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ROOF LEAKS IN COLD REGIONS: SCHOOL AT CHEVAK, ALASKA,(U)

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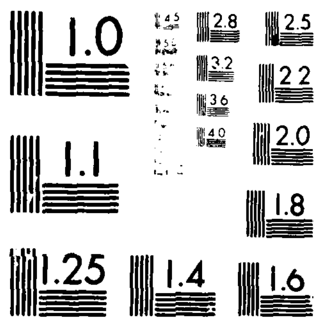


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## REPORT 80-11

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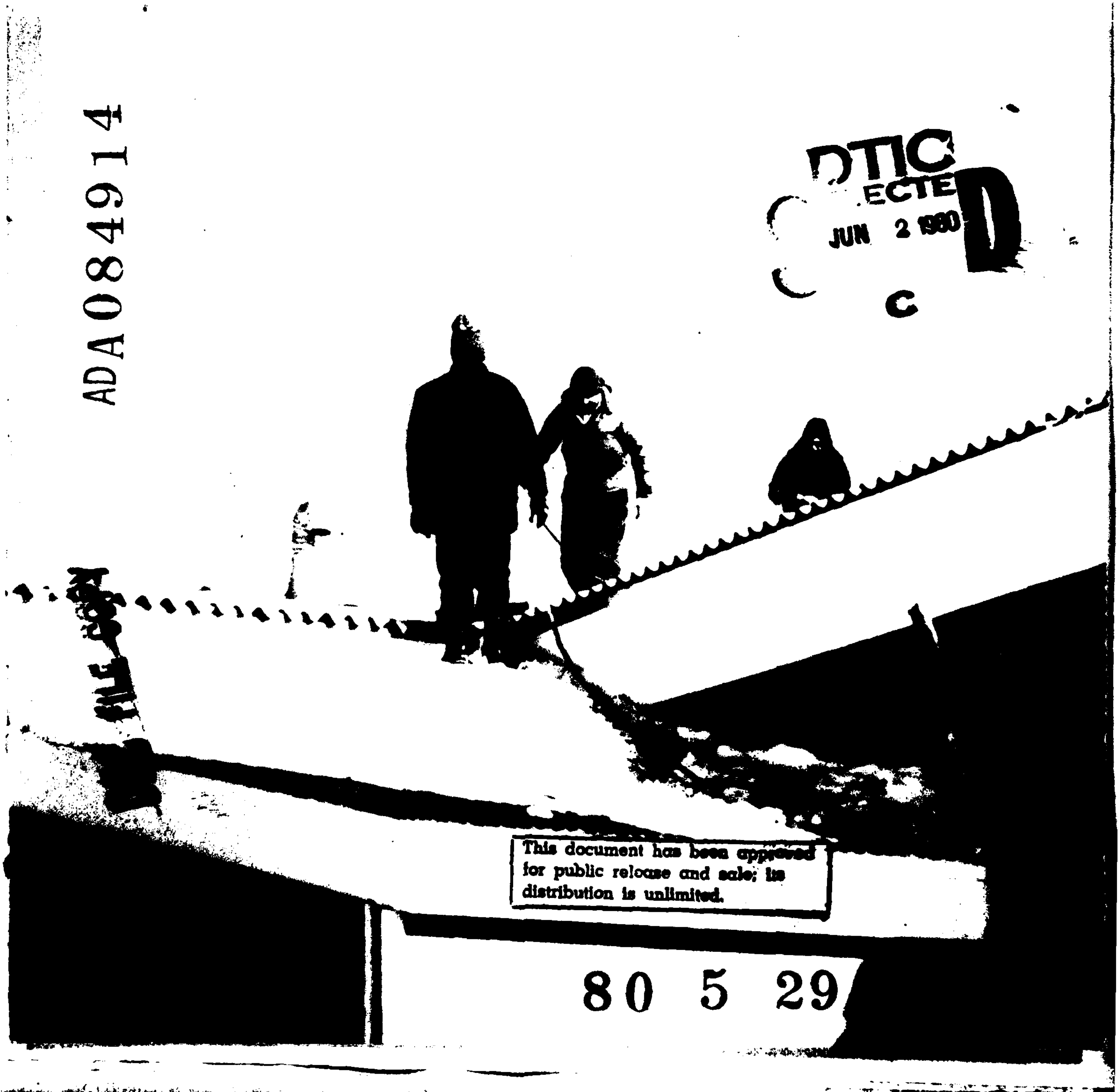
# *Roof leaks in cold regions: School at Chevak, Alaska*







