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ROOF TEMPERATURES AND ICE DAMS

by J.K. Latta

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PREFACE

Icicles and associated ice along the roof edge are often a result of defects in roof and ceiling construction. They present a danger to people and property below but the water backed up by this ice may also cause damage to the roof, ceiling, and wall. These ice dams form when the snow in contact with the roof surface melts and runs down a sloping roof until it emerges at the edge of the snow cover where it refreezes. The resulting layer of ice may be very thick and the volume of water that overtops the roof shingles may be large.

Frequently in an attempt to stop the water from entering the building, a continuous band of impervious material is laid along the edge of the roof and in extreme cases heating cables are used to melt drainage paths through the ice. Both measures treat the symptom rather than the cause. It is preferable to reduce the amount of snow melting so as to limit the accumulation of ice. Thus it follows that heat should be contained in the building as much as possible and such heat as does escape should be carried away by ventilation before it warms the roof deck.

In order to obtain some information about the weather conditions necessary for the formation of ice dams, thermocouples were installed at various points on the roof at the time of an extensive rebuilding of the author's house. The roof temperatures under changing weather conditions were recorded and the effects of reflective insulation installed on the underside of the roof deck were also observed. Similar readings were taken in summer to determine the maximum shingle temperature which might occur.

The results of these observations are presented in this report. One possible means of alleviating the problem of ice dams is proposed although further investigation is needed to establish its effectiveness.

Ottawa
April 1976

C. B. Crawford,
Director,
DBR/NRC.

ROOF TEMPERATURES AND ICE DAMS

by

J.K. Latta

INTRODUCTION

It is usually accepted that ice dams form on roofs when the snow in contact with the roof melts, runs down the roof and freezes on emerging from under the snow blanket at the eave. For this to occur, it is necessary for the temperature of the roof surface to rise above 32°F at a time when the ambient air temperature is below freezing. This can happen when the roof surface is warmed by heat loss from the building below and also by solar radiation which penetrates the snow.

It is doubtful that much can be done to modify the heat gain from the sun other than by shading the roof with tall trees or in some similar manner. Work carried out elsewhere showed that snow temperatures immediately above an aluminum-covered roof and an asphalt-shingled roof were similar [CRREL, Quarterly Report, April-May-June, 1973]. This would indicate that the reflectivity of the roof surface has little effect on roof surface temperature under a cover of snow.

The conventional method of dealing with the problem is to insulate the ceiling below the roof and to ventilate the attic so as to carry away the heat which would otherwise warm the roof. In order to stop the formation of ice dams, the roof should ideally be formed like an umbrella under which the wind could blow freely. For various reasons, such as snow being blown onto the insulation, this is not a practical form of construction, and one is normally restricted to ventilation through gable ends and through the eave soffit.

INSTALLATION

For the purpose of obtaining specific information about roof temperatures, thermocouples were installed in various places on the roof when the opportunity presented itself at the time of a major renovation and extension of the author's house. During the course of this renovation, the roof, which had been a simple ridge roof with gable ends, was changed to a gambrel roof extending down to the second floor level. The upstairs windows were converted into dormer windows and ventilation was provided through the gable ends of these dormers as well as through the main gable ends of the house. An eave soffit strip ventilator was installed at the rear, where a shed dormer was provided over the bathroom. In addition to these conventional forms of ventilation, a ventilation passage was provided up the lower slope of the gambrel roof and into the attic. This space was formed by planting 2 by 2's on top of the wall/roof sheathing over the 2 by 4 studs. One-half inch thick plywood sheathing, to which the shingles were nailed, was then added over the 2 by 2's. The 1-1/2 by 14-1/2 in. space formed in this way connected the attic with a continuous strip vent at the 2nd storey floor level. The dormers interrupted these passages and therefore there was no ventilation up the lower roof/wall where they occurred. The ceiling of the original house was insulated with 5-1/2 in. of rock-wool-paper faced insulation which filled the 2 by 6 joist spaces. There was an open spaced board floor over the centre 8 ft. The insulation in the extension was R.20 glass fibre insulation with no paper enclosure, but the centre 8 ft. strip was covered with sheets of 3/8 in. plywood loosely laid in place.

Figures 1 to 8 illustrate front and rear elevations, a cross section of the house, some details of construction, and the location of the thermocouples. These were installed at the time of construction on the outside of the roof deck or roof/wall sheathing before the application of the underlay and shingles. The leads were run down to the basement where they were connected to a 16 point speedomax recorder. The front of the house faced 12° west of north. The slope of the upper roof was 25 1/2°, and that of the back (south facing) roof/wall was 67° from the horizontal. (The slope of the front roof/wall was slightly steeper.) The sun's rays, therefore, would strike the upper roof approximately at right angles in mid-summer and the rear roof/wall approximately at right angles in mid-winter.

Thermocouples were provided to measure outside and attic air temperatures, and were installed on both the north and south sides of the house in the roof/wall ventilation space, under the roof/wall shingles and the upper roof shingles 1 ft from the break in the roof line and 4 ft from the ridge. Because it was not possible to install the thermocouples other than at the time of construction, the installation in the modified house was duplicated in the extension to enable a comparison of different ventilation or insulation systems to be made later if it was felt desirable to do so. Of the 19 thermocouples installed, only 16 could be connected to the recorder and 3 had to be left unconnected. Because of the duplication, the measurement of the attic and two upper roof temperatures 4 ft from the ridge in the extension was omitted. It was felt that there would be little difference between these temperatures and the corresponding ones in the modified house.

The installation was completed on 4th January 1973 and, except for some short periods when the recorder was switched off, the temperature of each point was recorded automatically at intervals of approximately 16 min until 16th April 1973. By this time all the snow and ice had melted off the roof. Further readings were taken between 12th June and 11th July 1973 in order to check the maximum shingle temperatures in summer.

In order to prevent ice damming, the roof temperature must be kept as low as possible; heat transfer to the roof from the attic must be minimized. The effect of reflective insulation (aluminum foil) applied to the underside of the roof deck was therefore investigated in the fall of 1973 in the original house at the location of thermocouples No. 4 and 5. The recorder connections were changed so as to measure outside air temperature and only the attic and upper roof temperatures in the original house and the extension. Readings were then taken intermittently from 29th October 1973 to 4th January 1974. Further readings were taken from 5th to 23rd July 1974 in order to determine if the use of aluminum foil reduced the amount of heat loss from the shingles to the attic in summer so much as to raise the maximum shingle temperatures dangerously high.

