DESIGN OF VENTILATED ATTIC SPACES FOR BUILDINGS SITED IN COLD REGIONS

BY

Mark Fryer
and
E. Staples Brown

FRYER/PRESSLEY ENGINEERING, INC.
1818 University Avenue South
Fairbanks, Alaska 99701

January 1986

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
Division of Planning and Programming
Research Section
2301 Peger Road
Fairbanks, Alaska 99701

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Alaska Department of Transportation and Public Facilities. This report does not constitute a standard, specification or regulation.

ACKNOWLEDGEMENTS

The authors would like to thank the many building designers, owners and operating personnel who provided survey information. We also wish to thank Gene Klymko of Livingston-Slone Architects and Steve Bettis of Haeg-Bettis Architects for providing the authors special information; also Meredith Lind who edited the work. Finally, recognition is due the late Clare Duklet who worked on the development of theoretical models presented in this paper.

TABLE OF CONTENTS

List of Figures

List of Tables

1.0 SUMMARY

A substantial amount of research has been conducted into the design and materials specifications for "flat" roofs; the so called IRMA or inverted roof designs resulted from that roof. The design of cold, pitched roofs, however, has not been as intensely researched. During 1984 and 1985, the Alaska Department of Transportation and Public Facilities, Division of Research, undertook an investigation of the design of venting serving "cold" roofs.

Over the past ten years, the authors have developed an approach to limiting the accumulation of ice that develops at the eaves of some buildings and have also assisted in the design of attic venting schemes that diminish the amount of airborne snow that can enter attic spaces. This work has been incorporated into the design of roofs for some 30 new and renovated buildings located in Alaska. One objective of this report was to formally set down the design methodologies developed over the past ten years so that they may be discussed among building scientists and design professionals.

The specific aims of this research were two fold: First, the nature and extent of problems intrinsic to the cold roofs serving Alaskan buildings was to be estimated. Second, some basic design criteria concerning the design of venting of the roof structure was to be developed. The following summarizes the findings of this research.

1.1 Survey of Roof Performance

1.1.1 Alaska's climate is diverse and contains four basic climatic regimes that bear upon the design of building roofs serving Alaskan buildings. These regimes are characterized by the following natural phenomena:

1. Blowing snow
2. Blowing rain
3. Eave ice dam formation
4. Condensation of atmospheric moisture

In addition, transition zones combine these climatic characteristics to form subsets of the four regimes.

1.1.2 Notwithstanding the problems our survey uncovered in regard to the performance of pitched roofs, building owners surveyed professed that cold roof performance is superior to that of either the flat or hot roof.

1.2 Attic Space Venting Mechanisms

Adequate attic space venting can usually be achieved with designs which utilize naturally occurring forces.

1.2.1 The attic space venting requirements specified by the Uniform Building Code are inappropriate when applied to cold climates.

1.2.2 In locations where eave ice dam formation is a design consideration, this phenomenon can be mitigated by attic space ventilation systems that are driven by gravity, or natural convective forces.

1.2.3 In areas where blowing snow and rain are design considerations, adequate attic ventilation can be achieved with minimal introduction of air borne moisture through a ventilation system driven by wind forces.

1.3 The Current State of the Art

Although some literature exists on the general subject of cold roof ventilation systems, the researchers found no generally applicable monographs on the subject. Information that does exist is scattered in bits and pieces throughout the building science literature and does not appear to bear specifically upon the cold regions roof design problem.

1.3.1 A scholarly reseach of building science literature addressing attic space venting concerns as outlined in this paper needs to be accomplished. This project is most suited to academic research methods.

1.3.2 A definitive field survey of cold roof performance is yet to be accomplished.

2.0 INTRODUCTION

The roof of most low rise buildings (factories, etc., excluded) constitutes about 25% of the building envelope - a substantial part of the whole of the building's closure. The selection of roof type, detailing of the selected style, and execution of design into a finished construction are of great interest to the building industry.

This study investigates design concepts for venting attic spaces of cold roofs constructed in cold regions. The design concerns for venting attic spaces in cold regions are centered around meeting the requirements of the Uniform Building Code while minimizing eave ice dams and snow infiltration. Our investigations were of two basic kinds; a) empirical observations and surveys of designers and operators to define the severity and geographic scope of the problems and b) theoretical analysis of existing roof ventilation systems.

The authors have been professionally interested in the design of roofs for more than ten years. This interest has been brought about through observations of massive ice damming at the eaves and scuppers of some buildings as well as the observation of snow infiltration into attic and other enclosed spaces. This interest in roof design has resulted in the development of a design approach concerning means of ventilating attic spaces of "cold" roofs.

Over the past ten years, the authors have observed that problems associated with unusually heavy ice accumulations at the eave and scuppers would have not existed if one of the following features had been employed in the design of the roof.

1. Interior roof drains to eliminate scuppers function during winter.

2. Use of a well ventilated "cold" roof.

3. When the roof pitches to the eave, provide a slope greater than 2:12.

4. When the roof is provided with interior drains, the pitch of the roof should exceed an eighth of an inch per foot to the drain under both snow load conditions as well as unloaded conditions.

In our survey work we have spent little time in the field documenting specific cases of either failures or successes. We have, however, inquired of building designers and managers regarding their experience with the performance of cold roofs. Our survey work was not intended to quantify the various performance problems with any degree of accuracy. Rather, we are interested in determining whether or not damage to buildings from eave ice dams and infiltration of snow into attic spaces is an important factor in the maintenance of cold roof systems. We also wished to know the location of buildings displaying such problems so that, in the future, we could perhaps visit these structures and better analyze the phenomenon. Our survey work was designed to provide the approximate geographic, or climatological, boundaries associated with both eave ice dam problems and snow infiltration problems.

3.0 THE BUILDING ENVELOPE

The envelope of a modern building is constructed of four barriers: (1) the weather barrier, (2) the wind barrier, (3) the thermal barrier, and (4) the vapor barrier (see Figure 3.1). Each of these barriers, together with its juxtaposition, must be designed. Each part of the envelope can be thought of as a barrier that is subjected to its own set of environmental "stresses."

3.1 The Stresses

The outdoor environment can be characterized by temperature extremes and averages, wind direction and speed, intensity of precipitation, water vapor, intensity of sunlight, seismic accelerations, and variations of each of these parameters. The indoor environment is described by the requirements of the building occupants, functions conducted within the built space, and building codes and standards. The "stresses" experienced by the elements of the envelope are generally characterized by the difference between the value of indoor and outdoor environmental parameters (e.g., temperature differential); seismic accelerations being an exception to this definition.

3.2 The Weather Barrier

The internal parts of the the envelope as well as the built space must be protected from (or control) rain, sunlight, sand, rocks and other foreign material. The shakes on an old farm house roof form an effective weather barrier for buildings located in the temperate climate. For buildings located in more hostile environments, the shake roof is augmented with a wind barrier that effectively halts the infiltration of blowing rain and snow.

3.3 The Wind Barrier

The structure exposed to the wind presents an obstacle to the movement of air over the ground resulting in strong, local variations in air pressure; the windward side of the structure being subjected to positive air pressures and the lee side experiencing negative air pressures. The net air pressure differential may be as high as 20 pounds per square foot and sometimes more. Wind pressures cause air to infiltrate into and out of the built space. The rate of such air exchange will be controlled by the competence of the wind barrier and the speed and direction of the wind.

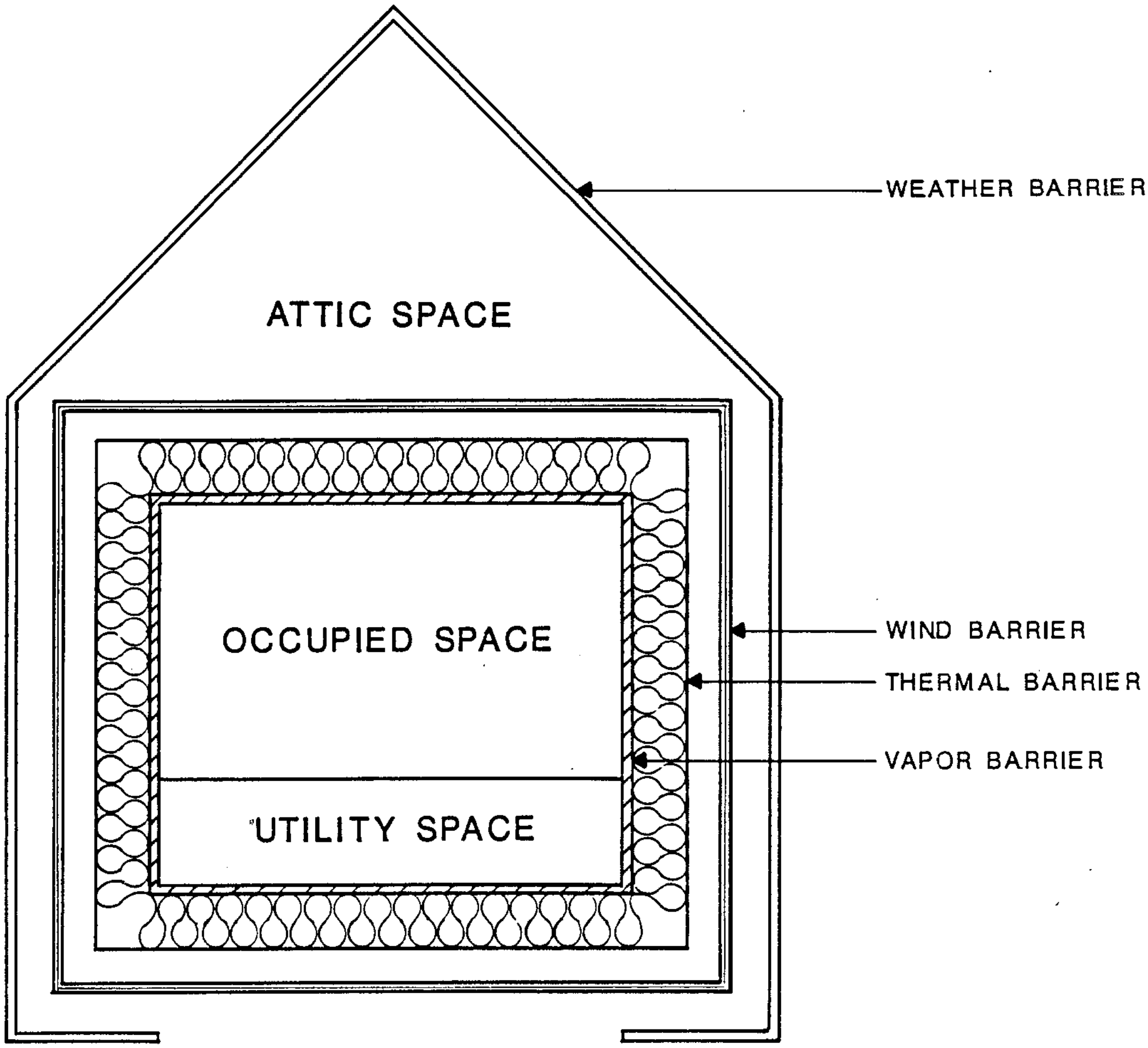


FIGURE 3.1 The Four Part Building Envelope

3.4 The Thermal Barrier

When the temperature of the built space and the out-of-doors is different, heat will flow from the warmer environment to the cooler. In the case of buildings sited in cold regions, this temperature differential can be as large as 135°F. In more moderate climates, the temperature differential through the thermal barrier is about half that experienced by buildings sited in cold regions.

3.5 The Vapor Barrier

Air in the environment is naturally moist. That is to say that even at low temperatures water from lakes, rivers and even snow fields evaporates to gaseous form and becomes a component of the air. Activities such as bathing and cooking are obvious generators of water vapor within the built space. Moreover, humans, even when engaged in sedentary activities, will produce as much as six pounds of atmospheric moisture per day.

