>
<td>5</td>
<td>30.0</td>
</tr>
<tr>
<td>6</td>
<td>27.4</td>
</tr>
</tbody>
</table>

**Part B: Area Required for Good Natural Attic Ventilation**

<table>
<thead>
<tr>
<th>Ventilation Rate (Q)</th>
<th>1000 cfm (1.0 cfm/sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resulting Attic Temperature</td>
<td>115°F</td>
</tr>
</tbody>
</table>

**Free Areas Required for Inlet and Outlet Openings (sq. ft.)**

<table>
<thead>
<tr>
<th>Difference in Height Between Inlet and Outlet Openings (in feet)</th>
<th>Free Areas Required for Inlet and Outlet Openings (sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When Openings of Equal Size</td>
</tr>
<tr>
<td></td>
<td>Inlet</td>
</tr>
<tr>
<td>1</td>
<td>23.6</td>
</tr>
<tr>
<td>2</td>
<td>16.9</td>
</tr>
<tr>
<td>3</td>
<td>13.7</td>
</tr>
<tr>
<td>4</td>
<td>11.9</td>
</tr>
<tr>
<td>5</td>
<td>10.7</td>
</tr>
<tr>
<td>6</td>
<td>9.7</td>
</tr>
</tbody>
</table>
This design is not attractive but, I am sure, it would be possible to design a good-looking ridge vent. Although no attic temperature measurements have been made, the comfort in the room below indicates that the ridge vent may be an important tool for reducing summer heat gain.

Factory-fabricated units for continuous ridge vents are being developed today. Such units will be smaller than our carpenter-built vent and, therefore, less conspicuous and more attractive than the one built on our laboratory.

In summary—we find that it is possible, without any fan, to reduce the attic air temperature from 130°F to a temperature of 115°F by installing gravity-flow vents at least 6 times the size of those required by present code requirements. Table 1 shows the recommended free area of vents necessary to reduce the attic temperature to either 105°F or 115°F.

\[ \text{Table 1, Part B, shows that a 4-foot stack height requires 11.9 sq. ft. of vent low and the same high. This free area times 1.25 establishes a total area of screened vent of 11.9 x 2 x 1.25 = 29.7 sq. ft.} \]
ATTIC VENTILATION REQUIREMENTS

William H. Kapple

Research Associate Professor of Architecture, Small Homes Council

To improve summer comfort and eliminate attic condensation in the winter, louver units of increasing sizes are being installed in the gable-ends of a large proportion of new houses. This practice has resulted in a new problem of rain and snow infiltration which frequently causes damage to the finished ceilings below.

The problem of getting air in and out of the attic—or the trussed area of the roof—without letting in birds, insects, rain or snow was studied by the Small Homes Council last year under a research grant given to the University of Illinois by the Home Builders Research Institute of the National Association of Home Builders. The study resulted in the development of a new-type construction for gable-ends.

PROBLEM

Winter Condensation Control

More and more top-floor ceilings of houses are insulated to prevent loss of heat. This insulation reduces the temperature of the attic in the winter. If enough water vapor enters the attic to bring the dew point either to or above the surface temperature of the structural parts, the vapor may condense on rafters, roof boards, and sometimes on the ceiling joists. The condensation penetrates the wood or, if the wood is below 32° Fahrenheit, freezes on the surface. If it freezes, it later melts and often soaks into the wood. The danger of such absorption of vapor by wood members is that the moisture content of the wood may be raised to a point where decay hazards may arise. Unless ventilation keeps the moisture content of the wood below 20 per cent, there is a strong danger of attack by decay fungi.

Based primarily upon this need, a minimum net ventilation area equal to 1/300 of the attic area is usually required. (1) (2) The gross area with wood louvers and 1/8 inch mesh screens is 21/4 times the net area. (5) In case of a 1,000 square foot house with a vapor barrier and one vent in each gable-end, the required gross area of each vent would be 3.75 square feet. Twice this amount is recommended if no vapor barrier is used. The net area of the gable vent, however, can be cut to 1/900 of the attic area if sofit vents of the same area are also used.