*Cover: Inspecting "problem valley" of BIA school roof. (Photograph by P. Johnson.)*

# CRREL Report 80-11

# *Roof leaks in cold regions: School at Chevak, Alaska*

Wayne Tobiasson and Philip R. Johnson

April 1980



Prepared for
U.S. BUREAU OF INDIAN AFFAIRS
By
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Four types of roof leaks occurred at a new school building in Chevak, Alaska: (1) blowing snow entered the roof through eave vents and then melted, (2) slush and ice in roof valleys caused meltwater to overflow the valley flashing and run into the building, (3) water entered at a roof/wall intersection and (4) in many areas water entered through gaps in the sloping plywood deck. Sealing the eave vents made it impossible for blowing snow to enter the roof at the eaves. Electric heat tapes eliminated the valley icing problem. Missing flashing was responsible for the roof/wall intersection leaks. The absence of a vapor barrier in the roof was the cause of many leaks. We recommended that the roof be repaired from the exterior by removing component elements down to the plywood deck,

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installing an adhered continuous vapor barrier and reassembling the roof. An alternative roof cladding of composition shingles was discussed as was conversion to a "cold roof." The roof was repaired and modified following our recommendations, and problems appear to have been solved.

## PREFACE

This report was prepared by Wayne Tobiasson, Research Civil Engineer, of the Civil Engineering Research Branch, Experimental Engineering Division, and Philip R. Johnson, formerly a Research Civil Engineer at the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory.

This study was conducted for the Division of Facilities Engineering, Bureau of Indian Affairs (BIA), United States Department of the Interior under Letter Agreement W56-566 dated 17 March 1978 and entitled *Condensation Problems, BIA School, Chevak, Alaska*. The on-site inspection was made by Philip Johnson of CRREL and George Morgan, Jim Goddard and Dave Trantham of the Bureau of Indian Affairs. This report was technically reviewed by E. Lobacz, S. Flanders and C. Korhonen of CRREL.

A report to the Bureau of Indian Affairs in May 1978 summarized the CRREL findings and provided recommendations for eliminating roof leaks. This report is a somewhat more comprehensive overview of the many roof leak problems of the Chevak school.

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**ILLUSTRATIONS**



**CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT**

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

| *Multiply* | *By* | *To obtain* |
|---|---|---|
| inch | 25.4* | millimeter |
| foot | 0.3048* | meter |
| mile | 1.609347 | kilometer |
| degrees Fahrenheit | $t_{°C} = (t_{°F} - 32)/1.8$ | degrees Celsius |

*Exact

# ROOF LEAKS IN COLD REGIONS: SCHOOL AT CHEVAK, ALASKA

Wayne Tobiasson and Philip R. Johnson

## INTRODUCTION

In 1975-76 the Bureau of Indian Affairs (BIA) built a large school in Chevak, Alaska, to replace a smaller school that had burned. Even before the new building was first occupied in November 1976, serious roof leaks developed and several corrective measures attempted during the next 16 months did not eliminate these leaks. During March 1978 we studied engineering drawings of the school and examined correspondence relative to the roof leaks. On 21-22 March 1978 an on-site inspection was made of the Chevak School.

Chevak is an Eskimo village of about 550 persons on the Yukon-Kuskokwim Delta in western Alaska. It is 140 miles WNW of Bethel and 17 miles east of Hooper Bay (Fig. 1). Transportation to Chevak is by river during the summer and by air from Bethel year-round. The Yukon-Kuskokwim Delta is a flat, treeless, low-lying area covered with innumerable small lakes. The area is snow-covered and essentially featureless during the winter and almost impassable in the summer.

## DESCRIPTION OF SCHOOL

The school was being used for its second academic year during the March 1978 on-site inspection. At that time it had an enrollment of 165 pupils ranging in grade level from kindergarten to high school. The professional staff consisted of 14 teachers and 2 teacher's aides, while 3 janitors operated and maintained the building. The school was well furnished and equipped. Quality furniture, carpeting and numerous teaching aids were present. It was the newest and largest BIA rural school in the Bethel area and was generally built and furnished to high standards.