Water vapor is driven from an environment of high concentration to environments of less concentration. In the case of the building envelope, the pressure that drives the moisture vapor (its partial pressure) can be as great as 40 pounds per square foot.

3.6 The Roof as the Weather Barrier

The "cold" roof has long been a favorite style of roof for buildings located in the cold regions. This type of roof is frequently used to cover small commercial, institutional, and residential buildings which do not utilize internal roof drainage systems. The cold roof gets its name from the provision for ventilation on its underside. The cold roof provides a barrier to solar radiation, rain and snow; it is a barrier to the weather only. Some control of air pressure gradients across the roof can be made through design of this sort of roof. The purpose of the cold roof, however, is to protect the materials of the building envelope from the deleterious effects of rain, ice, snow, debris, erosion from the wind, and solar radiation. It is our impression that the problems associated with poor roof performance in northern climates are caused when designers try to make the roof function as both a thermal and weather barrier (i.e., the so called hot roof).

The covering of the cold roof is the weather barrier of the roof envelope structure. It should not be designed to function as a vapor barrier because such design would result in trapping moisture from the building within cold parts of the envelope where the moisture would condense from vapor to liquid water, thus risking damage to the insulation materials or perhaps even the built space. By definition the cold roof cannot act as the thermal barrier. If it did, the roof would be termed a hot roof. Section 5.0 explains why the cold roof may not act as an effective wind barrier. Thus, we must think of the cold roof structure in terms of weather barrier only.

A number of design parameters must be defined before a person can undertake the design of a cold roof. We must select wind, snow and seismic structural loading criteria and a pitch or slope of the roof.

The slope of the roof is most often selected on the basis of a combination of structural and aesthetic considerations. From a maintenance perspective, the pitch of the roof should have a slope of at least 2% so that water drains without ponding.

3.7 Ventilation of Attic Spaces

Good design practice, as well as some building codes, requires the direct and positive venting of the attic space to the out-of-doors. The Uniform Building Code (1982 edition) asserts, "The net free ventilating area shall be not less than 1/150 of the area of the space ventilated...." Such venting requirements promote the outward migration of water vapor thus helping to keep attic spaces dry while moderating the temperature in that space. (See Appendix I for the full text of the cited code.)

Under the conditions defined by the Uniform Building Code, buildings having an attic area of 6,000 square feet must be provided with at least the provision of 40 square feet of "net free ventilating area" connecting the attic space to the out-of-doors. (Under some conditions, the venting area may be reduced to one three hundredth of the attic area.) The challenge to the designer is to accommodate the code requirements in a manner that will minimize the development of eave ice dams, restrict the infiltration of blowing snow, promote the dehumidification of materials exposed to the attic environment and help to regulate the temperature within the attic space.

4.0 SURVEY AND QUESTIONNAIRE

The objectives of this study included:

1. An attempt to define the scope of the problems of roof designs interacting with snow in northern environments, and

2. Determining the general geographic distribution of problems associated with roofs in the arctic and subarctic.

This was done by observing various roof designs in interior and south-central Alaska and by canvassing designers and building operators throughout the state.

4.1 Field Observations

The photographs in Figures 4.1 and 4.2 show the extent of ice dam formation which can occur when a hot roof design is utilized in snow country.

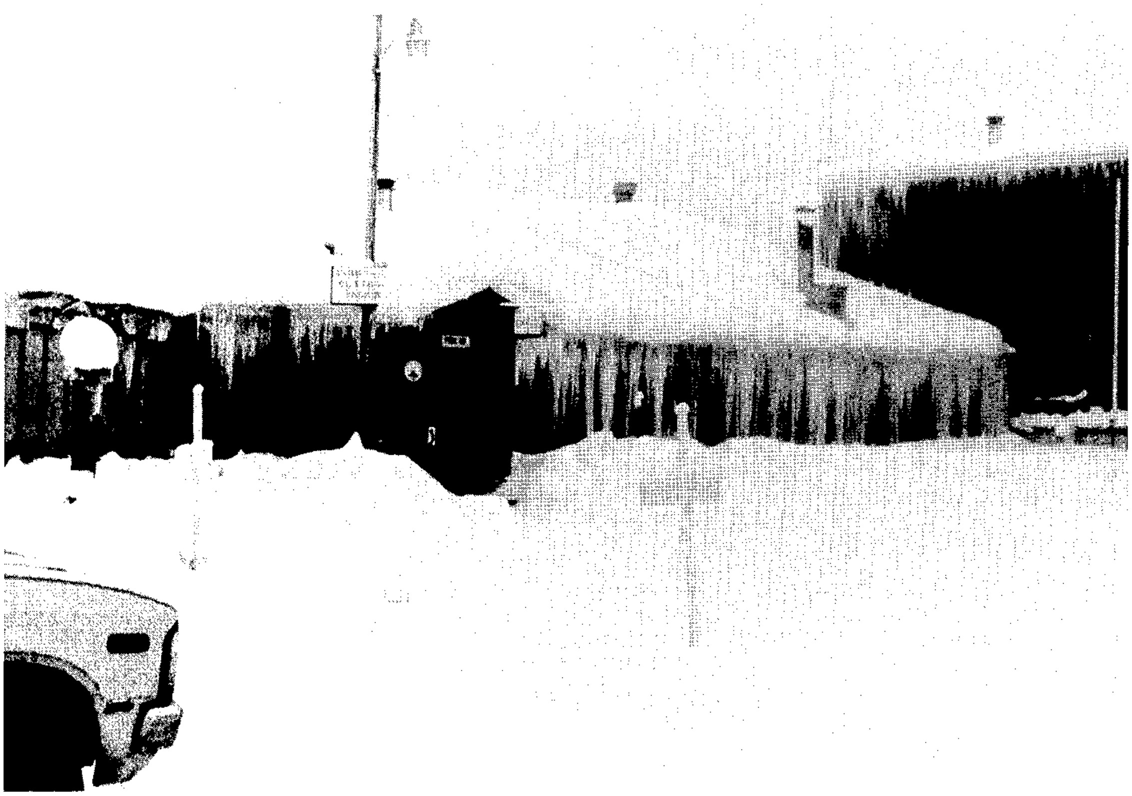


Figure 4.1 Eave ice formation on hot roof; Fairbanks, Alaska.

Figure 4.2 Eave ice formations associated with hot roof; Fairbanks, Alaska.

Figures 4.3 and 4.4 show what happens when roof meltwater is channelled to scuppers as an attempt to mitigate the ice dam problems associated with hot roofs.

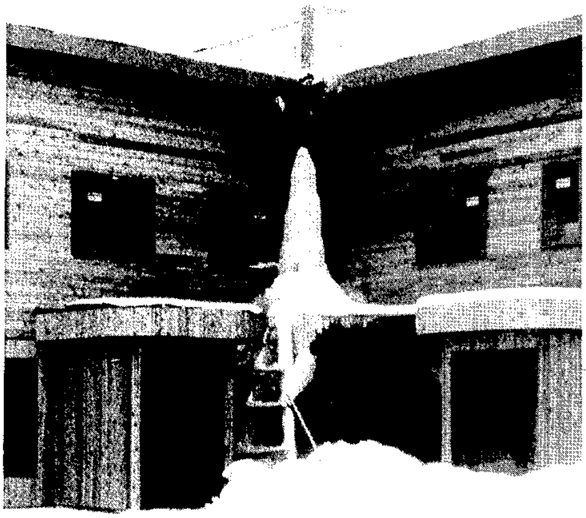


Figure 4.3 Ice formation associated with scupper drainage from hot roof; Fairbanks, Alaska.

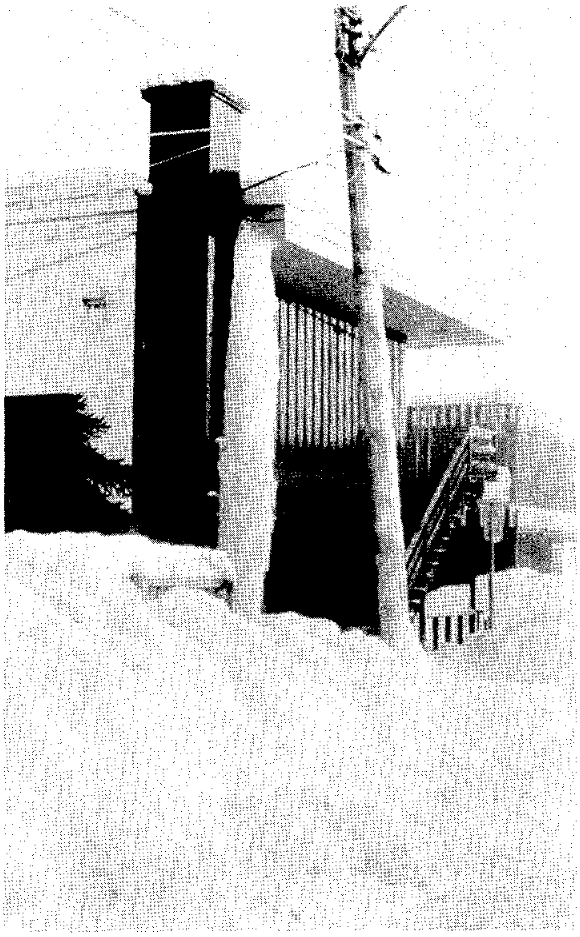


Figure 4.4 Ice formed by scupper drainage from hot roof; Fairbanks, Alaska.

Figure 4.5 shows the most typical solution to dealing with eave ice dam problems associated with hot roofs; that is, shoveling the roof. Not only is this expensive in terms of labor, but more often than not results in structural damage to the roof membrane caused by the shoveling effort.

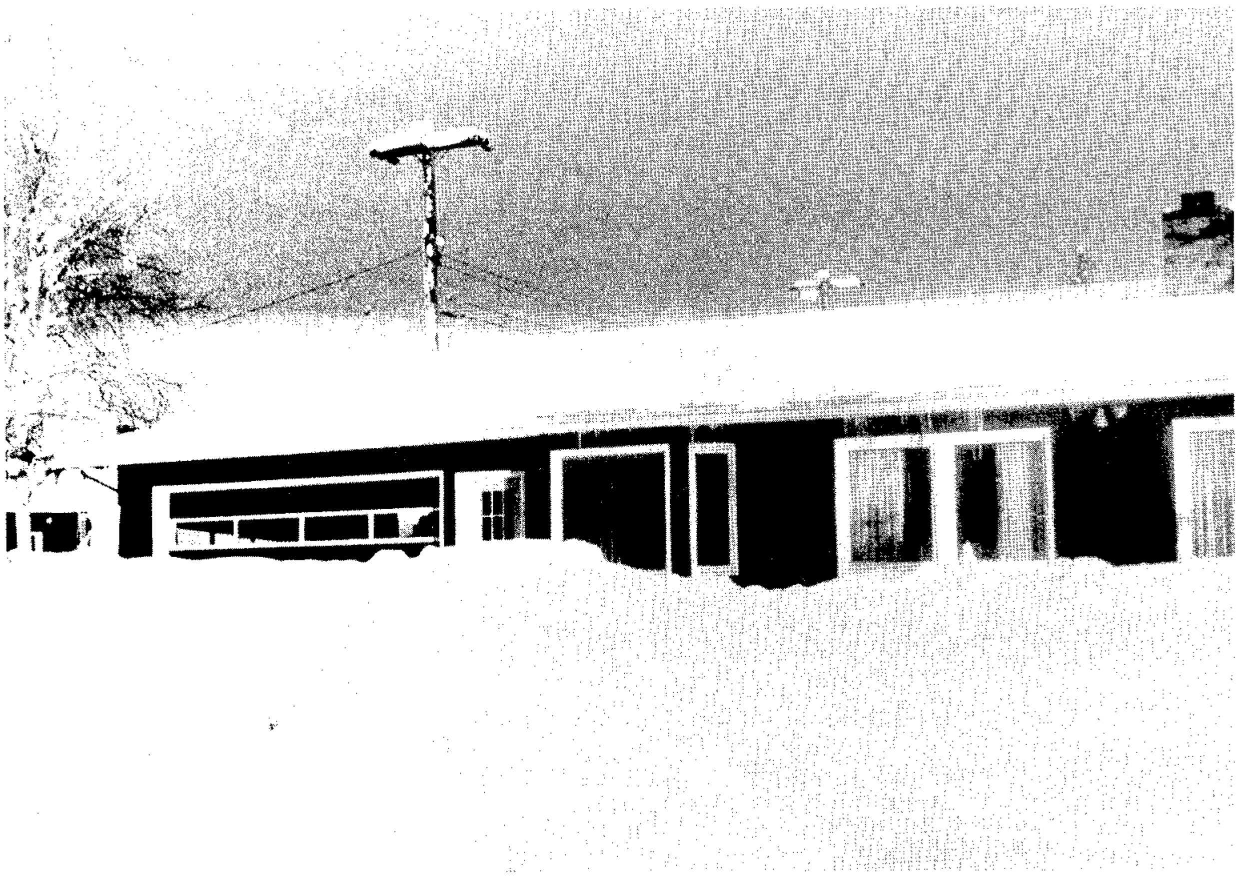


Figure 4.5 Roof shoveling as means to mitigate eave ice on hot roof; Fairbanks, Alaska.