Gable vents can be eliminated entirely if adequate roof vents are used elsewhere in the attic. Vents low in the soffit or low in the gable are not as effective by themselves as a combination of high and low vents. A combination of ventilation units, with 1/3 to 1/2 of the vents high and the rest low in the attic, is essential to allow the air to flow out by gravity without the aid of wind pressure. For maximum air flow, the area of high roof vents should equal or exceed the area of low vents.

Where vents of necessity are all low, such as in a roof having a slope of 2 inches in 12 or less, the vents should have an effective area equal to 1/150 of the attic area.

Summer Comfort

The sun beating down on the roof of a house having a poorly ventilated attic can easily build up the temperature in the attic to 130° Fahrenheit. (9) (12) Summer comfort and economy in the operation of air-conditioning equipment require adequate ventilation to prevent this build-up of hot air in the attic.

Very little data exist on which to establish the amount of attic ventilation that is desirable for summer comfort. There is good reason to believe that the amount of ventilation specified for winter condensation control would not be adequate for summer comfort. If attic fans are used, the recommended ventilation units should be three times as large as those specified for winter-condensation control—i.e., 1/100 of the attic area. (1)

THEORY OF AIR FLOW

Gravity Air Flow

In most houses, the ventilation of the attic is achieved by gravity flow of warm air through the vents. Just as tall chimneys give better draft, so tall attics with openings at the top give better draft. The effectiveness of such gravity flow depends on the difference in the height of the inlet and outlet openings, as well as the difference in temperature of the air in the attic and the air outside. The temperature difference between well-ventilated attics and the outside can be as little as 10 or 15 degrees. This results in an extremely low pressure head. With such a low pressure head, the air moves at extremely low velocities—approximately two miles per hour. The amount and size of vent required are determined by this low velocity air movement which is active most of the time. It removes hot air in the summer and moist air in the winter.

Wind Intensity

Even though winds are usually at a low velocity all but a few hours of the month, winds of high velocities occur in most localities, along with rain, during some days of each year.

As stated in published reports on wind pressure and natural ventilation of houses (2), (6), (7), although the wind may have an over-all direction.
of flow, high winds are broken up by much turbulence and many small swirls. While steady winds may last more than several minutes, the highest velocities are reached in gusts of almost momentary duration.

In order to evaluate the ability of louvers and windows to withstand rain infiltration and strong winds, a test procedure was devised at the University of Miami. Two separate tests were developed using a high velocity artificial wind which was created by a 1200 horsepower airplane motor and propeller.

One test subjected the louver to gusts of wind with velocities changing from 80 to 140 miles per hour for a period of 1½ minutes. This test showed whether the louver was strong enough to withstand the pumping action caused by the sudden changes in high velocity winds that occur during hurricanes.

The other test subjected the louver to a wind of 100 miles per hour for 5 minutes with water introduced into the air stream at 20 gallons per minute. This test showed whether the louver would adequately limit the penetration of wind-driven rain.

These two tests illustrate the extreme conditions of wind and rain penetration which some attic vents must withstand. Design for such extreme winds may not be essential in all parts of the country; on the other hand, winds of 50 miles per hour are common for relatively long intervals of 10 to 15 minutes in almost all localities throughout the United States. Most attic ventilating units, therefore, should be designed to withstand rain borne by winds of at least 50 miles per hour.

Behavior of Wind Around a House
A knowledge of the behavior of winds around a house is also helpful to an understanding of attic ventilation. The following principles of air movement for high velocity winds—about 50 miles per hour—affect vents in the attic:

1. A high-pressure area is created on the windward side when air strikes a building. This results in an air flow up and around the building. As a result, most winds strike the building at an upward angle, especially in the higher portions of the gable-end where the ventilating units are normally located. (Figure 1A.)