In March 1974 a 4 ft square area of the north roof of the extension was insulated with R.20 glass fibre batts. There were no thermocouples at this location but the rate at which the snow melted from the insulated area was compared with that of the snow on the remainder of the roof.

ROOF TEMPERATURES IN THE ABSENCE OF SOLAR RADIATION

Meteorological records were examined to locate cold but overcast days in an attempt to determine the effect of heat loss from the house alone on the temperature distribution between the various points on the roof and roof/wall. No very cold days could be found that were not also clear sunny ones and it was found that the air temperature was usually +15°F or higher under overcast skies. During one such period (6th and 7th February 1973) when the air temperature was +14°F, the temperatures measured at the other locations were no more than 6 F deg higher except for the attic which was 29°F. This would indicate that all outside surface temperatures tended to follow the air temperature very closely as might be expected for well-insulated buildings. Unfortunately, no record of the depth of snow on the roof was available but there was unlikely to have been more than a few inches owing to mild temperatures and the lack of heavy snowfalls in January.

Similarly, on 28th January the attic was at 29 to 30°F all day with air temperature at 19°F. The temperatures of the remaining points were between 22 and 27°F.

During the period from 28th February to 2nd March, following a sunny day on 28th February, it became overcast overnight and it was snowing by 0700 hr on 1st March. The air temperature remained more or less constant all night at 16 to 17°F while the attic temperature dropped steadily from 34°F at 2000 hr to 30°F at 0600 hr the following morning. All other points except one were between 17 and 24°F and did not fluctuate more than 1 or 2 F deg. The one exception was the temperature in the ventilation space on the south side of the extension which followed the attic temperature more closely. As will be shown later, this suggested that there was an air leak from the house into this space. During 1st March, the air temperature rose slightly to 21°F by 0900 hr, then remained steady, and that of the attic rose a similar amount to 35°F but did not reach this point until 1430 hr. The difference in temperature between the other points increased slightly during the day which may have been due to the insulating effect of the blanket of fresh snow (8.6 in. fell during the day). Some support is given to this suggestion by the fact that the temperatures of the shingles on the upper roof where the snow would collect were somewhat higher than those on the lower roof/wall. The difference was not great, however, and there was some overlap in temperature between the two sets. At about 2200 hr, for example, the temperatures of the roof shingles were in the range of 25 to 32°F and the wall shingles were in the range of 22 to 26°F.

It appears, therefore, that for a reasonably well-insulated house, the temperature of the roof shingles are unlikely to rise above 32°F on a dull day, even with the insulating effect of a blanket of fresh snow, when the air temperature is in the low 20's. With less snow on the roof, the air temperature would have to be in the upper 20's for melting to occur.

ROOF TEMPERATURES ON A COLD AND SUNNY DAY

Consider the conditions on 6th, 7th and 8th January 1973. There is no record of the depth of snow on the roof but a photograph taken on 24th December 1972 (Fig. 9) shows about 6 in. on the north roof; a second one taken on 3rd January 1973 (Fig. 10) shows slightly more snow. A third photograph, also taken on 3rd January 1973 (Fig. 11), shows about 3 in. of snow on the south roof. The weather records for Ottawa International Airport show that December 1972 was a month of more than average snowfall. The following snowfalls were recorded between 24th December and 6th January:

26th December 1972	2.7 in.
27th December 1972	1.3 in.
28th December 1972	0.9 in.
30th December 1972	4.9 in.
4th January 1973	2.0 in.
5th January 1973	3.6 in.

for a total of 15.4 in. The relatively small quantity of snow on the south roof on 3rd January and the fact that the roof was already bare of snow about 2 or 3 in. from the eave indicated that the snow did not remain long on that side (2nd and 3rd January were sunny days). One could not reasonably assume, therefore, that there was more than about 8 in. of snow on the south roof on the morning of the 6th (3 in. + 2.0 in. + 3.6 in. = 8.6 in.) following the snowfalls on the 4th and 5th. The depth of snow on the north roof would have been greater but it is unlikely to have been as much as the 6 in. plus the 15 in. snowfall. A figure of 12 to 15 in. would be more likely.

In passing, it may be observed that the tunnel under the snow, which can be seen in Fig. 9, was caused by an air leak which allowed hot air to flow up the rafter space and warm the roof sheathing along this line as is shown by the pattern of frost on the roof seen in Fig. 1.

Upper Roof

A study of the recorded roof temperatures during the snow conditions described previously yielded the following:

(1) Shingles 1 ft. from eave on the north side (Fig. 12). There was no great difference between the temperatures of the shingles on the original house and the extension, the maximum difference being less than 4 F deg between 0800 and 0900 hr on the 6th. The temperatures were between 0 and 10 F deg warmer than the outside air. They also lagged behind the air temperature by 1 to 2 hr and so tended to be closest to it shortly after noon when the air temperature was at its maximum.

(2) Shingles 1 ft. from eave on south side (Fig. 13). The temperature of the shingles rose well above the ambient air temperature and, in fact, above the attic temperature on both the original house and the extension. Those on the original house reached a maximum of 43°F at 1330 hr on the 7th, compared to a maximum attic temperature of 24°F which was not reached until 1600 hr. The differences in temperature were not so great on the extension, being 3°F above attic temperature at 1500 hr. No definite explanation can be offered for the difference between the two thermocouples. It may be noted, however, that the ventilation space in the wall of the original house is connected to the attic just below the location of the thermocouple. It is possible that air in this space was warmed by the sun and rose to flow over the underside of the roof boards. The maximum temperature recorded in the ventilation space was about 5 to 10 F deg cooler than the maximum shingle temperature, but it preceded the shingle temperatures slightly. The photograph taken on 3rd January (Fig. 11) shows that there was more ice along the conventional eave of the extension where that thermocouple was located than on the

original house. The sun, therefore, may not have been able to warm the roof at that point as easily as on the original house. It may be noted also that the maximum temperature recorded each day for the shingles on the original house rose slightly day by day despite a falling air temperature. The peak temperatures of the attic and the shingles at the other locations tended to fall.