An isometric drawing of the school is shown in Figure 2. Classrooms, offices, a kitchen and a cafeteria are located in the 96- × 209-ft main portion, which we will call the "school." A 33- × 84-ft connecting section, which we will call the "locker rooms," contains the main entries, toilets and locker rooms. It leads to the 57- × 84-ft gymnasium.

The complex is elevated above the ice-rich permafrost on wooden piles. Wooden skirting, open near the ground, is present along the perimeter of the building. Glued laminated wooden floor beams placed on the piles support wood floor trusses. Steel and wooden columns and bearing walls with 2 × 6 studs support the roof which, like the floor, consists of glued laminated roof beams, wooden trusses and the roof itself. Each roof is sloped 3 on 12 and consists of a 1-1/8-in. plywood deck resting on the roof trusses. Above the plywood, 2 × 6 purlins run along the roof, 6 ft—1½ in. on center, parallel to the eaves. Four inches of expanded bead polystyrene insulation is placed between the purlins which support corrugated metal roofing. This roof system is shown in Figure 3. No vapor barrier is indicated on the as-built drawings.

Before modifications were made by BIA personnel, the roof was ventilated by a system consisting of the eave vents shown in Figure 4, the shallow space between the top of the

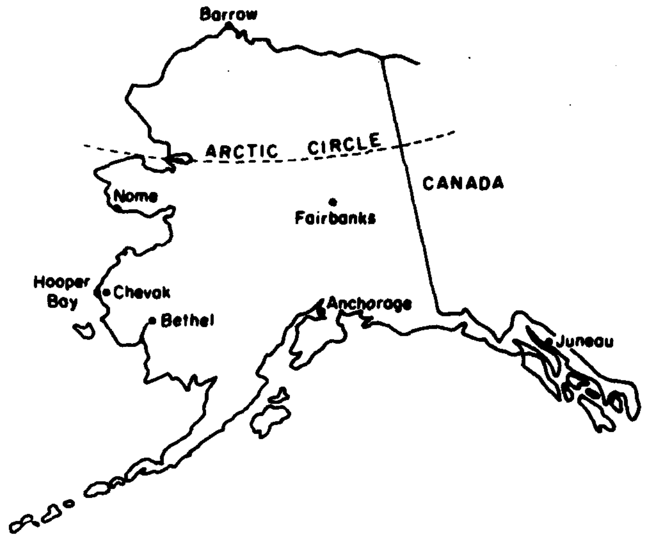


*Figure 1. Location map.*

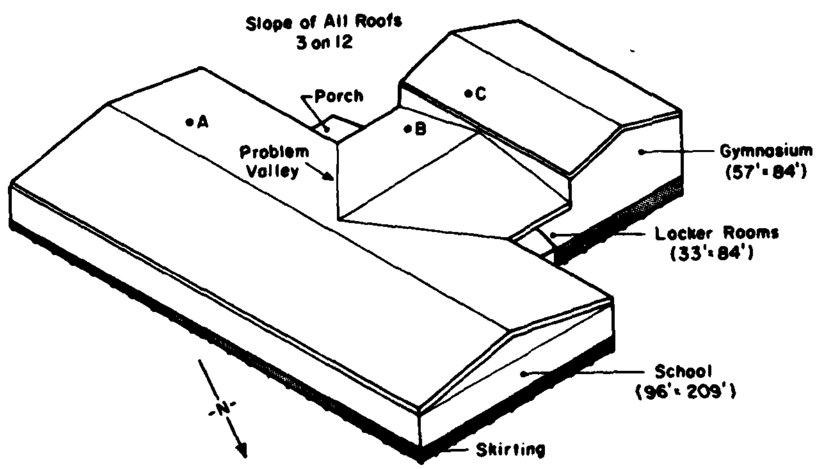


*Figure 2. Isometric drawing of Chevak school.*

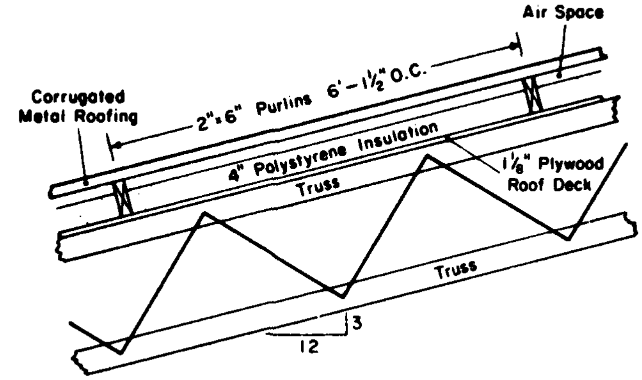


*Figure 3. Cross section of roof.*

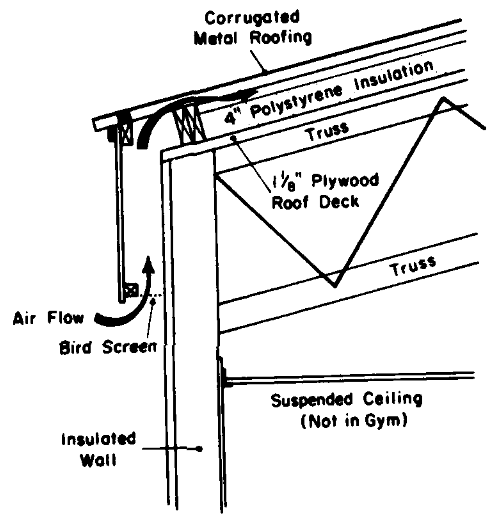


*Figure 4. Detail of ventilated eave.*

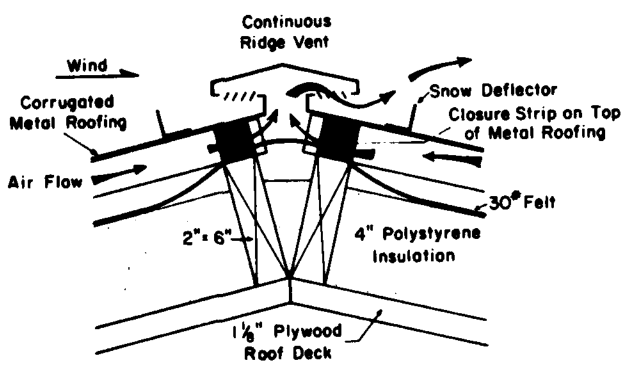


*Figure 5. Detail of ventilated ridge.*

polystyrene insulation and the metal roofing, and the ridge vent shown in Figure 5. Ventilation was provided to prevent moisture accumulation in the roof. The ability of such a roof to accumulate moisture from within the building is greatest in the winter and the ability of the ventilation system to remove such moisture is greatest in the summer. Ventilation also serves to cool the underside of the corrugated metal, thereby reducing the potential for eave icings. Most of the building has an uninsulated suspended ceiling which in many areas has been badly water stained (Fig. 6). However, some portions including the gymnasium have no ceiling and are open to the underside of the roof deck as shown in Figure 7.