2. Low-pressure areas are created on the leeward side of the building, resulting in suction which causes vents on this side to become air outlets even though they are located low in the attic.

3. Air flows into vents with maximum velocity if the vents are on the windward side—in the area of maximum pressure—and are sloped at the same angle as the wind flow. Wood louvers in gable-ends are frequently located to satisfy all of these conditions of maximum penetration by high velocity winds. (Figure 1B.)

4. Obstacles in the path of moving air cause it to change direction, thus slowing it down—i.e., slats or screen mesh on the back or front of louvers will reduce the air speed. (Figures 3C and D.)

Screens Used for Insect Control
Although air friction from screens may cause no problem during high-pressure winds, it is not desirable when the ventilation is entirely by gravity because slow moving air is retarded by screen mesh much more than the reduction in net area caused by the screening. With screen mesh 1/8" or larger, the reduction in velocity is less than the reduction in net area; however, the larger mesh will not keep out all insects.

There is a conflict, therefore, between the size of the screen mesh that is best for insect control and the size that offers minimum resistance to gravity air flow through the vent.

Published criteria specify that the gross area of vent to satisfy calculated net area needs must be increased 100% with 1/16" mesh screen; 25% with 1/8" mesh screen. With 1/4" mesh screen, no increase in vent area is needed. The control of insects, on the other hand, is best achieved with fine mesh screen. Generally accepted as the best compromise between the needs for insect control and the needs for maximum air flow is 1/8" mesh.

LOUVERS AS A MEANS OF VENTILATING ATTICS
Rain and Snow Control
Attic louvers cannot be too large or located in areas of maximum wind pressure if rain and snow infiltration are to be avoided.

Under storm conditions, wind-driven rain or snow will penetrate many types of louvers and cause damage to the structure, such as warping of floors and loosening of plaster. It may also damage furnishings. The amount of water admitted to the climate, building exposure, size and type of louver, and its position in relation to roof slopes, overhangs and trees.

Rain entering a louver acts in three ways (Figure 5):

1. Large wind-borne drops.

These drops fall steadily but with lateral velocity that varies with the wind velocity. When the rain drops pass into a louver, the wind may lift them. Due to their weight, however, they never rise above a specific “top line of rain climb” which is determined by the wind velocity, the angle of the wind, and the design of the louver.

2. Large free-falling drops.

These drops from the front edge of louver slats without any initial lateral velocity. This water is collected on one slat and drips down into the path of the wind, entering the slot
3. Fine wind-borne spray.

This fine spray remains suspended in the moving air and settles very slowly. All snow acts in this manner.

Dotted curved lines, "A—A" of Figure 5 divide the fine drops (which will contact the slat) from those above (which will blow through without contacting the slat). Fine wind-borne spray and snow will rise above the "top line of rain climb" for large wind-borne drops.

Effect of Turbulence on Rain and Snow Penetration of Conventional Louvers: During a heavy wind and rain an air cushion at least a foot or two deep builds up on the windward side of the house. (8) This air cushion is nearly static, the oncoming air being deflected from it. The pressure in front of an attic louver is higher than the pressure inside and forces the air through at high velocity.

The oncoming rain, however, will carry through the air cushion due to its momentum, but it will travel in a straight line, sloping upwards due to the upward direction of the wind just before the rain reaches the air cushion. If a louver or a vent in the path of the wind has a continuous straight opening into the attic, the water will continue into the attic even though this path may have an upward slope (Figure 3). A pinhole opening on the axis of the rain flow will admit more water than a loosely constructed baffle. (6)

Wind going through the louver is slowest immediately above each slat and increases to a maximum velocity a small distance away from the slat. A pattern of turbulence is created just below each slat (Figure 4A) unless the wind is upswpt at the same angle as the louver slats (Figure 4B).