It would seem that considerable benefit in the control of ice dams could be obtained on southerly exposures if the edge of the roof could be kept clear of snow. The presence of an eaves trough to contain the snow would probably prevent this edge clearing occurring by natural means and also hinder any attempt by the owner to clear the roof edge manually. It is unlikely that a similar clearing on the north eave would have any effect. In an endeavour to verify the effect of a snow-free edge on the roof, a small steeply-sloping extension to which the snow would not stick was built onto half of the eave over the bathroom and the snow and ice accumulations on the two halves were compared during the winter of 1974-75. It was found that the icicle formation below the extension was much greater than that on the unmodified eave (Fig. 14). It was found later that there was no ice on the roof above the extension (Fig. 15) whereas a small ice dam had started to form on the other half (Fig. 16). In the early part of the winter, however, the conditions were such that many icicles were formed but later conditions were not conducive to the formation of large ice dams. The evidence is therefore not conclusive. Earlier studies conducted during the winter of 1972-73 on the west facing eaves of other houses indicated that only slight benefit could be obtained from similar eave extensions (Fig. 17).

(3) Shingles 4 ft. from the ridge (original house) (Fig. 18). The temperatures of these roof shingles were between those of the outside air and the attic. They fluctuated in sympathy with the changes in the other two and that on the south side responded also to the effects of solar radiation

The north side shingle fluctuated in temperature less than either the outside air or the attic, varying less that 5 F deg compared with 8 or 9 F deg for the attic and 15 to 25 F deg for the outside air.

Maximum temperatures were also reached at different times: 1400 to 1500 hr for the outside air, 1500 to 1700 hr for the attic and 1800 to 2200 hr for the shingle, which remained at or near its maximum temperature for longer periods of time.

On the south side, the shingle temperature fluctuated much more than that on the north side owing to the influence of the sun. It varied through a range of 20 to 25 F deg and although it peaked after the outside air temperature, this peak sometimes preceded that of the attic air temperature. At no time during the period under consideration did it exceed the attic temperature indicating that, with about 8 in. of snow on the roof, the heat flow was always outwards. In other words, no heat was transferred to the attic through solar radiation penetrating the roof. It should also be noted that of the six roof shingles whose temperatures were recorded, only the temperature of the shingles 1 ft from the eave on the south side of the old house rose above attic temperature to any appreciable degree and for any length of time. Thus the direct solar heat gain to the attic through this depth of snow on the roof may well be minimized. The rise in attic temperature would therefore seem to be the result of a balance between a more or less constant heat loss from the house and ventilation with outside air. In the case of this particular house with its somewhat unusual roof and wall construction it is possible that solar heat gain through the shingles on the lower roof/wall into the ventilation space also affected the attic temperature. This space, however, covered only 13 ft on the south side out of a total length of 39 ft.

Roof/wall and Ventilation Space Temperatures

(1) Roof/Wall shingles on the north side (Fig. 19).

The shingles on both the old house and the extension followed almost identical temperature patterns, which were also very similar to those of the outside air. During the day, the shingle temperature rose more rapidly than the air temperature and was two or three degrees warmer about midday when the air temperature was close to 0°F. Overnight, there was very little difference between the shingle and air temperatures although the shingles tended to be a degree or so colder.

(2) Roof/Wall shingles on the south side (Fig. 20).

As one would expect, the situation was vastly different from the north side since the sun's rays were approximately normal to the shingle surface about midday in mid-winter. At noon, both shingle temperatures were over 80 F deg above the air temperature. Indeed, the temperature of the shingles on the original house rose to a high of 95 F deg on 8th January 1973 for a gain of almost 100 F deg over the air temperature which was slightly below 0°F. It may be noted that the wind on the 8th had dropped to 5 mph as compared to about 15 mph on the 6th and 7th. In all cases, the peak shingle temperature occurred an hour or so before the maximum air temperature. This could have been due to the orientation of the house with the rear facing slightly east of south.

Overnight, the shingle temperature on the original house dropped slightly below air temperature owing to radiation to a clear night sky. It varied between 1 and 5 F deg on the dates under consideration. No record of the degree of clarity on the different nights was available, however. As noted earlier, the temperature of the shingles on the north side did not drop below the air temperature to the same extent as did that of the shingles on the south side. It is probable that this difference between the northern and southern exposures was due to the greater number of large trees on the north side even though they are deciduous trees and bare of leaves in winter.

The shingles on the south side of the extension did not, however, fit into the same pattern, for although the temperature rose about 80 F deg above the air temperature during the day, it remained 7 to 10 F deg above it during the night. It is possible that the position of these shingles in a recess between two dormers may have had an effect on their temperature, but it is more probable that there was an air leak from the house into the ventilation space behind them. The temperature in that space was consistently higher than in similar spaces elsewhere on the house.

(3) Roof/Wall ventilation spaces on the north side.

The temperatures in the ventilation spaces on the north side of both the original house and the extension were, like the shingles, essentially similar. They followed the pattern of air temperature but were 5 to 7 F deg warmer.

(4) Roof/Wall ventilation spaces on the south side.

(a) Original house

On the south side of the house, at or shortly after midday, the temperature in the ventilation space was about 30 F deg above the air temperature because of solar radiation. At the same time the shingles were 80 to 100 F deg above air temperature. On the night of 5th/6th January the space temperature was approximately 15 F deg warmer than the air temperature which was falling at that time. It was 10 F deg warmer on the night of 6th/7th January. These overnight temperatures were about 2 to 5 F deg warmer than those in the corresponding space on the north side at a time when the temperature of the roof/wall shingles on the south side were either the same as or slightly colder than that of the shingles on the north side. On the night of 7th/8th January, the temperature difference between the two spaces was less pronounced and between 0600 and 0800 hr, the south space was slightly colder than the north one. During the night of 8th/9th January, the two roof/wall space temperatures were virtually the same. The wind speed and direction records for NRC (situated approximately 2 miles east of the house) showed that on the nights of 5th/6th and 6th/7th January, the wind was predominantly from the northwest at a speed of between 14 and 19 mph. On the night of the 7th/8th, the direction was still predominantly northwest but the speed had dropped to between 8 and 10 mph. On 8th January, the wind speed dropped to 5 mph from the northwest and 6 mph from the west at 0700 and 0800 hrs respectively. The south roof/wall space was slightly cooler than that on the north side at this time. By the night of the 8th/9th, the speed had moderated still further to between calm and 5 mph and its direction had changed to southwest. The records for the ventilation space temperatures, the wind speeds and directions for the periods of 28th, 29th, and 30th January (Fig. 21) and 9th, 10th and 11th February 1973 show similar patterns. One may conclude, therefore, that a flow of air is promoted in the roof/wall ventilation spaces from one side of the house to the other when the wind impinges more or less directly on one face. The wind speeds around the house were not measured but because of the sheltering effect of surrounding houses they would be considerably less than those recorded at NRC.