## ROOF PROBLEMS

Serious roof leaks, which developed even before construction was completed, have continued to plague this building. The leaks have consisted of four types, two of which have been diagnosed and eliminated by BIA personnel. We have given the four types of leaks the following designations:

1. Snow infiltration leaks
2. Valley leaks
3. Intersection leaks
4. Condensation leaks.

Although many leaks on sloping roofs in cold regions can be traced to eave icings, there have been no serious eave icings reported at the Chevak school except at the valleys.

## SNOW INFILTRATION LEAKS

Snow infiltration leaks developed during the late fall and early winter of 1975 while the buildings were closed-in but still being finished. Water entered the building in many areas at seams in the plywood roof deck. Some of the metal roofing was removed and it was found that snow had blown into the roof through the eave vents (Fig. 4) and was packed in the shallow ventilation space between the top of the insulation and the metal roofing. When the building was heated, the snow melted and the meltwater entered the building.

These leaks were easily cured. BIA personnel sealed the vents with plywood, making it impossible for snow to blow into the roof at the eaves.

## VALLEY LEAKS

Once the building was occupied, severe leaks developed in the areas of the roof valleys, particularly in the lower portion of the "problem valley" shown in Figure 2. Valley leaks were caused by entry of snow meltwater. These leaks did extensive damage to the suspended ceilings and threatened to ruin the carpet and other inside furnishings.

Strong prevailing winter winds from the north and northeast keep the roofs of this building generally, but not completely, free of snow. Snow does drift into and around the "problem valley" which is on the lee side of the two intersecting roofs. With snow in the valley and on the slopes above the valley, conditions are conducive to ice buildup in the valley. On calm and sunny winter or spring afternoons when the ambient temperature rises toward the freezing point, snow on the roof begins to melt due to additional heat gain from solar radiation. The meltwater runs down into the valley where it wets the snow, forming slush. As the sun goes down, the temperature drops and the slush in the valley freezes. Repetitions of this daily cycle choke the valley with slush and ice so that meltwater draining into it overtops the valley flashing and enters the roof.