Figures 4.6 and 4.7 show the type of damage which can be expected when these massive amounts of ice come off the structure in the spring. Note the severe eave facia damage; this is typical. The buildings shown in these photographs are heated by furnaces which had their stacks protruding from the round vents on the exterior walls. The damaged ductwork is air delivery from an exterior ventilating system.

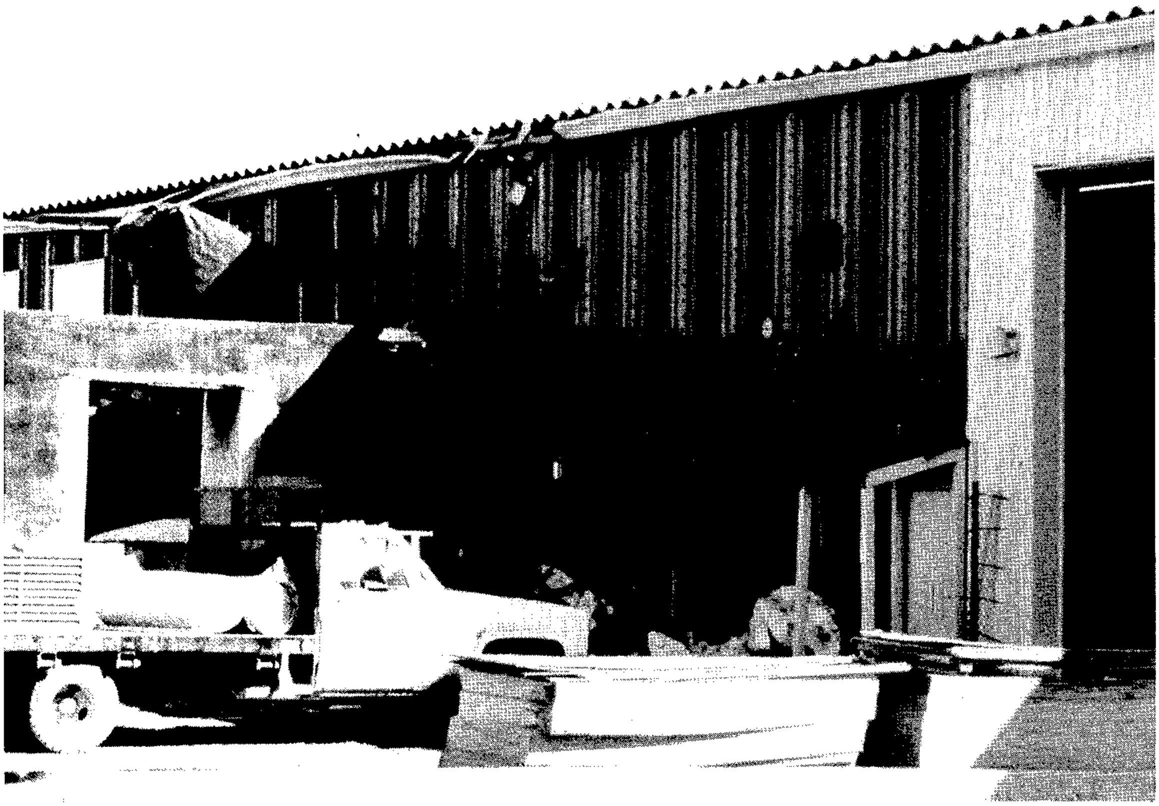


Figure 4.6 Building exteriors sustain damage from ice formations; Fairbanks, Alaska.

Figure 4.7 Damaged eave facia and protruding ductwork caused by ice formations; Fairbanks, Alaska.

Figure 4.8 depicts one of the effects of snow infiltration into ventilated attic spaces. In this case, warming in early spring caused melting of snow lodged in the attic area; the resulting meltwater drained through openings formed by light fixtures and refroze.

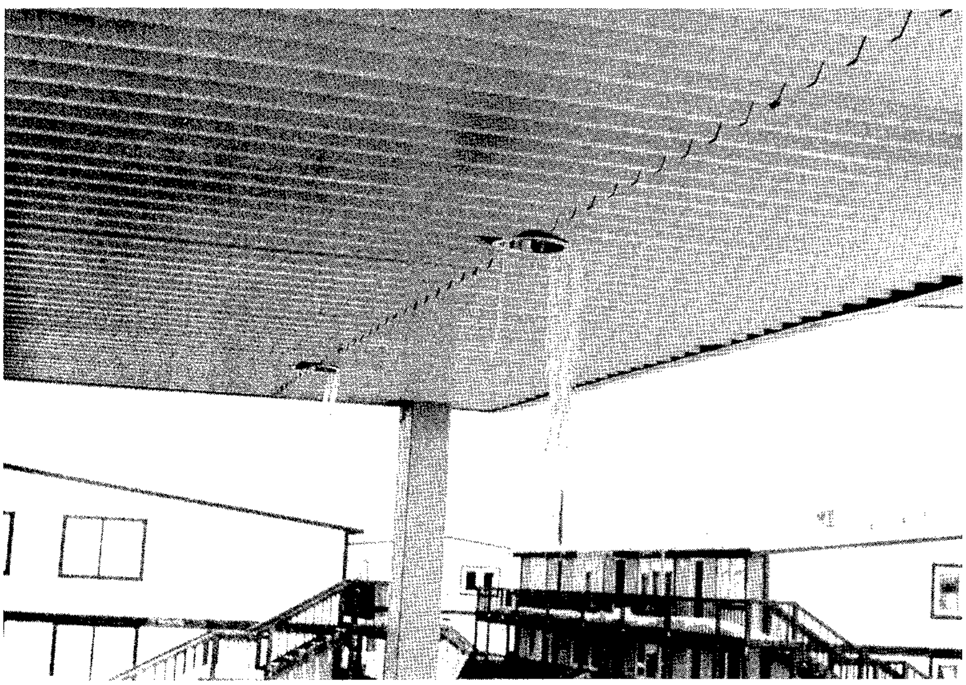


Figure 4.8 Example of associated effects of snow infiltration into attic space; Barrow, Alaska.

Figure 4.9 illustrates the potential for snow infiltration in windy areas.

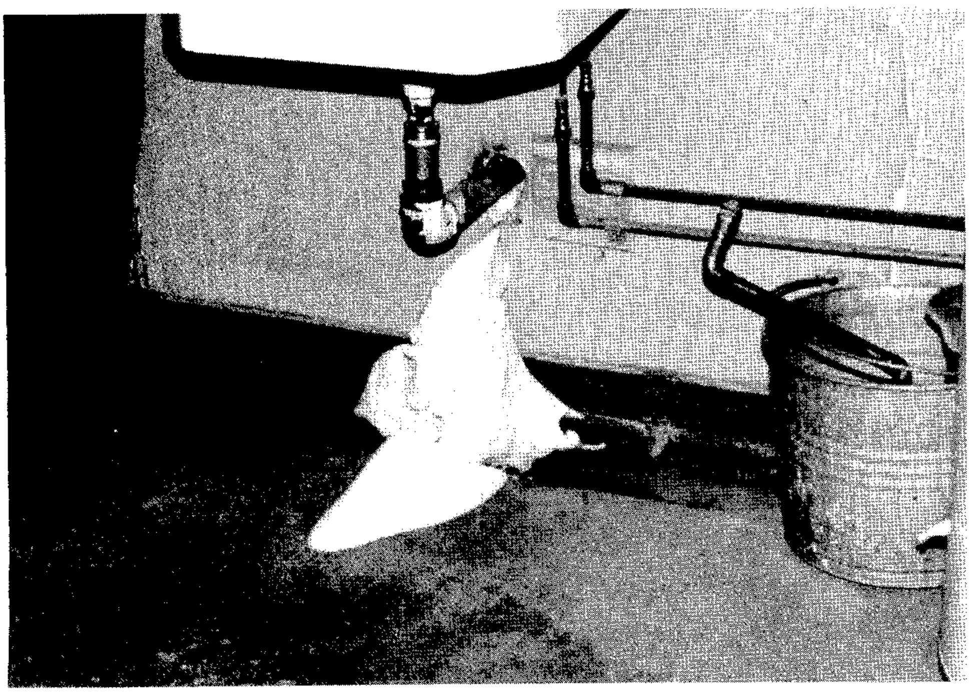


Figure 4.9 Blowing snow infiltration into built space; Barrow, Alaska.

Finally, Figure 4.10 shows a building with a well ventilated cold roof functioning in Fairbanks, Alaska, in the spring of the year. Note the total lack of eave ice dam problems and the full, even crest of snow over all portions of the roof. Since this structure is located in a geographic area where blowing snow into the ventilated space is not a problem, one can conclude that this is an excellent design which is functioning well.

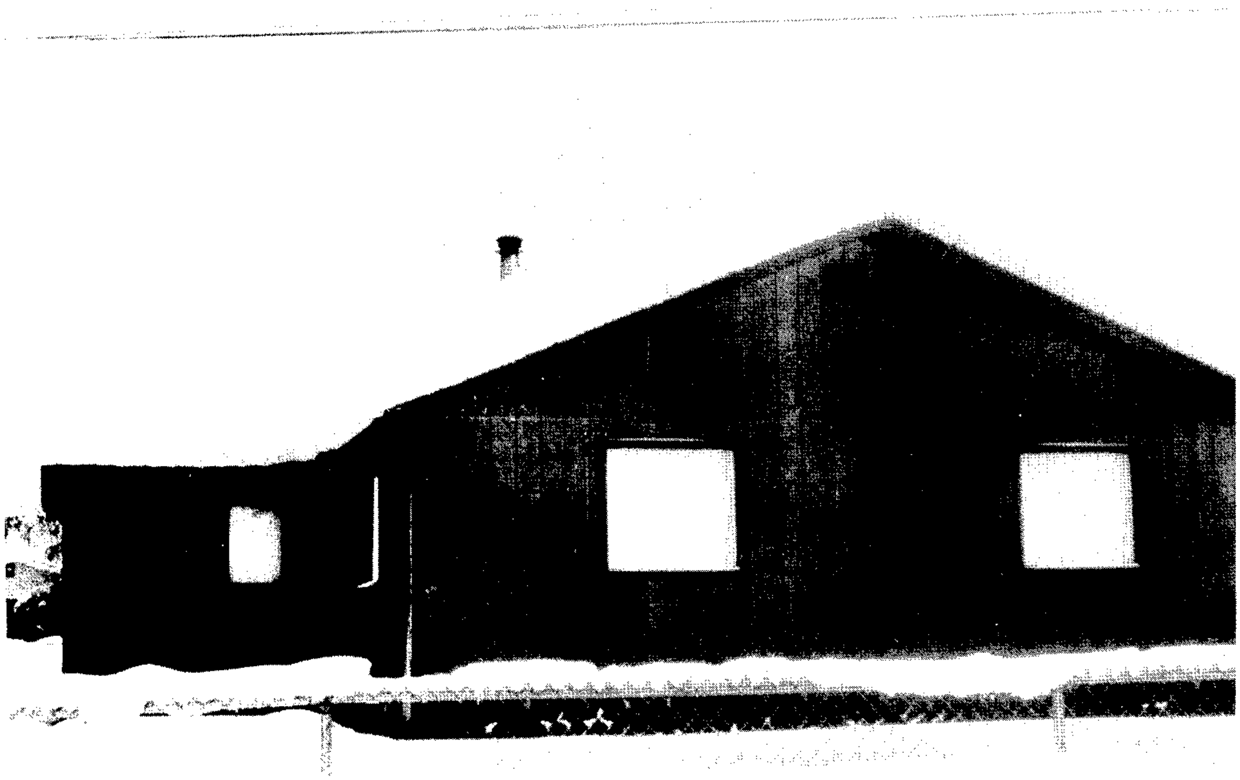


Figure 4.10 Well ventilated cold roof; Fairbanks, Alaska.