(b) Extension

The temperatures recorded in the ventilation space on the south side of the extension did not correspond to those in the space on the original house. They were consistently higher by 10 or even 20 F deg during the night and peaked at about 60°F during the day as compared to 30 to 35°F in the original house. This, as noted earlier, leads one to the conclusion that the air in this space on the extension was being warmed to some extent by a convective leakage of air from inside the house. This theory is supported by the absence of frost on the roof to the right of the left dormer as seen in Fig. 2.

MAXIMUM ROOF SHINGLE TEMPERATURES IN SUMMER

Because it had been found that the roof/wall shingles rose 80 or even 100 F deg above ambient air temperature on a sunny day in midwinter when the sun's rays were approximately normal to them, it was decided to investigate the maximum temperature which might be reached by the roof shingles in mid-summer. The slope of the roof was such that the sun's rays would be normal to the roof surface shortly before and after the summer solstice. The temperatures were therefore recorded between 12th June and 11th July 1973, i.e., a period straddling the solstice.

The highest temperatures were recorded for the thermocouple under the shingles 4 ft. from the ridge of the roof on the south side of the original house. The maximum shingle temperature was 172°F at 1230 hr EST on 9th July when the air temperature was 95°F, a day which the Uplands weather office recorded as "mainly sunny and warm". This was a rise of 77 F deg above air temperature. The maximum rise above air temperature was 88 F deg recorded at 1145 hr EST on 13th June when the shingle was 168°F and the air temperature was 80°F. It can be seen, therefore, that the rise in shingle temperature because of solar radiation in summer was very similar to that of the roof/wall shingle in winter. The sun's rays would be more or less normal to the shingle in each case.

The shingles 1 ft from the eave were considerably cooler than the ones near the ridge. This may have been due to some ventilation occurring in the roof/wall space, which would cool the shingles near the eave, whereas the shingles 4 ft. from the ridge may have been over an almost still pocket of air. There was little or no difference in temperature between the shingles near the eave of the old house and those on the extension despite the fact that the shingles on the extension were near a conventionally ventilated eave rather than above the space in the roof/wall, which would be expected to produce more convective ventilation.

The shingles near the eave had a maximum temperature of 157°F on 9th July 1973 as compared to 172°F for those 4 ft. from the ridge; the roof/wall space was at 116°F and the attic reached a maximum of 130°F about two hours later. On 13th June, when the shingles 4 ft. from the ridge experienced their maximum rise above ambient air temperature and reached 168°F, the eave shingles rose to 149°F, the roof/wall space to 96°F, and the attic to 115°F. For the nine sunny days examined, the maximum and average rise above air temperature for the two positions of roof shingles, the attic, and the roof/wall ventilation spaces were as follows:

Rise Above Air Temperature (F deg)

	Maximum	Average
Roof shingles 4 ft from ridge	88	77
Roof shingles 1 ft from eave	69	58
Attic	47	34
Roof/Wall ventilation spaces	25	21

EFFECT OF INSULATION PLACED UNDER THE ROOF DECK

An examination of the temperature records taken in the fall and early winter of 1973-74 indicated that the aluminum foil insulation had no significant effect on the shingle temperatures. Prior to installation of the foil, temperature differences of up to 4 F deg were recorded between corresponding thermocouples in the original house and in the extension although the two attic air temperatures remained within 2 F deg of one another, the old house being slightly warmer.

After installation of the foil the difference in air temperature in the two halves of the attic remained unchanged. The effect of the foil on the shingle temperatures was not clear. There was some slight indication that when the heat flow was outward, i.e., when the attic was warmer than the shingles, the shingles with the foil below them were slightly cooler than the others. When the heat flow was inward because of solar radiation warming the shingles, the reverse appeared to be true. One might conclude, therefore, that the aluminum foil did restrict the heat flow slightly but the change in shingle temperature was at most 7 F deg. There was, moreover, no noticeable difference in the rate at which the snow melted from the areas with aluminum foil under them as compared to the remainder of the roof. The R.20 glass fibre insulation, on the other hand, retarded the snow melt considerably. R.20 insulation was used because it was readily available but it is possible that benefit in the control of ice damming could be obtained from smaller thicknesses.

In summer, the evidence as to the effect of reflective insulation was once again inconclusive. The heat flow under solar radiation was always inward on both the north and south slopes of the roof but only the shingles on the south side, 4 ft. from the ridge with foil under them, showed evidence of becoming warmer than those with no foil. The difference was always less than 10 F deg however.

CONCLUSIONS

An ice dam forms when the snow in contact with the roof is warmed to about 32°F at a time when the ambient air temperature is less than 32°F. The necessary heat can be supplied to the snow both from solar radiation and heat loss from the house. When attempting to control the formation of ice dams little can be done to modify the direct heat gain from the sun other than by shading the roof with tall trees because roof colour apparently has little effect. Efforts must therefore be directed to reducing the amount of heat transferred from the house to the roof by increasing both the amount of insulation and the attic ventilation.

With a moderately well-insulated house (between R.15 and R.20 insulation in the ceiling) with reasonably good attic ventilation, it is unlikely that snow will melt on a dull day unless the air temperature rises above 20 or 25°F. The precise temperature will be influenced by many factors including the depth of snow on the roof. On a cold (0°F) but sunny day with 6 to 12 in. of snow on the roof, only the temperature of the shingles close to the eave on the southern exposure would be expected to rise above attic temperature. Where there is little snow this temperature could rise above the freezing point. To minimize ice damming, therefore, there may be some advantage in keeping the eave free of snow on a southern exposure so that the shingles can be warmed by the sun and so prevent the formation of ice. It is doubtful that much benefit would be obtained on other exposures. At other locations on the roof and under snow cover, the heat flow is always outward and would appear to be largely a result of the balance between the rate of heat loss from the house and the amount of ventilation in the attic. Houses with cathedral ceilings and no attics should be more prone to ice damming than are those with attics.