The main problem area is the lower half of the valley where snow tends to accumulate and meltwater from a large area of the roof concentrates.

Figure 8 is a cross section of the Chevak school's roof valley. Considering the thermal movements to which the metal is subjected, it must be assumed that the seals between the flashing, closure strip and corrugated metal are not water-tight. As long as the valley is clear, water drains down the valley and off the roof. However, when the valley contains slush and ice, meltwater rises in the valley and gets behind the closure strips (Fig. 8). Since the depth of the channel provided by the valley flashing is only about 2 in., it does not take much ice and slush to cause water to overtop the flashing and enter the roof.

BIA personnel solved the problem of valley leaks by installing electrical heat tapes in the lower half of each valley (Fig. 9). These heat tapes maintain an open channel down each valley which allows drainage of the meltwater.

Many simple corrugated metal roofs (i.e. those without valleys) perform well in cold regions. However, valleys in corrugated metal roofing in

*Figure 6. Suspended ceiling stained by water in many areas.*

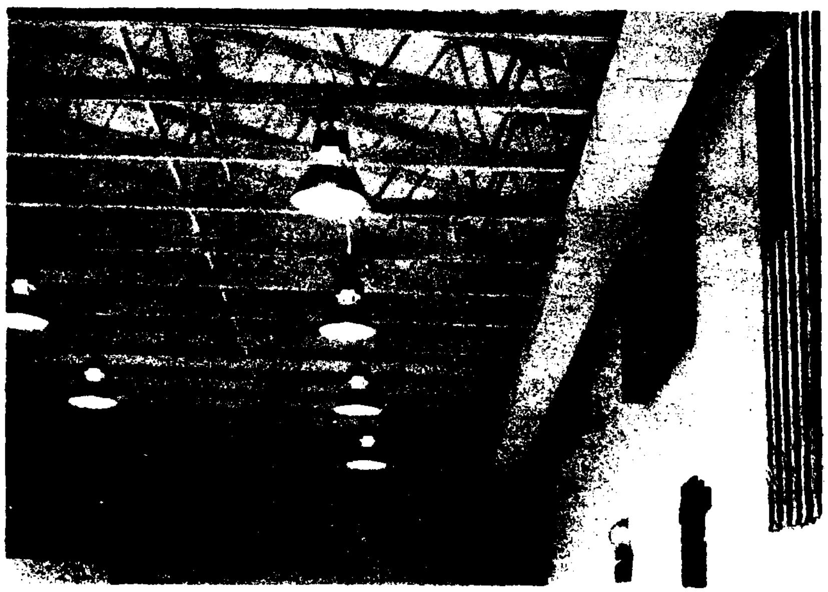

*Figure 7. Inside the gymnasium.*

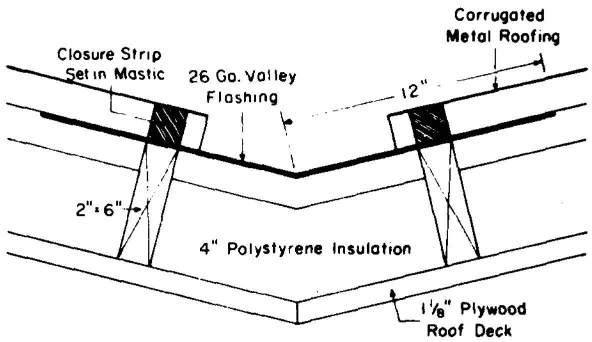


*Figure 8. Valley detail.*

*Figure 9. Electrical heat tape that has prevented the formation of slush and ice dams in the valley.*

cold regions have significant problems. It is possible to design and build valleys that *shed* water but it is virtually impossible to make a valley in a corrugated metal roof *hold* ponded water.

During the inspection, a localized problem was observed at the eave of the "problem valley." Water draining down this valley falls on the sloped roof of an unheated porch (Fig. 10 and cover). Snow drifts onto this roof, and meltwater from the valley soaks into the snow and may freeze, creating heavy ice loads. During warm weather the ice melts loose and slides off this roof. This introduces a potential danger. A heat tape placed down the porch roof would allow drainage and minimize these problems.