4.2 Geographic Survey

When this study began, it was anticipated that the eave ice dam and blowing snow problems would vary geographically throughout the study area. To determine what this geographic distribution might be, and also to attempt to determine the overall severity of the problems as perceived by roof designers and building operators, a questionnaire was developed and distributed to 94 architects, school districts and military facilities throughout Alaska. A summary of responses is shown in Table 4.1.

Table 4.1 Summary of Results of Geographic Survey

Type of Problem	Number of Responses	Square Feet of Roof Involved
1. Blowing snow in attic spaces	5	5,100,000
2. Eave ice dam formation	8	2,200,000
3. Eave ice dams and blowing snow	5	500,000
4. No problems with either eave ice dams or blowing snow	8	1,400,000
TOTALS	26	9,200,000

The results of the geographic survey verified the original premises of this study. That is:

1. Roof related blowing snow problems are most significant in northern coastal and mountain pass regions of Alaska.

2. The occurrence of eave ice damage to buildings and the potential hazards related to these problems are more severe in interior regions of the state as well as regions characterized by the relatively milder climates. This observation is supported by survey data. Although the authors feel there is a direct link between eave ice damage problems and intensity of solar radiation between eave ice damage problems and intensity of solar radiation during the late winter and spring months, we can offer no theory or convincing data to assert such a conclusion.

Figure 4.11 shows the geographic distribution of the problems as reported by respondents to the survey as well as personal experiences of the authors.

5.0 DISCUSSION

Two sets of ventilation mechanics are presented in Sections 5.1 and 5.2 of this paper. Section 5.1 develops a model of natural convective, or gravity, venting for attic spaces. This scheme of roof venting is typically associated with a system of venting designed to mitigate the formation of ice dams and icicles that form at the eave of the roof.

In Section 5.2 an approach is developed for moving air through the attic space under natural wind forces. This approach is taken when addressing the problem of snow infiltration into the attic spaces. The designers dilemma is to provide for the free flow of air through the space while discouraging the infiltration of snow.

The reason the convective system of attic ventilation is used to prevent ice dam phenomena is that the weather regimes which promote ice dams and their associated problems are thought to be most evident where the climate is typified by the sunny, calm spring weather of more continental regions and wind forces are not a dominant design consideration. On the other hand, in the arctic coastal area and mountainous regions of Alaska and Canada, often typified by a windy climate, blowing snow can become a real design problem which should be addressed in a forthright way.

Promoting the uniform ventilation of attic spaces with outside air requires an understanding of the forces that move ventilation air into and out of the ventilated spaces. Most buildings are designed so that natural forces can be relied upon to adequately promote proper attic ventilation. These forces include the velocity pressure provided by the wind and gravity allowing heated air to rise as in the chimney effect.

Utilizing either or both of these natural forces requires a basic understanding of the mechanics of the forces, an analysis of the geometry of the building, and an estimate of the magnitude and direction of prevailing and storm winds. These building parameters are typically addressed at one time or another during the design of a building, thus the information will be at hand when the actual analysis of the venting system is devised.

The difficulty in designing attic venting systems is greatly reduced if the designer addresses the venting requirements when developing the shape of the roof, the structural systems used to support the roof, as well as the requirements of some codes to discontinue eave soffit venting near openable windows, a requirement of the Uniform Building Code, 1976 edition.

5.1 Ice Dams on Roofs

Ice dams form at the eave of roofs when meltwater from snow runs down the pitched roof and encounters freezing temperatures as it surfaces at the eave. This phenomena is most pronounced when a substantial snow pack is present on the roof and heat can freely move from the building to the roof providing energy to melt the snow. Flat roofs that rely on scuppers to drain water melting from the snow pack suffer extreme ice formation at the scupers. Even though icicles along the eaves of roofs may be picturesque, they have the potential to damage the roof eaves and soffits, exterior building cladding, and in some cases threaten the safety of passers-by. See Section 4.0 for photographs of examples.

It is difficult to eliminate ice dams completely; however, it is possible to minimize their formation to a large degree, thus diminishing their deleterious effect.

The growth of ice at the eave of a roof requires two conditions: First, there must exist a source of liquid water, and second, that water must be exposed to freezing temperatures. The source of the liquid water is a melting snow pack. Obviously, if the snow pack is melting while the ambient conditions promote freezing at the eave, the snow pack must be supplied with an energy source not available to the water freezing at the eave. Typically, the energy source available to produce meltwater is the warm building below the roof and/or solar radiation.

If the roof is of the hot type, little can be done to reduce the production of meltwater at the roof/snow pack interface. On the other hand, if the space between the attic insulation and the roof is ventilated, the temperature at the roof/snow pack interface can be maintained at near the ambient outdoor temperature (i.e., freezing or below). It must be recognized that ventilating the roof may go a long way toward reducing melt caused by interior space heat; although solar radiation from above can still produce meltwater, even when the outdoor temperature is below freezing. However, when solar radiation is the source of energy that produces meltwater from the snow pack, that same energy source is often available to ablate the ice forming at the eave of the building. Thus, the primary culprit in ice dam development is snow pack melting at the roof surface due to building heat loss and refreezing at the eave.

It is important to remember that snow is an insulator. When snow accumulates on a hot roof, the temperature of the snow pack at the roof/snow interface will rise until, at some time, melting will occur. Even the extremely well insulated hot roof (R value in excess of 80) can produce more than a tenth of a pound of meltwater a day per square foot of roof area. If the distance from peak of roof to eave is 25 feet, for example, nearly three pounds of ice per day can form along a lineal foot of eave. Figure 5.1 illustrates the change in isothermal patterns with snow depth on a hot roof.

5.1.1 A Method of Designing Attic Space Ventilation to Minimize Eave Ice Dams

If outside air is allowed to enter the attic space at the eave and leave the space at a higher elevation, such as the peak of the roof, and if heat is lost into the ventilating air from interior spaces below, the ventilation air will be warmed and will establish a stable flow through the attic space. The force driving such a ventilation system is the difference in weight between the column of cool outside air and the column of warmer ventilating air (see Figure 5.2). The forces that resist the flow of air through the attic space are the friction forces produced by the air flowing over surfaces within the attic space as well as inertial forces. Both driving and resisting forces can be estimated with a fair degree of accuracy.

The critical parameters driving this natural convective system are the air temperature within the ventilated space and the difference in elevation between entering and exiting air. The critical parameters resisting the flow of air through the attic space are the size and shape of the vents that allow the air to pass in and out of the system, other restrictions to air flow produced by structural elements (e.g., shear membranes), or restriction in the path the air must follow on its route through the ventilated space.

5.1.2 The Attic Venting Equation

A mathematical model for natural convective attic venting is appended to this paper as Appendix II. In that appendix the ventilation model's use is demonstrated when applied to simple roof geometry. The equation that results from the example is:

$$Av = \frac{Aa \quad (Ts-Ta)}{60 \quad R \quad Ue \quad De \quad Cp \quad (To-Te)} \qquad \text{Equation 1}$$

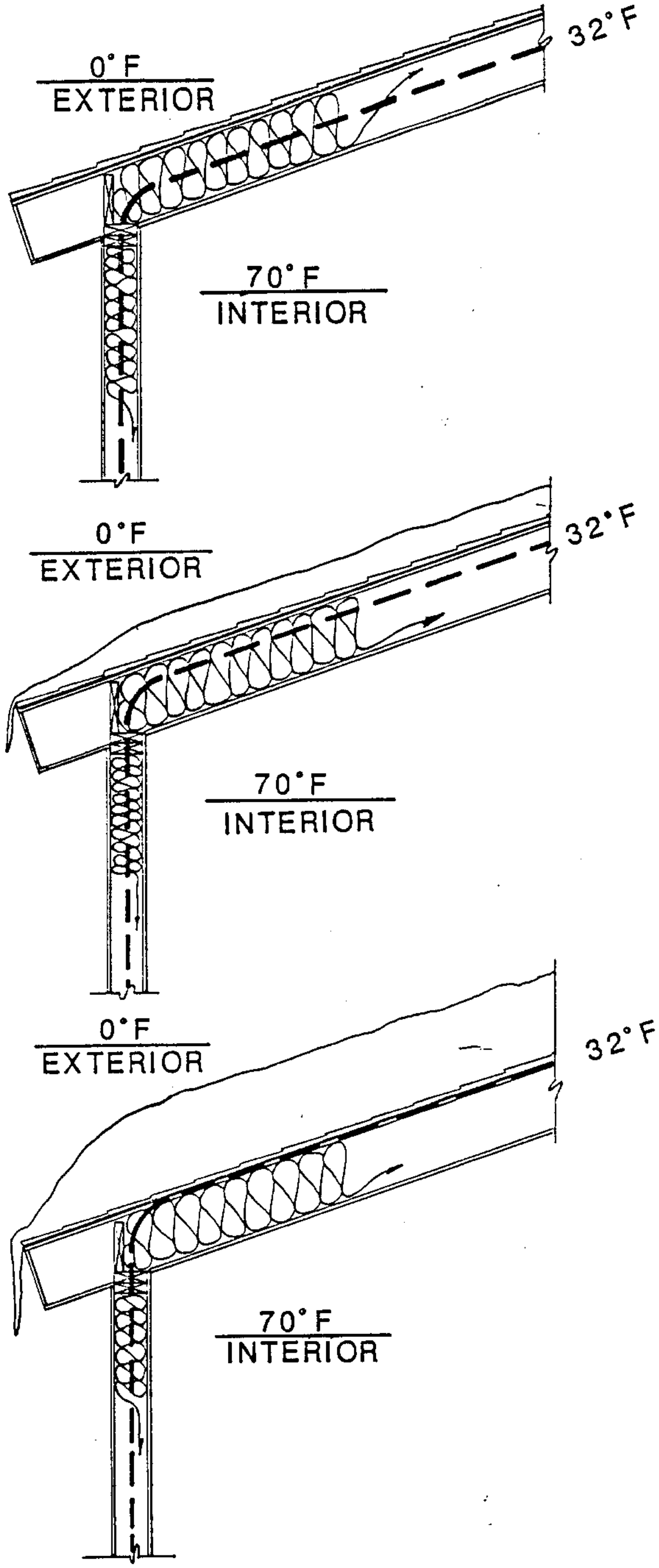
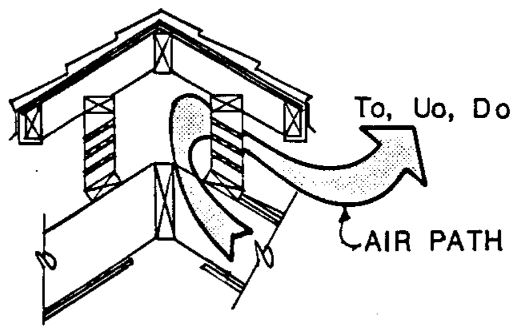
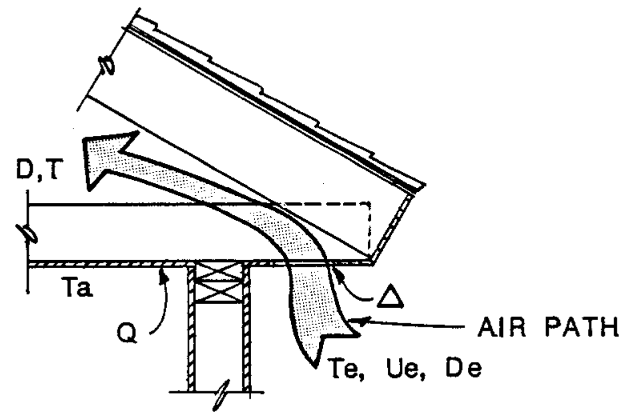