Shingles on a steeply pitched roof with a southern exposure, which is free of snow except for brief periods following a snow storm, can experience a temperature rise of up to 100 F deg above ambient air temperature. Shingles on a less steeply pitched roof can have a similar temperature rise on sunny days in summer.

Aluminum foil reflective insulation placed on the underside of the roof deck does not appear to restrict outward heat flow effectively enough to reduce the rate at which the snow melts. Nor does it appear to restrict the inward heat flow in summer sufficiently to raise the roof shingle temperatures materially.

The range of temperatures experienced by the shingles and the attic during clear cold winter conditions are illustrated in Fig. 22. The difference from air temperature for each location is the difference at a specific time but the times at which the maximum or minimum differences occur at different locations do not necessarily coincide with one another nor with the maximum or minimum air temperature.

FIGURE 1 FRONT ELEVATION OF HOUSE

FIGURE 2 REAR ELEVATION OF HOUSE

FIGURE 3 FRONT WALL CONSTRUCTION

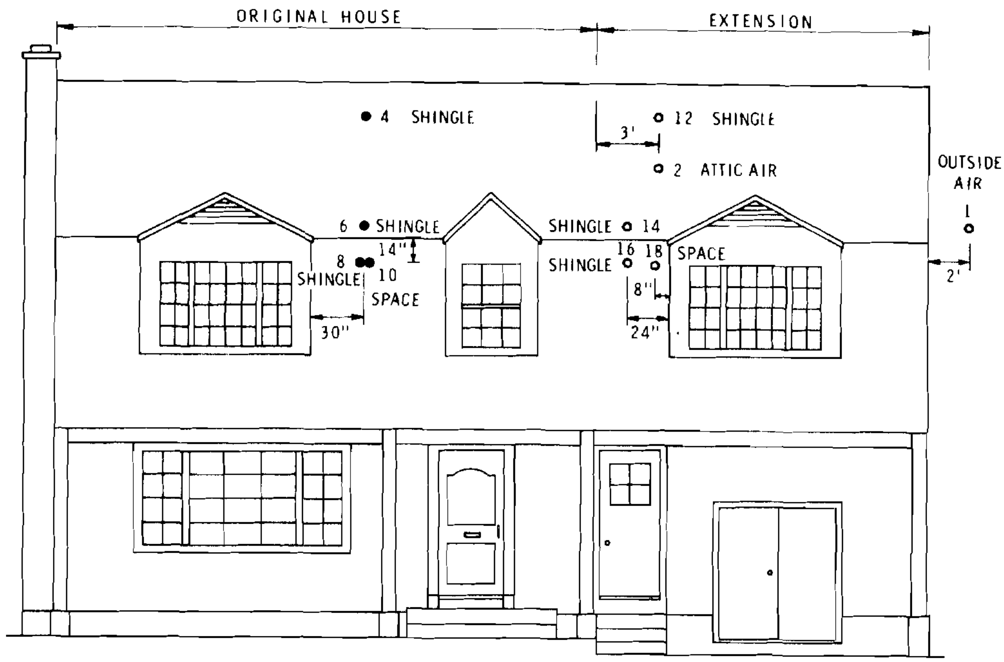

FIGURE 4
LOCATION OF THERMOCOUPLES ON FRONT ELEVATION OF HOUSE

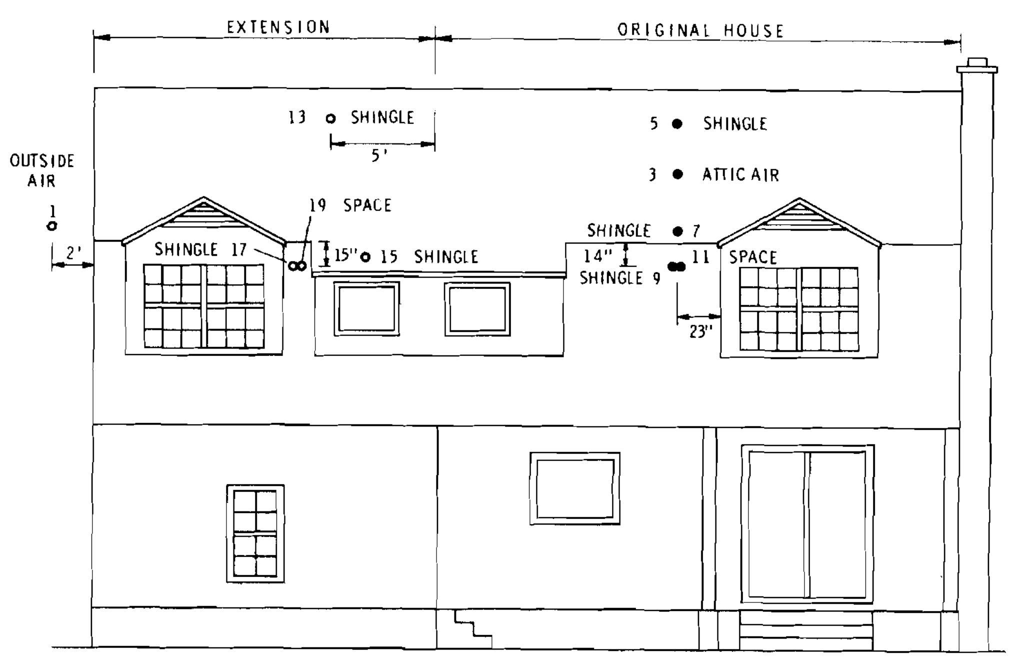

FIGURE 5
LOCATION THERMOCOUPLES ON REAR ELEVATION OF HOUSE

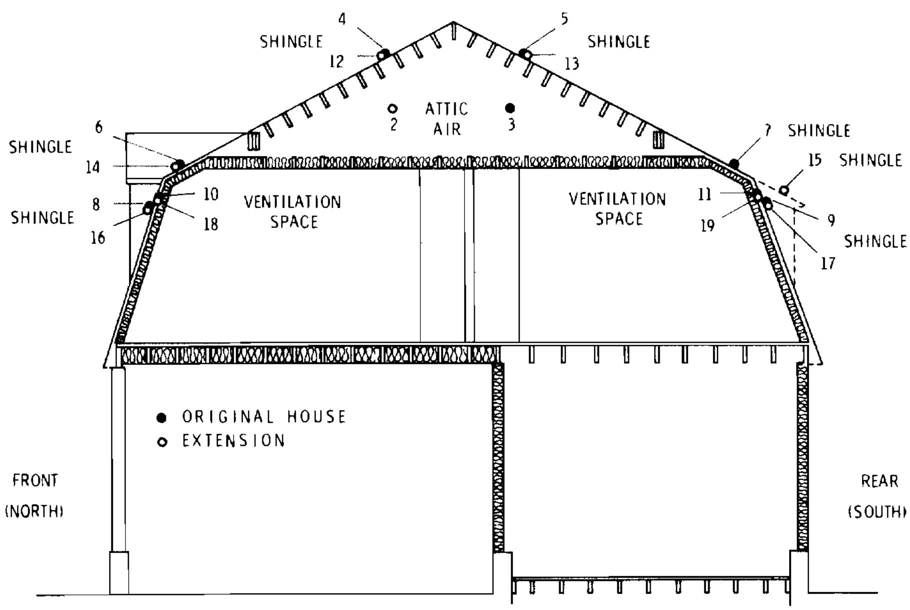

FIGURE 6
CROSS SECTION OF HOUSE (THROUGH EXTENSION)