The thickness of the film of slow moving air above each slat depends upon the shape of the slat and the opening.

Wind Force Required for Rain Penetration: The ability of a louver to keep out heavy rain drops that drip from the slat above is proportional to the minimum force required to blow a free-falling drop through the slot in the louver. This force varies with changes in the slope of the "top line of rain climb" and the slope of the louver slat.

This force can be determined graphically as a function of the force of gravity (Figure 6). In this example, the wind force required to carry rain drops through the louver is $2\frac{1}{4}$ times the force of gravity. With slats of a steeper slope, less wind is required to blow air-suspended rain through the louver; with slats of a lesser slope, more wind is required.

This criterion was used for the evaluation of different types of louvers with various widths of slats and various slopes. The analysis revealed that 1" x 6" slats are better than 1" x 4" slats, 1" x 8" or larger boards. A louver with 1" x 6" slats spaced 1 inch apart requires a wind with a force that is $2\frac{1}{4}$ times the force of gravity in order to carry air-suspended rain through the louver. This is 50% more than the force required to carry air-suspended rain through a similar louver with slats on a 60° slope. A flatter slope proved better graphically, but not as effective in keeping out rain once it collected on top of the louver slat.

Steeper sloped slats will minimize the penetration of rain that collects on top of the slats. On the other hand, maximum protection from "wind-borne drops" requires louvers with a lower slope. To achieve optimum protection from rain in both stages, the slope should be 45°.

Influence of Baffles on Rain and Snow Penetration of Louvers: Baffles on the back of the slats create a thicker film of slow moving air than when no baffles are used. If the film is thick enough, any water falling on the slat can run down into the path of the wind below the slat. If the wind is slow enough, none of this water will go through the louver. Baffles below and on the front of the slats create more turbulence below each slat.

A baffle at the back of a louver slat reduces rain and snow penetration in three ways (Figure 5B):

1. It blocks the path of the large drops, both wind-borne and those dripping from the slat above.

2. It thickens the layer of low velocity wind on top of the slat, thus allowing water to run down off the slat. It also blocks the flow of water which may collect on the top of the slat and may tend to blow upward into the attic.

3. It blocks a larger proportion of the fine spray and snow which would otherwise blow through the louver.

A stop at the front and bottom of the louver slat blocks the path of more fine spray or snow. If it projects down to line "A—A" of Figure 5C, it will stop almost all of the fine spray or snow.

At the same time, a front stop increases the slope of the "top line of rain climb", thereby making it even more difficult for heavy drops to penetrate; however, the front lip is less important than the back lip.*

Influence of Screen Mesh on Rain and Snow Penetration of Louvers: With screens on the inside face of the louver, it is likely that the amount of water entering will be increased with the use of larger mesh screen due to the fact that the controlling factor is the velocity of the wind. Some tests indicate that this is not necessarily true with

---

* Without design data for the line separation, "A—A", it has generally been assumed that the downward projection of the baffle in front should be level with the upper part of the baffle on the back.
screen mesh in the middle or on the outer face of louvers. Due to the need for further tests to establish the full effect of inside and outside screens of various mesh sizes, this report does not include any allowance for the effect of screens when planning for rain control.

It is possible that 1/8" or 1/16" mesh screen might be a problem in some areas where icing is a factor. The frequency of this problem is not known and further research is also necessary to identify the importance of this problem.

**Design Criteria**

Based on published standards and this analysis, it is possible to establish design criteria for louvers.

**FHA Requirements, Miami, Florida:** According to the recommendations of the Miami, FHA-Insuring Office, based on the findings of the University of Miami Housing Research Laboratory—

All gable-ventilation units should have sufficient strength to withstand gusts of wind up to 140 miles per hour.

Metal pans, which are required inside the attic to reduce water infiltration, should be designed so that the pan does not reduce the open area when installed in the structure.

Eave soffit vents should be kept away from the exterior wall, and gable-end vents should be dropped as far as practicable below any gable overhang.