FIGURE 5.1 Movement of Freezing Isotherms with changing Snow Patterns



DETAIL - RIDGE VENT



DETAIL - EAVE VENT

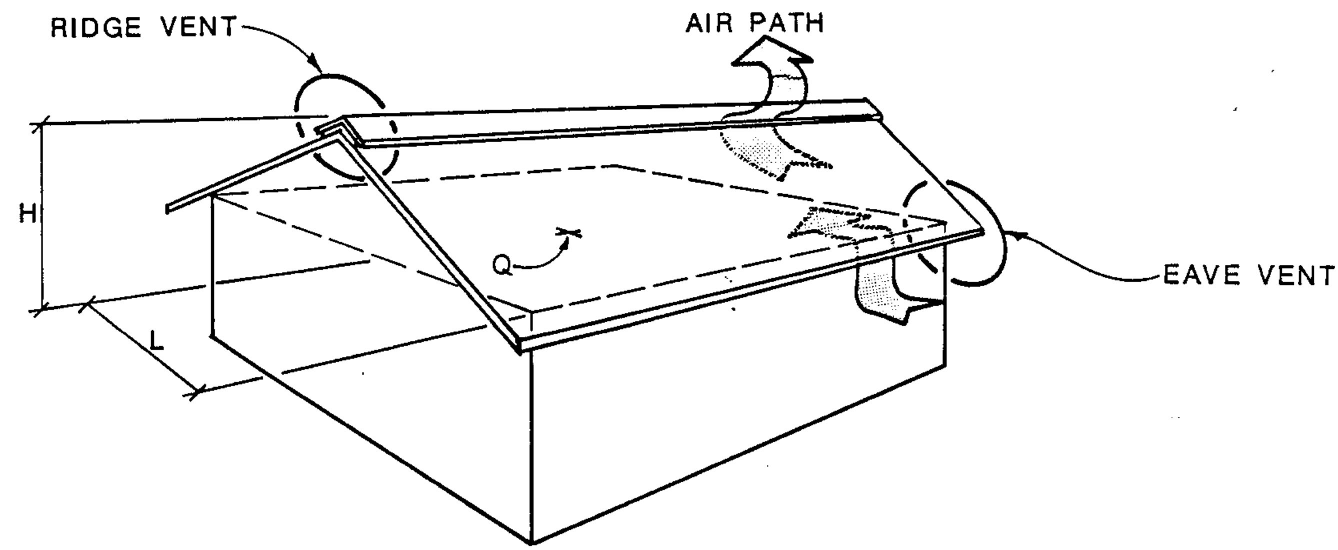


FIGURE 5.2 Convective Air Flow Through Attic Space

Where:

Av = The unit area of the vent at the eave
Note: The area of the vent located at the high point should be equal to the sum of the areas of the vent openings located at the eaves.

Aa = Unit of ventilated attic area per unit of eave vent length (square feet per foot)

R = Thermal resistance to heat flow (sq. ft.-hour-°F. per BTU)

Ue = Velocity of air entering the attic at the vent opening (feet per minute)

De = Air density at outside conditions (pounds per cubic foot)

Cp = Specific heat of air (BTU per pound -°F.)

Te = Temperature of ventilation air entering attic space (°F.)

To = Temperature of air leaving attic space (°F.)

Ts = Temperature of the occupied space (°F.)

Ta = Average temperature of attic space as calculated from the following equation (°F.)

$$Ta = \frac{(Te + To)}{2} \qquad \text{Equation 2}$$

And:

$$Ue = 60 \frac{[2 \quad g \quad H \quad (De-Da)]^{0.5}}{[C \quad De]^{0.5}} \qquad \text{Equation 3}$$

g = Acceleration of gravity

H = Height of the air column

De = Density of entering air

Da = Density of attic air

C = Coefficient of frictional resistance
(Note: Two orifices are accounted for; at the eave and at the ridge of the roof).

An approximation of this equation, under typical conditions favorable to formation of eave ice is:

$$Av = \frac{2.37 \quad L}{R \quad H^{0.5} \quad \Delta T} \qquad \text{Equation 4}$$

Where:

L = Horizontal distance from edge of attic space near point of eave vent to a point just below the vent located at the peak of the roof (Feet)

R = Thermal resistance to heat flow from the enclosed space to the attic space (Sq. Ft.-Hour-°F/BTU)

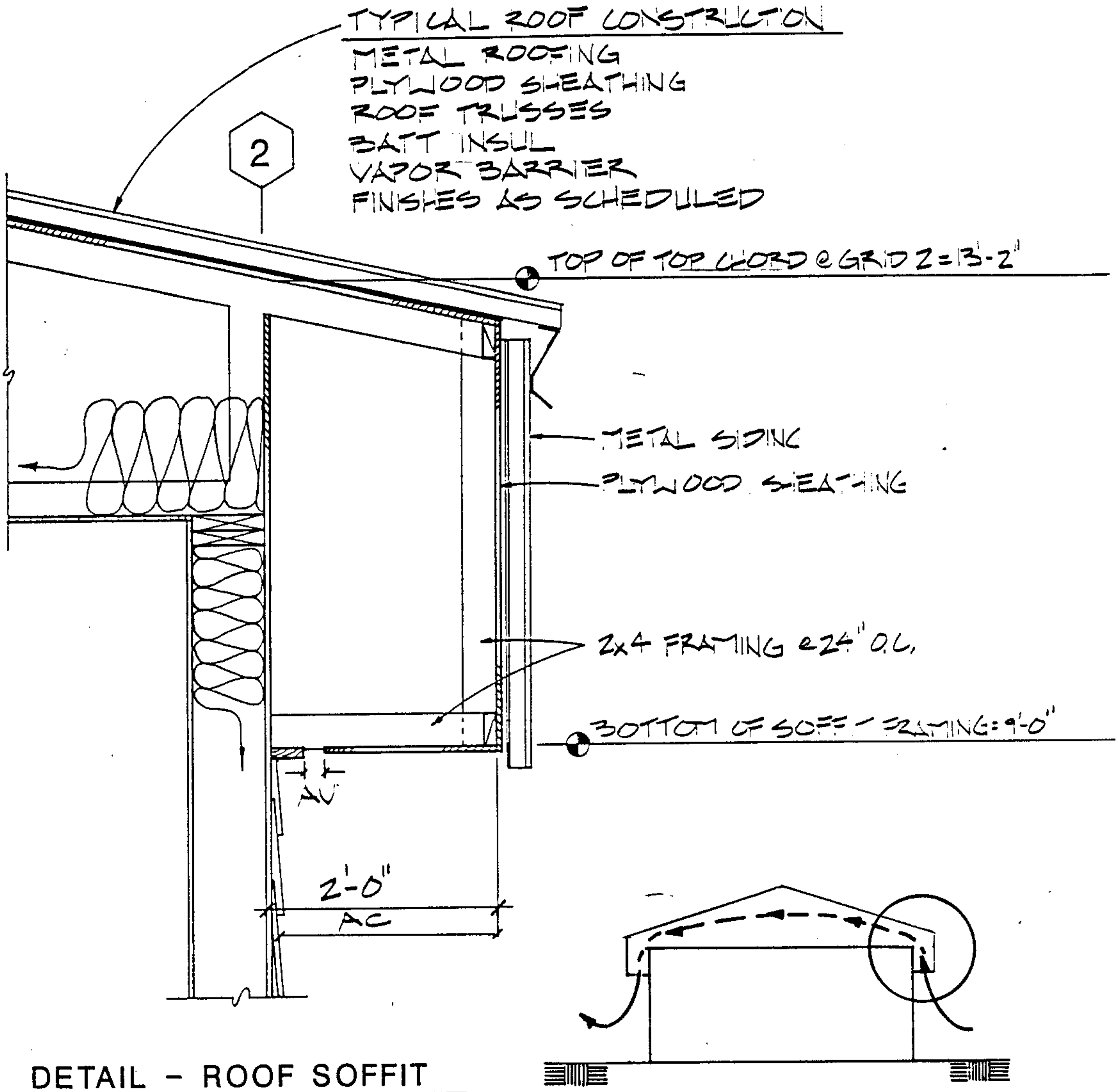
H = Vertical distance from eave to the vent located at roof peak (Feet)

ΔT = The design temperature difference between entering and leaving ventilation air. Recommended value is 4°F. (°F.)

The constant term in Equation 4 (2.37) is made of units conversion constants and typical variable values listed in the example contained in Appendix II.

5.2 Blowing Snow

The cold roof is preferred by many designers and building operators because of its superior performance compared to some other roofing systems. For buildings sited in the coastal and mountain regions of the North, however, the problems brought on by snow infiltration into attic spaces can be so severe as to make hot roofs preferable. If the cold roof could be designed so as to eliminate the snow infiltration problem, the cold roof could offer performance superior to alternative design concepts. In 1978 the authors worked with Steve Bettis of Haeg-Bettis Architects to address the subject. Figure 5.3 shows the eave venting detail that resulted from that early work.



DETAIL - ROOF SOFFIT

IDEALIZED BUILDING SECTION

FIGURE 5.3 Roof Soffit Detail from Akhiok School Design (Haeg.Bettis Associates, Architect)

Bettis has used variations of the pictured detail in the design of some 29 buildings sited at various locations throughout Alaska's coastal arctic. To date we know of no performance failure of this method of attic space venting. The design is developed around two concepts: (a) reduction of the speed of the air moving into the attic space to a level that will encourage airborne snow particles to fall from the air stream before entering the attic space and (b) designing the vent openings so that they will plug with snow under the more severe storm conditions.

This section discusses these design concepts and suggests other methods of approaching the design of ventilated attics where buildings are subjected to a blowing snow environment.

5.2.1 The Model

Our objective is to devise a means of providing adequate attic venting while limiting the infiltration of snow into the attic space. To get an idea of the amount of snow we may safely allow into the attic, we can estimate the sublimation rate of snow resting upon the attic insulation when the attic ventilation air is 0 degrees F. at 75% relative humidity. That calculation yields a sublimation rate of only .03 inches of snow per day - enough to remove a trace of accumulated snow. It is apparent then that the method of preventing snow from entering the attic space must be fairly effective.

The parameters that govern design of attic venting methods in a blowing snow environment are: (1) the properties of blowing snow, (2) the forces provided by prevailing and storm winds, and (3) the physics of air flow through the attic space. Therefore, we must also establish minimum venting criteria that accounts for the fundamental physics of the problem.

5.2.2 Properties of Blowing Snow

When the snow pack is cold and fresh, a wind of about ten miles per hour can cause snowflakes to roll along the ground, becoming partially air born at times and settling back to the ground at other times (see Blowing Snow by Malcomb Mellor). This snow transport mode is known as saltations. When the snowflakes are tumbled along the ground, the dendritic petals of the flake are sheared off leaving the smaller ice core of the snow flake. The size of that tiny ice particle is measured in tenths of millimeters. Such tiny, light particles can easily be held in the air by the slightest updraft of the wind.