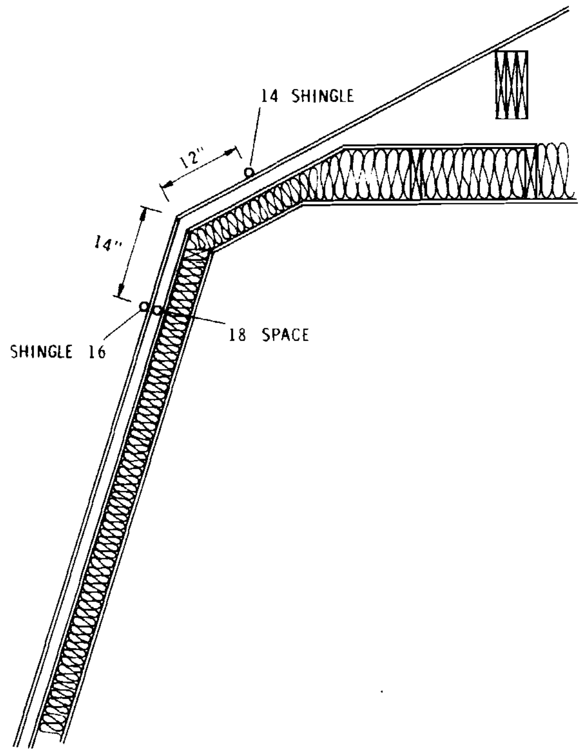

FIGURE 7

LOCATION OF THERMOCOUPLES IN JUNCTION BETWEEN LOWER ROOF/WALL AND UPPER ROOF IN EXTENSION

BR 5457-5

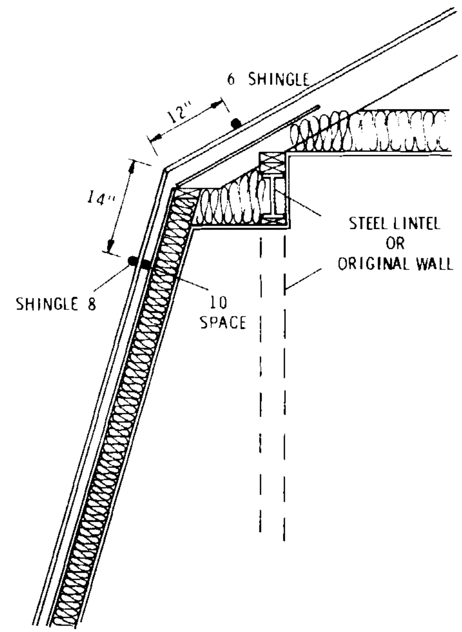

FIGURE 8

LOCATION OF THERMOCOUPLES IN JUNCTION BETWEEN LOWER ROOF/WALL AND UPPER ROOF IN MODIFICATION OF ORIGINAL HOUSE

BR 5457-6

FIGURE 9 SNOW COVER ON NORTH ROOF 24TH DECEMBER 1972

FIGURE 10 SNOW COVER ON NORTH ROOF 3RD JANUARY 1973

FIGURE 11 SNOW COVER ON SOUTH ROOF

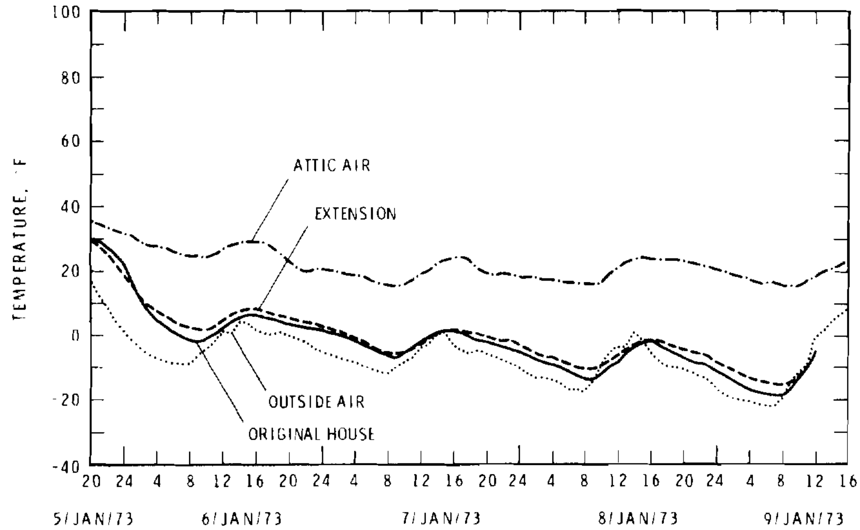

FIGURE 12