These criteria seem valid in the light of available data.

**Design Criteria for Simple Louvers:** Simple louvers, such as those commonly made of wood, may continue to be used; however, to avoid problems of rain and snow penetration, any designer should recognize their limitations. In addition to those listed by the Miami FHA Office, it is desirable to:

1. Use 1" x 6" slats at a 45° angle with 1" space between slats in order to achieve economy, and to control rain, snow, and bird penetration.

---

† Tests have shown that additional rain control may be obtained by the use of screens properly located and with the proper size of mesh. Without test data, it would be logical to assume that rain penetration would be in proportion to wind penetration. Two tests conducted at Miami University indicate differently.

The tests conducted for a Study of Jalousie Windows (6) showed that outside screens on double-hung windows collect wind-driven rain between the window and the lower member of the screen frame. The water comes into the large area of the screen much faster than it can drain out through any holes in the bottom of the screen frame, and causes a collection of water that is difficult to control.

Test #178 (10) shows that a similar collection of water occurred with metal louvers which are made from two metal sheets stamped with "eye-brow" type openings. These are placed back-to-back with the "eye-brow" down on the outside and up on the inside. Screen mesh is then placed between the two stamped sheets. With this type of louver, wind-driven rain collects on the inside behind the 16-mesh screen to a greater extent than with 8-mesh screen. As a result, 8-mesh screen reduces water infiltration but allows greater air flow.

With screens on the outer face of the louver, the same might also be true.

* To locate economical rainproof louvers, several manufacturers were contacted.

One firm making a stationary louver of aluminum with a double baffle advertised it as "storm-tight". None of the literature refers to tests proving the storm-tight quality and the recommended specifications do not contain reference to the storm-tight quality of the louver. Another louver manufacturer, interviewed to determine the success of their firm in creating economical rainproof louvers, pointed out that such a louver could be built if price was not a factor. The depth of the louver would probably have to be 6 inches instead of 1/2 or 2 inches, as is customary with most metal louvers, and the price would be well in excess of the price that home builders probably would be willing to pay. This firm felt that it was far better to use their roof ventilator units, which are more readily manufactured in a weatherproof design and are recognized by some codes as requiring less area than a gable vent.

**Spacing for Bird Control:** Louvers of normal design encourage nesting of birds particularly in northern climates where birds are attracted by the warmth of the air flowing out through the louvers in the winter. The smallest bird which is inclined to nest in such heated openings is the wren.

Nesting of birds can be eliminated either by narrowing the openings between the louver slats or by locating the screen near the surface of the opening.

Neither sparrows nor wrens can enter louver openings on a 45° slope with the slats spaced 1" apart. (Oval openings in bird houses are sized 7/8" high and 1 1/4" wide to admit house wrens and keep out sparrows. If openings are sloped, wrens require more than 7/8" openings.) It is possible that sloping slats could be spaced up to 1 1/4" apart and still keep out sparrows and wrens.

Outside screens, used as a means to keep out birds, have definite aesthetic limitations and should be reserved for use only as a corrective measure.

2. Use supplemental vents in soffit or elsewhere to limit the size of simple louvers—i.e., no more than 3 or 4 square feet of louver in each gable. If larger louvers are needed, as is the case with attic fans, inside doors should be installed for closure during rain storms and cold weather.

**Design Criteria for Multiple-baffle Louvers:** Baffles at the front and the back of the slat are commonly used with the more complex type of louvers. These baffles, which are usually made of metal, are generally shallower than wood louvers. Although there is no test data, there is reason to believe that a metal louver 1 1/2" deep will not prevent rain and snow infiltration any more than the best type of simple wood louver described above. Double baffles obviously are better, but further research information is necessary before the term, "storm-tight", can be considered acceptable for this type of ventilating unit.
Design Criteria for Operating Louvers: The motor-controlled or manually-operated metal louver which can be closed in event of rain will, of course, provide adequate protection against rain and snow infiltration but it is too expensive for popular residential use.