A strong breeze passing over open snow fields is more turbulent near the ground's surface. That turbulent flow creates vortices and eddies that have strong vertically upward components. Under these conditions, the tiny snow particle may be swept to heights measured in tens of feet into the air. During a storm, snow may be carried several hundreds of feet aloft. Since the airborne snow particles are only one one-hundredth of an inch in diameter, they are easily entrained into air streams that enter the building envelope. All those familiar with the Arctic coastal regions will remember times when snow leaked past defective weather stripping to enter foyers and other spaces within the building.

The amount of snow entrained in the air during stormy conditions may seem trivial when measured at a pound of snow for every two thousand cubic feet of air, however, we know of many cases where buildings experienced enough infiltration of outdoor air during a storm to replace all of the air within the building twice every hour. For the modest home of 1,000 square feet, this amount of air may calculate to 12,000 to 15,000 cubic feet an hour. That quantity of air is capable of transporting as much as six pounds of snow an hour. If the storm lasts two days, perhaps 350 pounds of snow will have been introduced into the building envelope, if not the occupied spaces themselves.

To address these environmental realities when detailing the ventilated attic space, a method must be developed to deal with snow that becomes entrained in the ventilation air. Addressing this problem requires some knowledge of the physics of the problem as well as the properties of blowing snow.

5.2.3 The Settling or Fall Velocity

The settling velocity is the speed at which a particle will fall in calm air. Seen a different way, the settling velocity of a snow particle is the minimum vertical air velocity component required to keep such a particle from falling downward. Particles of blowing snow have a settling velocity ranging from 10 to 100 centimeters per second (0.2 to 2 miles per hour) (see Blowing Snow y Malcomb Mellor). These values can be ascertained by calculating the rate of fall of a sphere of appropriate density according to Stoke's Law or through empirical methods. Since snow particles are not truly spherical, the values used in this work have been developed through empirical means as reported by M. Mellor in his monograph on blowing snow (Mellor, 1965).

5.2.4 The Wind Pressure

Analysis of the flow of air through the attic space, as was discussed in section 5.1, requires the balancing of driving forces as well as forces that resist the flow of air. The forces resisting the flow of air in the case of the blowing snow problem are the same as those discussed in Section 5.1. The driving force in the blowing snow problem, however, is the force of the wind. The following development leans heavily upon chapter 14 of the ASHRAE Fundamentals, 1985 edition. For a more complete development, the reader is directed to that document.

The velocity pressure of the wind can be approximated with the following equation:

$$Pw = 0.00643 \quad De \quad Cos\alpha \quad Uw^{2.0} \qquad \text{Equation 5}$$

Where:

Pw = Velocity pressure (inches of water column)

Uw = Wind speed in miles per hour

α = Angle of attack of the wind (measured in degrees of arc from a line normal to the vented side of the building)

De = Density of outside air (pounds per cubic foot - approximately 0.0863 #/Cu. Ft. at 0°F.)

The constant term (0.00643) is made of units conversion constants and the reciprocal of the gravitational acceleration constant.

As is pointed out in Appendix III, the total pressure differential across the building can be roughly estimated as twice the velocity pressure. (It should be pointed out that the assumption that total pressure equals twice the velocity pressure is a gross simplification; for more information on the subject, the reader is directed to Chapter 14 of the ASHRAE Fundamentals, 1985 edition.) This relationship arises because there exists a "negative" pressure on the leeward side of obstacles placed in a wind stream. The real pressure differential imposed upon a building (except in the most simple geometries) can only be estimated through model testing in a wind tunnel.

5.2.5 Minimum Attic Ventilation Requirements

The minimum attic ventilation requirements under the wind driven criteria are presumed to be equivalent to those in the natural convection driven case. That is to say, it is based upon attic temperature criteria. In Appendix II, a maximum average attic temperature of 2°F. above outdoor air is recommended. For lack of more formally developed criteria, the authors assume the 2°F. average temperature differential criteria to also be applicable to cases where attic ventilation is wind driven.

The authors' experience in achieving adequate attic ventilation so as to minimize ice dams at the eave of the building suggests that about a third of a cubic foot of air per minute should be provided to each square foot of ventilated attic space. This amount of air appears to be adequate to keep the attic cool so as to mitigate the production of meltwater from the snow pack on the roof as well as keeping the insulation and materials exposed to the attic environment dry. This relationship can be reduced to equation form when the scale of the building is on the order of single family residences and the roof geometry is conventional.

Since it is beyond the scope of this work to establish comprehensive criteria for the amount of air admitted to the attic space, we offer the following criteria with a note of caution. We hope others will continue this work to either verify our experience or develop new criteria based upon more accurately documented emperical evidence.

$$\text{Attic Venting Criteria} = \frac{0.21 \quad (Ts-22)}{R} \qquad \text{Equation 6}$$

Where:

Ts = Temperature of occupied space (°F.)

R = Thermal resistance to heat flow (sq. ft.-hour-°F. per BTU)

The constant (0.21) is made of units conversion constants.

Using values from the example conditions cited in Appendices II and III, Performance = 0.336 cubic feet of air per minute per square foot of attic space.

Since the quantity of air moving into the attic space is the product of the vent area and entrance velocity, performance can be stated as:

$$\text{Attic Venting Criteria} = \frac{Av \quad Ue}{Aa} \qquad \text{Equation 7}$$

5.2.6 The Attic Venting Equation

In Appendix III we demonstrate that:

$$Ue = 60 \quad \frac{[Pw \quad 2 \quad g]^{0.5}}{[De \quad C]^{0.5}} \qquad \text{Equation 8}$$

Where:

Ue = Velocity of air entering the attic at the vent opening (feet per minute)

Pw = The velocity pressure of the wind (pounds per square foot)

g = The acceleration of gravity (32.17 feet per second squared)

De = Density of the air (pounds per cubic foot) (approximately 0.0863 pounds per cubic foot at 0°F.)

C = Coefficient of frictional resistance (dimensionless)

By rearranging Equation 7 to solve for the eave vent area (Av) and substituting the results of Equations 5 and 6, we can determine the minimum eave vent area:

$$Av = \frac{0.013 \quad Aa \quad C^{0.5} \quad (Ts-22)}{Uw \quad R \quad (\cos \alpha)^{0.5}} \qquad \text{Equation 9}$$

Where:

Av = The unit area of the vent at the eave

Aa = Unit of ventilated attic area per unit of eave vent length (square feet per foot)

C = Coefficient of frinctional resistance (dimensionless)

Ts = Temperature of occupied space (°F.)

Uw = Wind speed in miles per hour

R = Thermal resistance to heat flow (sq. ft.-hour-°F. per BTU)

α = Angle of attack of the wind (measured in degrees of arc from a line normal to the vented side of the building)

Appendix III contains an example of the application of Equation 8 to design of attic venting in blowing snow conditions.

5.2.7 Settling Chamber Sizing

Appendix III points out that the eave slot is sized according to calculations involving average wind speeds and vectors. The problem with infiltration of snow arises, however, during storms. In Equation 5 the wind pressure is devalued by the "obliqueness" of the angle of the prevailing wind vector. When considering storm conditions, we must take into account the relative orientation of the storm wind to the eave. After determining the direction of the storm wind and the size of the opening at the eave (Av), we can calculate the rate that air passes into the soffit (Ue). When that value is calculated, the width of the settling chamber (Ac) may be calculated:

$$Ac = \frac{Ue \quad Av}{60} \qquad \text{Equation 10}$$

Where 60 feet per minute is the assumed settling velocity for snow.

Figure 5.3 suggests an approach to forming a settling chamber within the soffit construction. When such a detail is actually designed, we must realize that snow will accumulate in the chamber and must be allowed a place to drain when it melts. Another feature of the design is that during storm conditions, the slot will plug with snow settling from ventilation air, thus further reducing the flow of air during the storm.

When the storm is over, heat loss from the building will provide some energy to encourage the sublimation of snow trapped in the soffit. This natural action will act to slowly clear the soffit of snow as time passes. Only the spring thaw, however, will completely clear all the snow from the detail depicted in Figure 5.3.

6.0 CONCLUSIONS

6.1 The Uniform Building Code

The research performed on behalf of this projet points to a number of conclusions. The most unpredicted conclusion was the relationship between required attic venting, as developed through the analysis of gravity forces, and the Uniform Building Code (UBC) requirements. In the example problem shown in Appendix II, the area requirement of each vent opening at eave and ridge is 1/150 the area of the ventilated space. Close examination of the 1982 UBC reveals that each eave vent opening could be as small as 1/600 of the area of the ventilated space, 25% of the calculated value.

Under the example conditions described in Appendix II, if the attic space were ventilated according to the UBC requirements, the temperature of the space would be 42°F., allowing the roof to warm.

In the example shown in Appendix III, where the venting mechanism is wind, determining the eave vent opening size on the basis of the UBC requirements would have oversized the vent by five times, making it 1-7/8 inches wide as compared to 3/8 inches as calculated.

We conclude, therefore, that new guidelines be established for ventilating attic spaces in arctic and subarctic buildings.

Other findings of this research include the following:

1. The survey of building designers, owners and operators

   a. Analysis of responses to the survey questionnaire resulted in the definition of four climatic regimes; each of which is characterized by distinctly different attic space venting problems as follows:

      I. Blowing Snow
      II. Blowing Rain
      III. Eave Ice Dams
      IV. Atmospheric Moisture Condensation

   b. Some climatic design regimes display characteristics of more than one of these problems. In southeastern Alaska, for example, blowing rain and condensation of atmospheric moisture are both problems that must be addressed in the design of attic space venting.

c. Building operators surveyed expressed a preference for "cold" roof design rather than flat or "hot" roofs. Roofs designed in this manner are generally more trouble-free than roofs of other designs.

2. Roof ventilation schemes

The design of attic space venting for cold regions must address the infiltration of blowing snow and rain into the building envelope as well as the accumulation of ice on the eaves of the building. Analysis of these building design problems concluded that two distinctly different design approaches were warranted; one to address the ice dam problem and a second to combat the infiltration problem. Although the problems associated with condensation of atmospheric moisture within the attic space were not formally addressed in the preceding sections, our experience suggests that insulation "blown" onto the interior of the metal roof deck and the metal structure within the attic space tends to alleviate this problem.

a. To mitigate the growth of ice dams at the eave of the building, the attic space should be kept as cool as possible. Heat escaping from the built space should be used to force convection of air through the attic space and away from the roof deck, where it may contribute to generation of meltwater at the snow/roof interface. The critical design parameters governing adequate ventilation of the attic space for buildings located in the eave ice dam climate regime are listed below:

H = The vertical distance from eave to the vent located at roof peak. (Feet)

R = Thermal resistance of attic insulation. (Sq. ft.-Hour-°F./BTU)

Aa = Attic area ventilated per lineal foot of eave vent. (Sq. ft. per ft.)

The area of eave and "high point" venting (Av) per linear foot of eave can be estimated (for simple roof geometries) with the equation:

$$Av = \frac{2.37 \quad L}{R \quad H^{0.5} \quad \triangle T} \qquad \text{Equation 4}$$

Where:

L = Horizontal distance from edge of attic space near point of eave vent to a point just below the vent located at the roof peak. (Feet)

$\triangle T$ = The design temperature difference between entering and leaving ventilation air. (°F.)

The constant term (2.37) is made of units conversion constants and the typical variable values listed in the example in Appendix II.

b. To inhibit the infiltration of blowing snow into the attic space, the velocity of the air entering the attic space must be controlled. Furthermore, as the snow laden air passes into the building it must be routed vertically so that the entrained snow is settled out of the air stream.

The driving force in the design of attic ventilation in windy regions is the wind. The design of these systems involves analysis of attic ventilation when the building is subjected to both storm and prevailing wind conditions. Not only the air speed must be taken into account in this analysis, but also the vector.