SHINGLE TEMPERATURE 1 FOOT FROM EAVE, NORTH SIDE

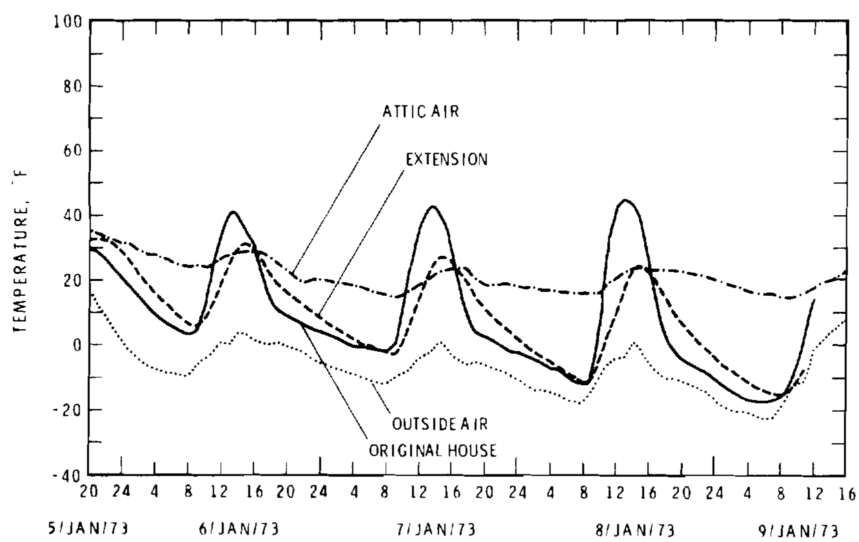

FIGURE 13
SHINGLE TEMPERATURE 1 FOOT FROM EAVE, SOUTH SIDE

FIGURE 14 ICICLE FORMATION

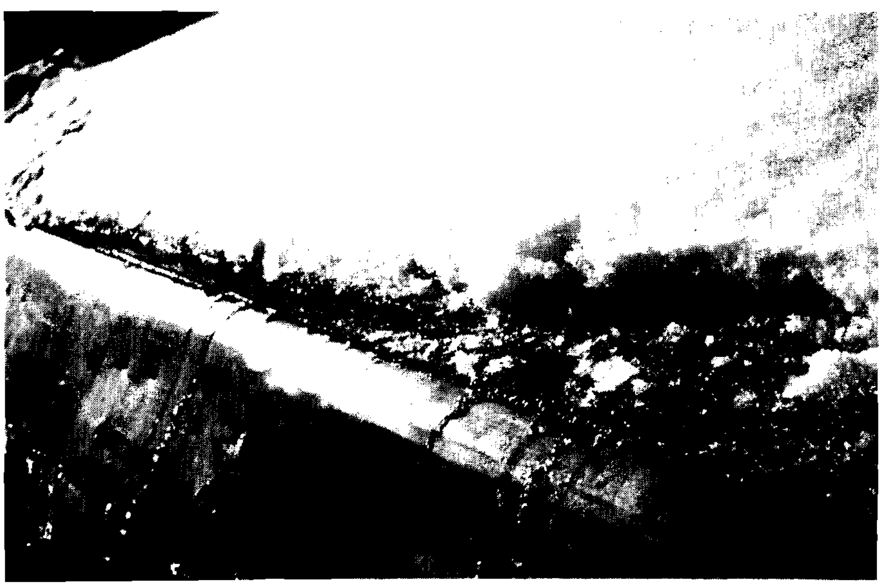

FIGURE 15 ICE-FREE MODIFIED EAVE

FIGURE 16 BEGINNING OF ICE DAM ON CONVENTIONAL EAVE

FIGURE 17 REDUCTION AND ICE ACCUMULATION OVER MODIFIED WEST-FACING EAVE

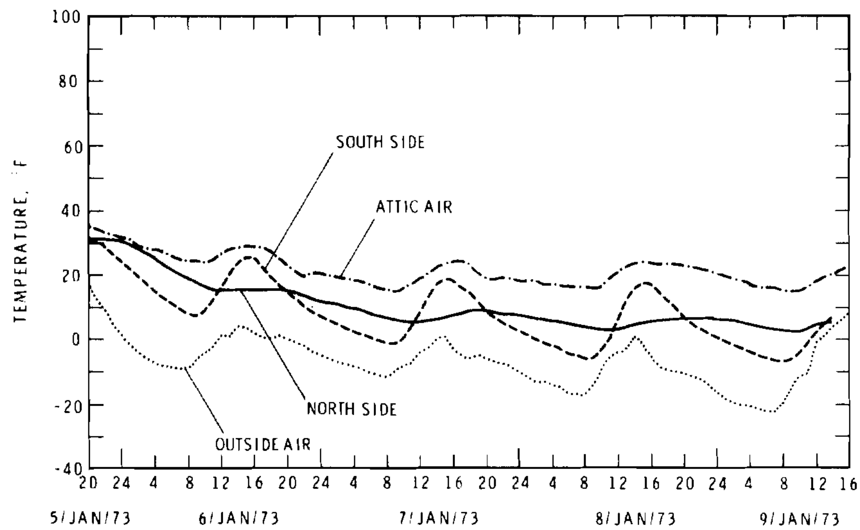

FIGURE 18
SHINGLE TEMPERATURES, 4 FEET FROM RIDGE ON THE ORIGINAL HOUSE

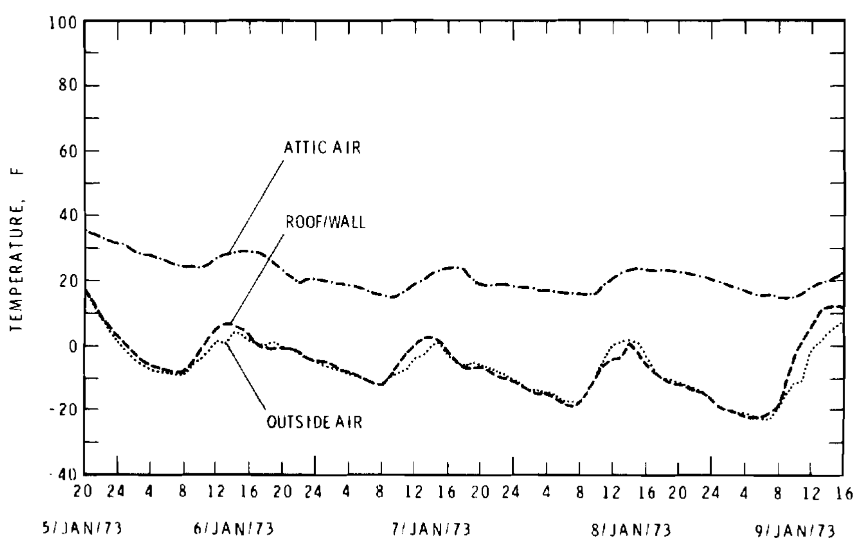