## INTERSECTION LEAKS

Leaks also developed at the intersection of the locker room roof and the gymnasium wall (Fig. 11). Water from these leaks damaged walls in the boys' and girls' locker rooms.

We did not investigate the leaks at the intersection of the gymnasium wall and the locker room roof. BIA personnel speculated that meltwater from the gymnasium roof was entering the ridge vent of the locker room roof where that roof intersects the wall of the gymnasium (Figs. 2 and 11).

We speculated that meltwater may have also entered the building along the joint between the gymnasium wall and the locker room roof in a manner similar to that described for valley leaks. If this had been the cause, electrical heat tapes could have prevented meltwater from backing up in this area.

When the roof was opened for repair and modification in 1979, the actual cause of this problem was found to be a missing piece of flashing along the gymnasium wall. This finding emphasized the difficulty of determining the cause of roof problems by visual examination only.

## CONDENSATION LEAKS

Condensation leaks have occurred in most areas of the building complex. Water drips into the building through seams in the roof deck, particularly during warm weather following a cold spell. At times these leaks yield sufficient water to disrupt school activities, particularly in the gymnasium.

Before the on-site inspection, BIA personnel reported to us that the Chevak school roof did not have a vapor barrier. They suspected that the condensation leaks were related in some way to this factor. The absence of a vapor barrier was confirmed by drilling through the roof deck and insulation from below.

The 1-1/8-in. plywood roof deck rests directly on the roof trusses. The 4-×8-ft sheets are tongue-and-grooved on the 8-ft sides but only butt jointed at their ends. The butt joints occur above the trusses. Gaps between the sheets suggest that some shrinkage has occurred since the deck was installed. The gaps appear to be larger on the gymnasium roof deck than on that of the rest of the building.

### Tests to verify the cause of condensation leaks

Air flow directions were determined by observing the movement of smoke and the ease by which doors would open or close. With all entry doors closed, the gymnasium was under a significant negative air pressure. Even with the fresh air intake of the forced hot air heating system opened and the oil burner operating, the negative pressure remained. Since such heating systems are designed to create positive pressure in heated spaces, the negative pressure observed here indicates that a significant amount of warm air was leaving the building through the roof deck.

Similar tests were conducted in other areas of the school. With the heating system operating and the fresh air intake blocked, these areas were also under negative pressure. When the fresh air system was activated, a slight positive pressure was generated. This indicated that the roofs of the "school" and "locker rooms" leaked air somewhat less than the gymnasium roof.

Roof leaks were observed in the gymnasium on 21 March 1978. The outside air temperature was around 20°F, the wind was almost calm, and the sun was shining. During the afternoon several roof leaks developed in the gymnasium near the ridge on the west-facing (sunlit) slope that persisted until late in the day. This was the warmest portion of that roof. Since there was no snow or ice on the roof at that time, it appeared that frost and ice *within* the roof was melted.

To verify that moisture was present within the roof, panels of the corrugated metal roofing

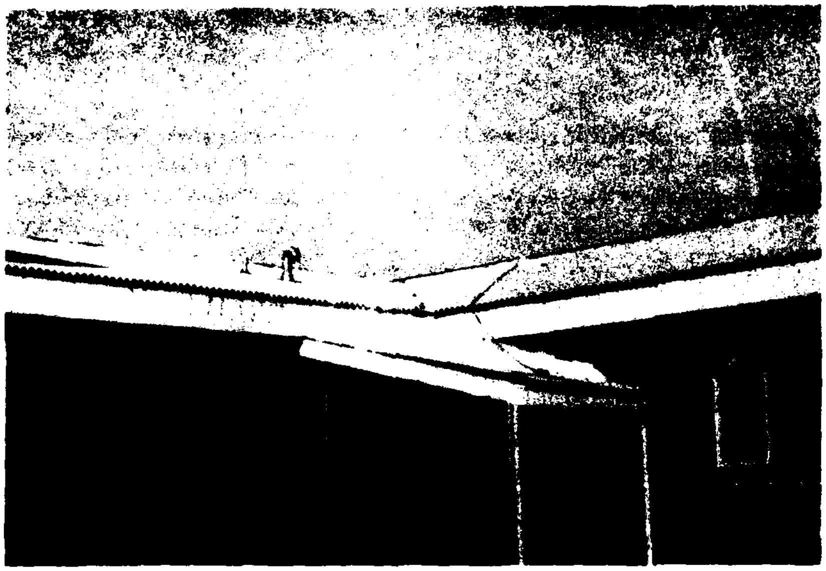

*Figure 10. Porch roof on which snow and ice accumulates below the "problem valley."*