7.0 BIBLIOGRAPHY

ASHRAE Handbook: 1985 Fundamentals. ed. Judith G. Mackintosh. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1985.

Mellor, Malcolm. Blowing Snow. Cold Regions Science and Engineering, U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) monographs, Part III, Section A3c, November 1965.

Orange, Howard L. and Hendricks, Lewis T. Roof-Snow Behavior and Ice-Dam Prevention in Residential Housing. Univeristy of Minnesota Agricultural Extension Service, Extension Bulletin 339-1976.

Uniform Building Code. Whittier: International Conference of Building Officials, 1982.

APPENDIX I

UNIFORM BUILDING CODE* REQUIREMENTS FOR ATTIC SPACE VENTILATION

Attics: Access, Draft Stops and Ventilation

Sec. 3205. (c) Ventilation. Where determined necessary by the building official due to atmospheric or climatic conditions, enclosed attics and enclosed rafter spaces formed where ceilings are applied direct to the underside of roof rafters shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain and snow. The net free ventilating area shall be not less than 1/150 of the area of the space ventilated, except that the area may be 1/300, provided at least 50 percent of the required ventilating area is provided by ventilators located in the upper portion of the space to be ventilated at least 3 feet above eave or cornice vents with the balance of the required ventilation provided by eave or cornice vents. The openings shall be covered with corrosion-resistant metal mesh with mesh openings of 1/4 inch in dimension.

*Uniform Building Code (1982), Sec. 3205(c), p. 538.

APPENDIX II

CALCULATION OF ATTIC VENTING TO MITIGATE ICE DAMMING AT THE EAVE

1.0 INTRODUCTION

Heat flow from the occupied spaces of a building to the attic spaces in winter causes the attic space to warm. As the attic space warms, the roof is heated causing snow at the interface of roof and snow pack to melt. Water thus produced flows along the roof to the eave where it is cooled and refrozen to form ice dams and icicles. Though it is probably impractical to provide a refrigerated roof capable of completely eliminating this phenomena, well designed ventilation of the roof deck will go a long way toward limiting the formation of ice structures at the eave.

If air used to ventilate the attic spaces is introduced at low points of the roof structure and allowed to exhaust at high points of the roof, the air will move under the influence of the "stack effect." This appendix discusses how the designer may use this natural force to achieve adequate attic space ventilation.

2.0 CRITERIA

The Uniform Building Code provides criteria for attic venting in terms of required area of vent opening (see Appendix I). This criteria, however, does not account for the specific environmental conditions encountered in interior Alaska and Canada. The criteria used in the following discussion is taken from personal observations by the authors. It should be accepted as preliminary only and subject to revision based upon more scientific observation or theory.

Our experience suggests that if the average attic space air temperature is maintained as nearly equal to the outdoor air temperature as practical, the formation of ice structures at the eave will be reduced to acceptable levels. It is also our experience that an average attic temperature of less than 2° F. warmer than outdoor air temperature can be practically attained.

3.0 A MODEL OF ATTIC SPACE VENTING TO MITIGATE EAVE ICE FORMATION

The energy that melts snow on the roof when the ambient outdoor air temperature is below freezing comes from solar radiation and heat lost from the attic space to the snow pack. The treatment of snow pack melt from solar radiation is beyond the scope of this work. Therefore, the following analysis of attic ventilation neglects the effects of solar radiation and addresses the energy transferred from the occupied spaces of the building to the attic.

3.1 Heat Transfer Considerations

Equation II-1 describes the transfer of heat from the occupied spaces to the attic:

$$Qc = \frac{Aa \quad (Ts-Ta)}{R} \qquad \text{Equation II-1}$$

Where:

Qc = Unit rate of heat transfer from occupied to attic spaces (BTU per hour-foot)

Aa = Unit of ventilated attic area per unit of building length (square feet per foot)

R = Thermal resistance to heat flow (sq. ft.-hour-°F. per BTU)

Ts = Temperature of the occupied space (°F.)

Ta = Average temperature of the attic space as calculated from equation II-2 (°F.)

$$Ta = \frac{(Te + To)}{2} \qquad \text{Equation II-2}$$

Where:

Te = Temperature of ventilation air entering attic space (°F.)

To = Temperature of air leaving attic space (°F.)

When the heat emerges from the insulation of the attic, it warms the air in the attic. Equation II-3 describes the warming of the attic air:

$$Qa = 60 \quad Ue \quad Av \quad De \quad Cp \quad (To-Te) \qquad \text{Equation II-3}$$

Where:

Qa = Unit rate of heat transferred into attic ventilation air (BTU per hour-foot)

Ue = Velocity of air entering the attic at the vent opening (feet per minute)

Av = Unit area of the vent opening at the eave (square feet per foot)

De = Air density at outside conditions (pounds per cubic foot)

Cp = Specific heat of air (BTU per pound-°F.)

This analysis presumes that all heat flows leaking from the occupied spaces to the attic (Qc) leaves the attic by heating the ventilation air (Qa) only. This simplification neglects the heat that is transferred to the roof deck and will eventually warm the snow pack. Those using this paper as a basis for solving a real problem having specific geometries and specified materials may wish to add a term into the energy balance equation, accounting for heat transferred to the snow pack (Qm).

$$Qc = Qa + Qm$$

Assuming Qm = 0 then:

$$Qc = Qa \qquad \text{Equation II-4}$$

When equations II-1 and II-3 are combined as suggested by equation II-4, and the resulting expression is solved for Av (the unit vent opening), we have:

$$Av = \frac{Aa \quad (Ts-Ta)}{60 \quad R \quad Ue \quad De \quad Cp \quad (To-Te)} \qquad \text{Equation II-5}$$

3.2 Mass Transfer Considerations

The "stack effect" is the manifestation of natural forces that, for example, causes smoke to go up the chimney or air to infiltrate into the lower levels of a building and exfiltrate through the upper levels. The effect is caused when a column of cold, dense air is properly vented to a column of relatively warm, light air. When the two columns are vented to one another at top and bottom, the cold air, being heavier than warm air, produces a higher pressure at the bottom vent than the lighter column can exert and will move to displace the lighter column. In the case under examination, the column of cold, dense air is the air outside the building, and the column of relatively warm, light air is the air within the attic. This effect is driven by gravity which acts in the vertical direction only. Thus, in defining the parameters of the stack effect, the "column" of air is measured in terms of vertical distance only.

The respective weights of columns of air are:

$$We = H \quad De \qquad \text{Equation II-6}$$

Where:

We = weight of the heavy column of outside air (pounds per square foot)

De = density of outside air (pounds per cubic foot)

H = height of the air column (feet)

And:

$$Wa = H \quad Da \qquad \text{Equation II-7}$$

Where:

Wa = weight of the light column of attic air (pounds per square foot)

Da = density of attic air (pounds per cubic foot)

Combining equations II-6 and II-7 will yield the pressure differential created by the proper venting of the two columns of air to one another ($\triangle Pc$).

$$\triangle Pc = H\ (De-Da) \qquad \text{Equation II-8}$$

We have now defined the forces that are exerted upon the air that passes through the attic. We need now to define the forces that resist that flow of air. Two such forces exist; the inertial force required to accelerate the air to some speed (Ue) and the frictional forces that resist the flow as the air drags upon surfaces within the attic.

Inertial forces are small compared to the frictional forces. Furthermore, the geometry of the constrictions in the path of the air as it travels through the attic will change its velocity causing both positive and negative inertial forces. Since these inertial forces are small, the authors chose to neglect them for the purposes of this work.

By far the greatest resistance to air flow will occur as the air enters the small slot, or orifice, at the eave of the roof and leaves by the slot at the ridge of the roof. This work presumes the frictional losses within the attic are, like the inertial forces, negligible. With these simplifying assumptions made, the frictional resistance forces may be estimated using equation II-9:

It should be pointed out that the value for the coefficient of frictional resistance, C, used in the example problem as outlined on page II-6 was selected from the cited ASHRAE reference assuming turbulent flow conditions. Depending upon the exact properties of air at design conditions, and depending upon the geometry of the vent opening, the flow of air through vent openings could either be turbulent or laminar. The authors have calculated Reynolds numbers of a few hundred, up to 7,000 depending upon assumptions as to problem geometry and air properties.

If a truly accurate analysis were to be undertaken, the calculation of vent size opening would require an iterative approach; first assuming a C value, calculating the Reynolds number, determining a revised value for C depending upon the calculated Reynolds number, calculating a new velocity value, and so on. The assumption of a turbulent flow regime is nonconservative, thus judgment should be used in selecting design criteria for any given problem condition.

$$\triangle Pv = \frac{De \quad C \quad Ue^{2.0}}{2 \quad g \quad 60^{2.0}} \qquad \text{Equation II-9}$$

Where:

$\triangle Pv$ = Pressure differential caused by the friction of the air entering and leaving the attic (inches of water column)

De = Density of the entering air (pounds per cubic foot)

C = Coefficient of frictional resistance (unitless)

Ue = Velocity of air entering the attic at the vent opening (feet per minute)

g = Acceleration of gravity (32.17 feet per second squared)

4.0 A SOLUTION TO THE PROBLEM OF DESIGNING ATTIC VENTILATION

The driving (Equation II-8) and resisting (Equation II-9) forces that control air movement through the attic space have now been defined. If we accept a steady state model then we may assert that the resisting forces equal the driving forces ($\triangle Pc = \triangle Pv$) and solve equations II-8 and II-9 for the velocity of the air entering the attic (Ue).

$$Ue = 60 \frac{[2 \quad g \quad H \quad (De-Da)]^{0.5}}{[C \quad De]^{0.5}} \qquad \text{Equation II-11}$$

All of the parameters required of the analysis are explained. Restating equation II-5:

$$Av = \frac{Aa \quad (Ts-Ta)}{60 \quad R \quad Ue \quad De \quad Cp\ (To-Te)} \qquad \text{Equation II-5}$$

4.1 An Example Problem

For the sake of this example, assume the following parameters:

Ts	=	Temperature of the occupied space	= 70°F
Ta	=	Average temperature of the attic space	= 32.5°F
To	=	Temperature of air leaving attic space	= 34.5°F
Te	=	Temperature of air entering attic space	= 30.5°F
De	=	Density of entering air	= 0.080513 pounds/cu. ft.
Da	=	Density of attic air	= 0.080114 pounds/cu. ft.
H	=	Height of the air column	= 8.0 feet
Cp	=	Specific heat of air	= 0.24 BTU/pound - °F.
Aa	=	Unit area ventilated per unit of building length	= 24 sq. ft./foot
R	=	Thermal resistance to heat flow	= 30 sq. ft.-hour-°F/BTU

C = Coefficient of frictional resistance (dimensionless) = 2 (1.5) = 3.0
(Note: Two orifices are accounted for; at the eave and at the ridge of the roof).

g = Acceleration of gravity = 32.17 ft/sec. sq.

Then:

$$Ue = (60)\ \frac{[(2)(32.17)(8)(0.080513-0.080114)]^{0.5}}{[(0.08114)(3)]^{0.5}} = 55.46 \text{ feet/min}$$

And:

$$Av = \frac{(24)(70-32.5)}{(60)(30)(55.46)(0.080114)(0.24)(34.5-30.5)} = 0.11722 \text{ sq.ft./foot}$$

This calculation suggests the vent opening at the eave should be at least one and one-half of an inch wide if it is to be continuous along the eave. Furthermore, a similar area should be provided at the ridge of the roof so that the ventilation air may exhaust freely to the outside. Also, restrictions in air flow within the attic (for example, at openings through shear connections between walls and roof deck) should be significantly larger than the eave and ridge opening or such obstructions should be accounted for in the analysis. Finally, since the actual construction may differ from assumptions made in the analysis, and until actual field verification of the design method outlined herein has been made, the authors suggest using a design factor of 1.25 to 1.50 in calculation of the vent area (Av). Thus:

$$Av = (1.25)(0.11722)(12) = 1.75 \text{ inches}$$

APPENDIX III

CALCULATION OF ATTIC VENTING IN A BLOWING SNOW ENVIRONMENT

1.0 CRITERIA

The minimum attic ventilation requirements under the wind driven criteria are presumed to be equivalent to those in the natural convection driven case. That is to say, it is based upon attic temperature criteria. In Appendix II, a maximum average attic temperature of 2°F. above outdoor air temperature is recommended. For lack of more formally developed criteria, the authors assume the "2°F. average temperature differential" criteria to also be applicable in cases where attic ventilation is wind driven.