FIGURE 19
ROOF/WALL SHINGLE TEMPERATURE, NORTH SIDE, ORIGINAL HOUSE

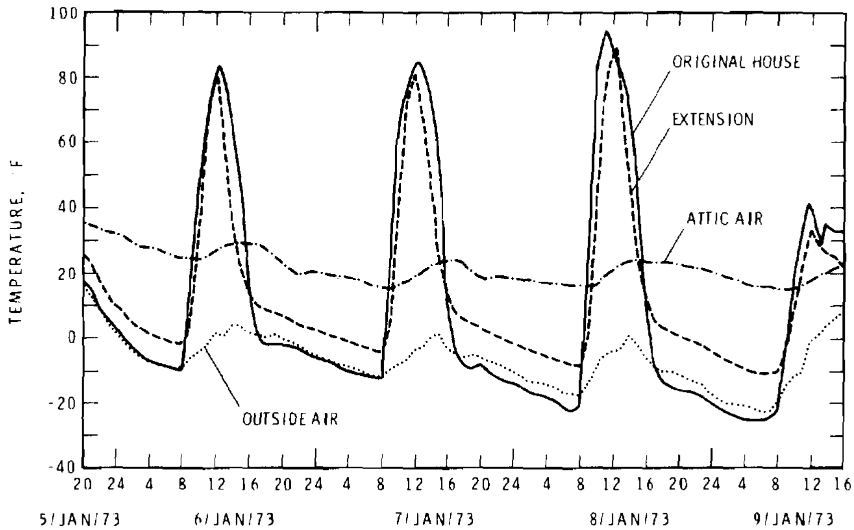

FIGURE 20
ROOF/WALL SHINGLE TEMPERATURE, SOUTH SIDE

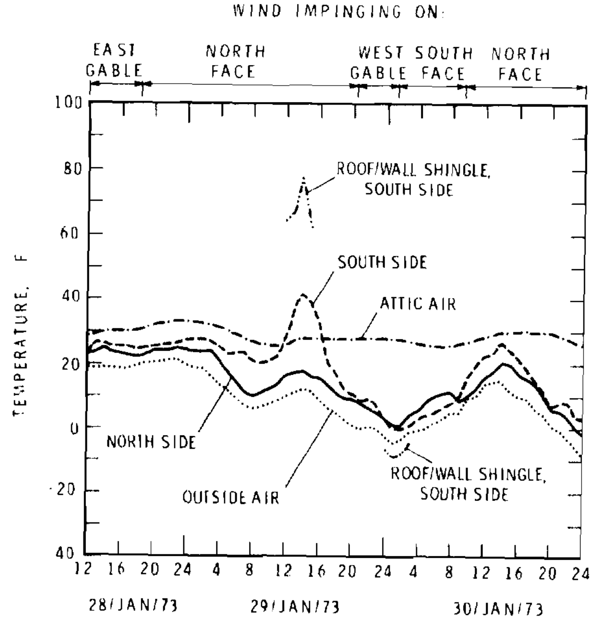

FIGURE 21
EFFECT OF WIND DIRECTION ON ROOF/WALL VENTILATION SPACE TEMPERATURE, ORIGINAL HOUSE

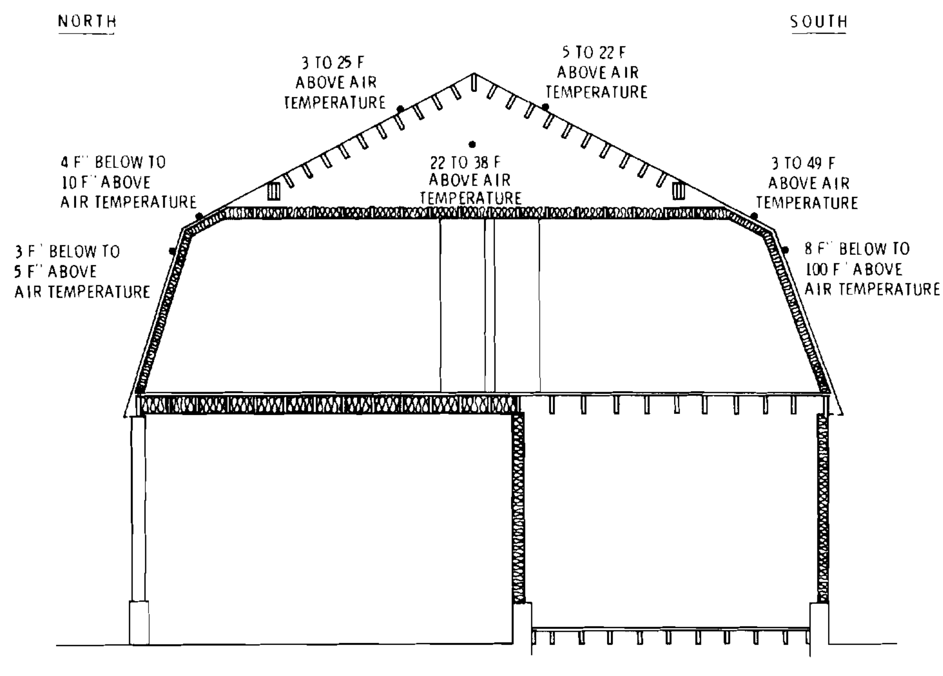

FIGURE 22

RANGE OF SHINGLE AND ATTIC TEMPERATURES RELATIVE TO AIR TEMPERATURE DURING CLEAR COLD WEATHER WITH 6" TO 12" OF SNOW ON ROOF.
AIR TEMPERATURE RANGE +4° TO -25°F