Evaluation of Louvers as a Means of Attic Ventilation

The aesthetic appeal of simple louvers has been a major factor in their continued and popular use; however, the limited ability of such louvers to control rain and snow infiltration, especially when the units are sized to provide adequate ventilation for summer comfort, makes their use far less practical than other types. The substitution of a complex louver seems to offer little economic advantage, especially since it offers very small improvement in resistance to rain and snow penetration unless the most expensive type is used. For these reasons, the following five types of attic ventilation are recommended as most practical for use in popular-priced homes.

FIVE OTHER MEANS OF VENTILATING ATTICS

Dummy Flue in Chimney

A dummy flue in a masonry or prefabricated chimney is an efficient way to obtain a high stack-height for an attic vent. Such flues can be designed so that any rain or snow that accumulates is drained from the bottom of the flue. The chimney should, of course, be located to draw air out of the highest part of the attic. This limitation will rule out the use of chimney vents on houses with the chimney near the eave walls. (Figures 7F and 8F.)

Ridge Vents

The use of a continuous vent along the entire ridge of the house would solve the problem of ventilating each rafter space in ridge-beam construction. It would also provide a large vent (of the size needed for maximum gravity air flow) which would prevent hot ceilings in the summer. The best design details must be developed by trial. Experience indicates that a high curb should be provided to minimize rain and snow infiltration.

Custom-made ridge vents would be suitable only for expensive homes. If public acceptance of such units could be established by their use on quality homes, a market could be created for similar prefabricated ridge-vent units, if they were pleasing in appearance and properly engineered for control of rain and snow infiltration.

High Gable Projection

Another type of gable vent, which is growing in popularity is created by projecting a portion of the gable to form a triangular-shaped unit reminiscent of bird houses sometimes built on the gables of garages. An opening can be left in the bottom of this projection for the purpose of ventilating the attic. A similar type of vent can easily be provided on houses which have projecting rakes on the gable end (Figures 7C, 8C, and 10).

With this type of vent, the air has to turn up vertically and make a 90° turn before it enters the attic. The rain that is carried vertically tends to continue up until it is stopped by the projecting part of the roof; hence, the rain falls back out while the air turns and goes into the attic. Any screen in the opening should be placed as close to the bottom as possible to avoid the problem of birds' building nests inside.

Houses with louvers under projecting rakes are often subjected to excessive rain infiltration because the louver is so located as to receive the maximum wind pressure and rain drive. Such louvers can be projected by a similar type of triangular sheet placed even with the fascia of the projecting gable and installed so that the air has to flow up and turn before entering the louver. This forms a turbulence pattern which will eliminate any noticeable rain penetration.

Soffit and Rake Vents

The eave soffit of an overhanging eave is well-suited for part of the openings for attic ventilation. Soffit vents adjacent to the house are in the area of greatest wind pressure and will be subjected to noticeable rain and snow infiltration. On the other hand, soffit vents located near the outer edge of the overhang are subject to far less wind pressure (Figure 2) and will reduce the rain infiltration. Furthermore, any rain, which does penetrate, will fall on the soffit boards and not on the finished ceiling of the house. These soffit boards can be of a material that will withstand some wetting; they can usually be sloped so that any water will readily drain off.

As long as roof vents project above the peak of the roof, they will require less ventilation area than other types of attic vents.
RECOMMENDED DESIGN FOR A GABLE-END

Advantages of Vents on Projecting Rake of Gable End

Eave soffit vents alone are not enough. A similar vent located in the bottom of a projecting rake on gable ends can provide the needed outlets high in the attic.

The installation of a ventilation unit in the rake soffit will make it possible to build a virtually rainproof vent which will remove hot air by gravity from the high section of the attic.