This design criteria can be accomplished by providing a minimum quantity of ventilation air as calculated in Appendix II. That calculation utilizes the following equation:

$$\text{Attic Vent Criteria} = (0.21)\,\frac{(Ts-32.5)}{R} \qquad \text{Equation III-1}$$

Where:

Ts = Temperature of occupied space (°F.)

R = Thermal resistance to heat flow (sq. ft.-hour-°F. per BTU)

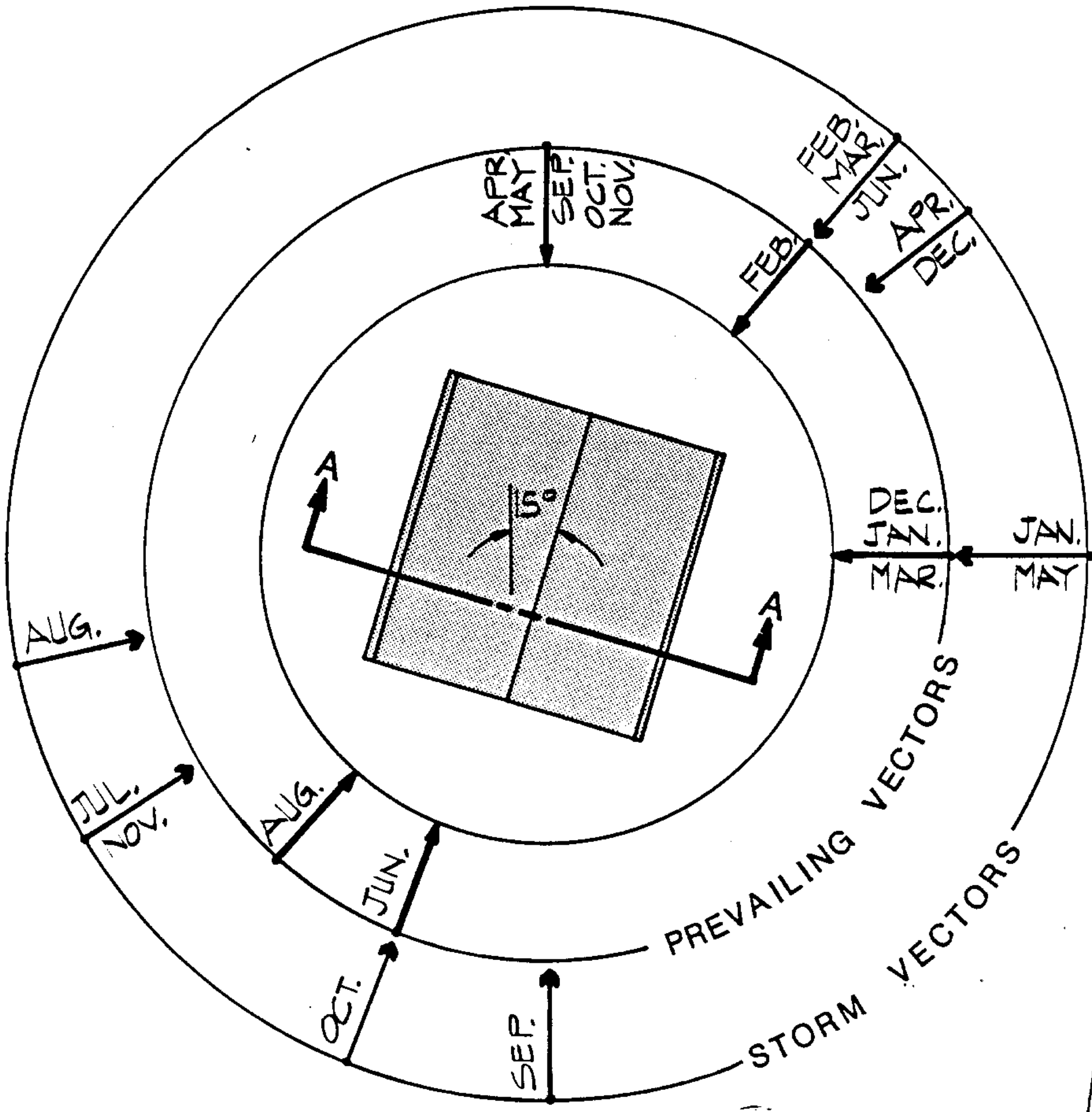
The constant (0.21) is made of units conversion constants.

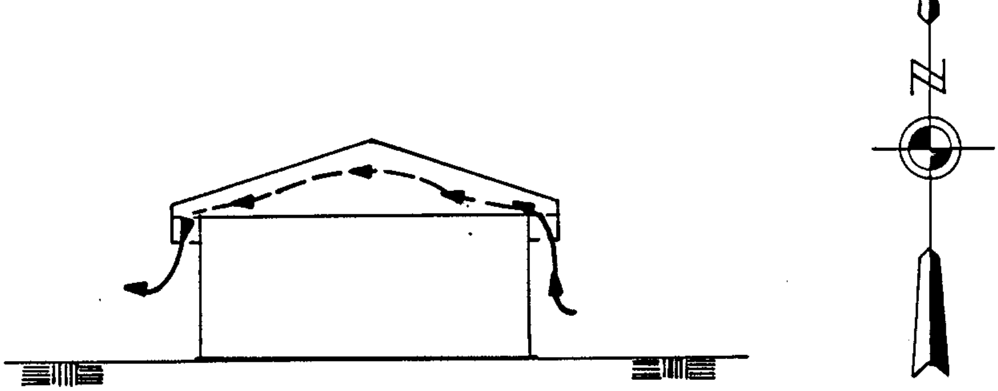
Using values from the example conditions cited in Appendices II and III, Performance = 0.336 cubic feet of air per minute per square foot of attic space.

Substituting numerical values into equation III-1:

$$\text{Attic Vent Criteria} = (0.21)\,\frac{(70-32.5)}{30} = 0.263 \text{ CFM/sq.ft.}$$

It should be noted that the venting scheme in blowing snow environments does not include venting at the roof ridge, so the unit area to be ventilated in the example in the following section (see Figure III-1) is twice that of the convection model from Appendix II.





SECTION A–A

FIGURE III-1 Prevailing and Storm Wind Vectors, Nome, Alaska

To achieve the stated criteria of a third of a cubic foot of air per minute per square foot of attic area when the driving force is the "average" wind, we must analyze the relationship of the vent openings to the prevailing wind.

2.0 DETERMINING AVERAGE WIND FOR DESIGN

When we analyze weather records, we find the monthly average wind speeds listed together with their vector. For most buildings, the maximum potential for moisture transport from the occupied space to the attic space is during the coldest months of the year. We should, therefore, design around the wind vector for those coldest months. Wind data for Nome, Alaska, will be used as an example:

TABLE III-1
WIND DATA FOR NOME, ALASKA
(Speed Expressed in Miles per Hour)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average												
Speed	11.8	11.1	10.5	10.8	10.3	10.1	10.1	10.7	11.3	11.3	12.2	10.3
Vector	09	04	09	00	00	20	20	22	00	00	00	09
Record												
Speed	54	51	44	45	44	35	38	40	44	52	58	54
Vector	09	04	04	05	09	04	24	26	18	20	24	05

Notes: (1) See wind diagram Figure III-1.
(2) Vector in units of 10° of arc, North = 00.

The data suggests we should design our venting to be effective when the wind is from the North, during winter, at 10 miles per hour. That vector is 15 degrees off of parallel to the eave and is the shallowest angle of attack of all vectors. The winter storm wind most oblique to the eave line is that of January. Since storm winds carry the most snow, we will be conservative and assume the storm vector to be normal to the building at 58 miles per hour.

3.0 THE MODEL

It is beyond the scope of this work to develop the theory of wind pressure distribution of buildings. Siting and building shape play a major role in the magnitude and location of wind pressure patterns around the building. For the purposes of this example, we will assume the wind pressure on the lee side of the building to be equal in magnitude to the wind pressure on the windward side, but negative in sign. Thus, the pressure <u>differential</u> across the building, the driving force in the problem, will be assumed to be twice the calculated velocity pressure. The velocity pressure can be estimated with the following equation:

$$Pw = 0.067 \quad De \quad \cos\alpha \quad Uw^2 \qquad \text{Equation III-2}$$

Where:

Pw = Velocity pressure of wind (pounds per square foot)

Uw = Wind speed (miles per hour)

α = Angle of attack of the wind measured from a line parallel to the eave of the building (degrees)

The constant term (0.067) is made of units conversion factors.

And:

$$\Delta Pw = 2 \quad Pw \qquad \text{Equation III-3}$$

Where:

ΔPw = Pressure differential (from windward to leeward sides of the building)

As in the example presented in Appendix II, we will assume the resisting forces to be:

$$\Delta Pv = \frac{De \quad C \quad Ue^2}{2 \quad g \quad 60^2} \qquad \text{Equation III-4}$$

Where:

ΔPv = Frictional pressure change (pounds per square foot)

De = Density of entering air (pounds per cubic foot)

C = Friction coefficient (dimensionless)

Ue = Velocity of the air entering through the vent opening (feet per minute)

g = Acceleration of gravity (32.17 feet per second squared)

Combining Equations III-2, III-3 and III-4 and solving for Ue:

$$Ue = 176.17 \quad Uw \quad \frac{(\cos \alpha)^{0.5}}{C^{0.5}} \qquad \text{Equation III-5}$$

If we use the same example as was used in Appendix II:

Where:

Uw = 10 miles per hour

α = 75 degrees

C = 2 (1.5) = 3.0

Then:

$$Ue = (176.17)(10)(0.2588/3.0)^{0.5} = 517.45 \text{ ft./min.}$$

Since:

Quantity of Ventilation Air = (Aa) Attic Vent Criteria

And:

Quantity of Ventilation Air = Av Ue

Therefore:

$$Av = \text{Attic Vent Criteria} \ \frac{Aa}{Ue} \qquad \text{Equation III-6}$$

Using values from our example, we can solve for the unit area of vent opening:

$$Av = 0.236 \ \frac{48}{517.45} = 0.024 \text{ sq. ft./ft.}$$

This calculated area amounts to a slot just three-eighths of an inch wide located along the eave of the building.

The velocity of air passing through the vent opening under storm conditions as defined in III. 2.0 can be calculated by solving Equation III-5:

$$Ue = 176.17 \quad Uw \quad \frac{(\cos \alpha)^{0.5}}{C^{0.5}} = 5{,}899 \text{ feet per minute}$$

Where:

Uw = 58 MPH

α = 00 degrees

C = Friction factor (dimensionless) = 3.0

If we wish to reduce the air speed enough to remove particles of snow from the stream of ventilation air, we must increase the size of the conduit that carries the air, thus creating a settling chamber. To accomplish this settling, the vertical component of air speed must be dropped to about 30 centimeters per second (60 feet per minute). The ratio of settling chamber area (Ac) to vent opening area (Av) must be equal to or greater than the ratio of air velocity at the vent opening (Ve) to that of the air passing through the settling chamber:

$$\text{Chamber Area} = \text{Vent Area} \quad \frac{Ue}{\text{Settling Velocity}} \qquad \text{Equation III-7}$$

For example,

$$\text{Chamber Area} = (0.024) \quad \frac{5899.3}{60} = 2.36 \text{ feet}$$

Thus, the settling chamber should be about 30 inches wide.