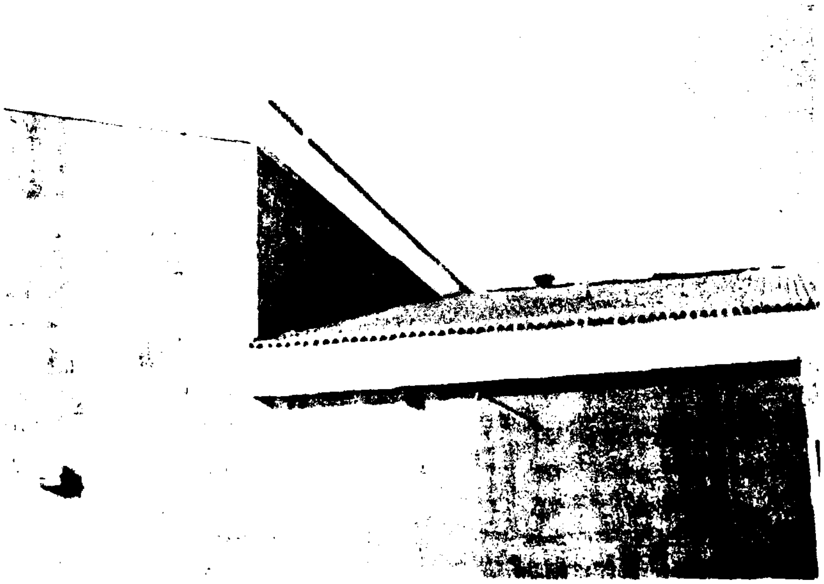

*Figure 11. Intersection of gymnasium wall and locker room roof.*

were lifted at points A, B and C in Figure 2. A small amount of frost was present on the underside of the roofing at point A. A quarter-inch of frost was present at B and 3/8 in. was present at C where some ice was observed on the insulation. These observations convinced all concerned that large quantities of warm moist air from within the building passed into the roof through gaps in the plywood deck and others in the insulation above. The underside of the cold corrugated metal roofing was an excellent condenser and, as the warm moist air passed up through the roof sandwich, frost formed on the metal. Warmer weather and sunshine warmed the frosted underside of the corrugated metal roofing. At some point it was warm enough to melt the frost and meltwater dripped onto the insulation where it either refroze, or in warmer weather flowed downslope. At a gap or seam in the insulation, the water flowed down to the deck. Since there were many gaps in the plywood deck, the water leaked into the building.

The purpose of a vapor barrier is to retard water vapor movement from the heated space both by diffusion and by air leakage. The absence of a vapor barrier was directly responsible for the condensation leaks experienced in this building. Without it moist air could leave the building and meltwater could return in many areas.

### Eliminating the condensation leaks

To solve the condensation leak problem it would be necessary to greatly reduce the amount of moisture that enters the roof from within the building. Since the internal relative humidity was not excessive, reducing it would not solve the problem.

Some opportunities were present to lower the underside temperature of the roof by insulating the heating ducts located in the space above the suspended ceiling. Although lowering the temperature of the roof would be beneficial, it would not cause enough change to eliminate this problem. However, reductions in the magnitude, frequency and time of occurrence of roof leaks might be achieved.

Shortly after the CRREL-BIA inspection of this building, heating ducts above the suspended ceiling were insulated and modifications were made to draw return air for the forced hot air heating system from the area between the roof deck and the ceiling. These changes noticeably decreased the temperature in that area.

The direct way of preventing moisture within the building from entering the roof would be to vapor seal the plywood roof deck. Since the most problematic gaps in the plywood deck were between the chord members of the trusses, and essentially inaccessible, it did not appear possible to seal the roof effectively from within the building. Consequently we recommended an external fix. Although this would be an expensive, time-consuming task, it appeared to be the only way that roof leaks caused by air exfiltration could be eliminated if the existing warm roof were to be retained.

## RECOMMENDATIONS FOR ELIMINATING CONDENSATION LEAKS

### Repairing existing roof

The recommendations for repairing the BIA school roof are summarized below.