Such vents should be located near the outside face of the rake (Figures 7B, 8B, and 9). The opening can be provided in a number of different ways. Two obvious ways are: (1) by drilling holes in the soffit of the rake projection, and (2) by installing a continuous screen slot.

The use of holes will provide for minimum ventilation needs. For instance, if holes 2 inches in diameter are drilled for a 1000 square foot house, and if the amount of ventilation to be provided in the soffit of the rake projection is 1/900 of the attic area, 32 holes spaced six inches on center will meet the need.*

If the vented area is to be increased, a continuous screen slot may be desirable. The use of a 2-inch continuous slot, will provide the same ventilation within 26 inches from the ridge. The amount of vented area can be readily increased to 4 or 6 times this minimum by the use of a wider and longer slot. There are many ways to apply the screen over soffit vents, but certain ways minimize the labor involved in its application. The use of the drilled holes with the screen stapled to the back side is an easy way to achieve this.

Construction

The gable projection vent can be provided economically by a new roof framing unit which we have named "a ladder panel". These panels are placed over regular trusses used in the roof, and sheathing is placed over the panels. The "rungs" support the roof and also allow air to flow out over the gable-end.

With this technique, gable ends can be framed at one-half their normal cost, and a saving can be achieved with the framing for projecting gables. At the same time, the attic ventilation system can be made more effective and free from problems of rain penetration and bird nesting.

---

* Thirty-two 2-inch diameter holes with an area of 3.1 square inches each will provide the 100 square inches of vent needed in each gable end. If spaced 6" on center, they will be within 8 feet of the peak.
A. The greater the turbulence, the less the chance there is that wind-borne rain will penetrate through an opening.

B. Horizontal winds have more turbulence than upswept winds and, therefore, will not carry rain through louvers as easily as upswept winds.

C. A so-called “stormproof” louver creates a turbulence pattern that keeps out rain when winds are horizontal but not when they are upswept.

D. Rain tends to travel in a straight line even though the wind may be deflected. Protection from rain penetration with high velocity winds requires a vent without a straight path for rain travel, such as the type shown in Figures 8B, 8C, 8D, 8E and 8F.

Fig. 3

VENT next to house is in the area of greatest wind pressure, and frequently allows rain or snow to penetrate and excessively dampen the ceiling construction.

VENT at the outer edge of the overhang creates turbulence which reduces wind, snow and rain penetration.

Any water that penetrates falls on the soffit boards. These can be sloped so the water can drain off. They can also be finished with wood or other material which is less sensitive to water damage than ceiling materials.

Fig. 2
Fig. 4

WIND FORCE REQUIRED FOR RAIN PENETRATION

Fig. 5

Fig. 6. The wind force, "AD", will carry a rain drop, which starts without lateral momentum, along the minimum line of rain climb for penetration.

AB Vertical line of specific length which represents the force of gravity acting on a rain drop.

AM Line in direction of path of least energy required to carry rain drop into the house—i.e., parallel to line of rain climb for penetration.

BN Line parallel to direction of wind force, which is assumed to be parallel to the louver slats.

AC Line graphically equal to net force required to carry rain drop on minimum line of rain climb for penetration, as related to force of gravity. This net force results from the combined force of gravity and force of the wind.

AP Line parallel to wind force.

CC Line parallel to AB.

AD Line equal to wind force required to carry rain drop inside of house as related to force of gravity—i.e., 2½ times gravity in this example.
AIR FLOW THROUGH VARIOUS ATTIC VENTS
WHEN WIND IS BLOWING

A. Louver high in gable - wind on gable end
B. Rake vent - wind on gable end
C. High gable projection - wind on gable end
D. Ridge vent - wind on eave side
E. Roof vents - sheet metal - wind on eave side
F. Dummy flue in chimney - wind on eave side

Fig. 7

VENT IN HIGH GABLE PROJECTION

A. Gable without projecting eaves
B. Gable with projecting eaves

Fig. 9

GRAVITY CIRCULATION OF AIR THROUGH VARIOUS ATTIC VENTS
WITH AIR INTAKE THROUGH EAVE SOFFIT

A. Louvers high in gable
B. Rake vent
C. High gable projection
D. Ridge vent
E. Roof vents - sheet metal
F. Dummy flue in chimney

Fig. 8

Fig. 10
A partial list of references reviewed in this study and referred to in this report is given below:

1. *Minimum Property Requirements for Properties of One or Two Living Units Located in the Southern Illinois District*—Federal Housing Administration, including revision through October 1953.


A GABLE-END LADDER FOR USE WITH TRUSSES

Donald H. Percival

Wood Technologist, Small Homes Council

Proper ventilation for the attic of the house can be costly if incorporated in a complicated gable-end structure. We here at the Small Homes Council have developed a gable-end system that should save you both time and money if you use trusses for your roofs.

The method incorporates conventional materials and simple connections. It can be used with either conventional exterior wall framing or a wall-panel system. Best of all, the new construction is lighter in weight than the conventional louvered gable-end—a factor that carpenters will appreciate.

The structural components of this gable-end system include ladder-type panels of 2" x 4" members which provide the ventilation passage into the attic. The ladder panels are placed on trusses at each end of the house. The trusses do not have to be specially designed; the same ones that are used in the rest of the roof are suitable with slight modifications.

When the roof trusses for the house are being constructed, make two additional trusses to take the place of the usual complicated gable-end. If Small Homes Council nail-glued trusses—these are single-plane—are built, the plywood gussets should be left off one side, and additional horizontal members should be inserted as sheathing and siding nailers. Multi-plane trusses are also acceptable but they will require more cutting and fitting to provide nailers for the sheathing. To eliminate another scaffolding worry, the sheathing and siding can be attached in the shop.

The ladder-panels are actually similar to a ladder. They have rungs made of 2" x 4"'s. If the house is symmetrical, you will need only four of these. The panels meet at the ridge-line when placed on the roof. The length of these ladder-panels will vary with each different roof slope and overhang.

The panels may be constructed on the ground, on the floor of the house, or at the truss fabrication site. The soffit and the insect or bird screen should be applied before the panels are taken to the roof, thereby eliminating another scaffolding job.

To erect these ladder panels, set all the roof trusses as usual. Place the gable-end trusses at the outside edges of the 2" x 4" plates on the end-walls to form a continuous surface of the sheathing material. These two trusses, one on each end of the house, will actually be lower than the others. This height difference provides clearance for the ladder-panel. Next take the panels up to the roof; nail the long-side member to the wide face of the first roof truss. The midpoint of the panel will rest on the gable truss. It can be fastened with metal strips or some type of metal connector. Toe-nailing may be faster, but it is not the best type of connection. A secure fastening is necessary because serious uplift and internal wind forces are common—more common than some of our required design loads of three to four feet of accumulated snow.
In this system, sheathing materials in 4' x 8' sheets, as well as the conventional 1” board sheathing, can be used. If the trusses have been set modular, one 4' x 8’ sheet will tie together three roof trusses, the gable-end truss, and the ladder panel. In our demonstration this afternoon, we will use 3/4” plywood sheathing. This has been acceptable for 24-inch truss spacing. Trimming and finish can be the same as usual.

In a panel system in which a 2” x 6” double header ties the house together, the header is left off the end walls. In its place, a 2” x 4” flat member is used to tie the panels together. The conventional header over the window is not necessary since, with the use of trusses, the roof load is not transmitted to the end wall as in conventional joists and rafters. The window frames do not have to support the roof load.

In tip-up wall construction, the end-wall studs should be cut shorter and the double 2’ x 4” plates nailed flat as usual.

In summary, this ladder-panel provides adequate ventilation for the attic and, at the same time, makes construction of complicated gable-ends unnecessary. It, moreover, does not require lifting a heavy structure into position.