The air leakage-vapor seal must be located on the warm side of the roof insulation. To place it there, the corrugated metal roofing, the insulation and the purlins must come off temporarily. All gaps between sheets of plywood and all roof penetrations should then be primed and sealed. Since the plywood has a relatively low permeability, sealing the joints should create an effective vapor seal. However, we consider it prudent to also install a continuous vapor barrier over the entire roof. An adhered continuous vapor barrier would not only reduce vapor flow by diffusion through the plywood but, more importantly, would prevent air leakage in the likely event that all gaps between sheets of plywood and at penetrations are not totally sealed. A loose-laid vapor barrier would permit lateral moisture migration and would be inappropriate.

Four alternative vapor barriers are recommended:

1. A spray or brush applied liquid.
2. Two layers of no. 15 asphaltic felt imbedded in cold applied asphalt.
3. A coated base sheet bonded to the plywood and lap sealed with a rubberized adhesive.
4. A kraft paper-asphalt composite bonded to the plywood and lap-sealed with a rubberized adhesive.

If solvent-based adhesives are used with the vapor barrier, a separation layer should be placed between it and the polystyrene insulation to prevent damage to the insulation from the solvents.

With the vapor barrier in place and the purlins reinstalled, the original 4-in.-thick polystyrene insulation should be reinstalled. We expect that most of the existing insulation would not be damaged during removal since it is not bonded to the plywood but held in place by friction at the purlins. However, some replacement insulation should be purchased to replace any that is damaged. When reinstalling the insulation, any gaps or holes caused by damage or misfit should be stuffed full of glass fiber insulation. To conserve energy, an additional inch of polystyrene insulation should be added to the roof. This insulation should be installed so that its seams mismatch the seams of the 4-in.-thick existing insulation. Space exists for this insulation without interfering with roof ventilation.

With the corrugated metal roofing temporarily removed, the valley flashing should be widened. The existing width of 2 ft may be adequate near the ridge, but a width of 4 ft or more seems necessary at the eaves. A quality sealant should be used when placing the new valley closure strips. Permanent electrical heating cables should be installed in each valley.

The corrugated metal roofing is in very good condition and with a little care in handling and numbering should be easy to reinstall.

The ridge is the only safe place for maintenance personnel to walk along these roofs, particularly when there is snow on them. Accordingly, the ridges have been used as foot paths and the ridge vents (Fig. 5) have been flattened against the ridges. Although crushed, some air can still pass through them. The flattened ridge vents should be removed and replaced with elastomeric closure strips and a solid galvanized cap, robust enough to sustain foot traffic. Every 20-ft, the ridge cap should be penetrated with a 2-½-to 3-in.-diam, 24-in.-high black-painted vent stack (upside-down J). The eaves should remain blocked to preclude snow infiltration. If the roof is vapor-sealed as recommended above, we expect that the combination of local winds, air leaks in the metal roofing, and the modified ridge ventilation system will provide enough air movement to facilitate the small amount of summer drying required by the roof.

**An alternative roof cladding**

The above solution to the roof leak problem will be expensive and the metal roofing will continue to be susceptible to leakage caused by slush and ice in the valleys. Electrical heat cables will still be required in the valleys and perhaps on the locker room roof at the gymnasium wall. There is also a question as to how effective the corrugated metal roofing will be after removal and reuse.

If the corrugated metal roofing cannot be reused it is suggested that it be replaced with a composition shingle roof. Wind-tab composition shingles, which are designed for use in windy areas such as Chevak, would clad the roof. The shingles would be embedded in roofing cement at eaves, valleys, roof ends and penetrations for increased resistance to winds and meltwater Such a roof can be made water-tight along valleys and at roof-wall intersections, thereby avoiding the dependency on electrical heat cables which can be problematic.

A composition shingle roof could be built on the existing deck and insulation after a vapor seal is applied as discussed previously, the insulation and purlins are restored and insulation is added. Two-by-four rafters 24-in. on center on the purlins would support a new plywood deck. Before installing the composition shingles on the plywood, roofing cement and no. 15 felt would be used to seal all plywood joints. Cement and felts would also be used to create a waterproof layer on the deck at the valleys and eaves where some slush and ice might accumulate. The plywood deck would be covered with loose-laid no. 15 felt placed shingle-fashion with a 50% overlap. New flashings would be installed in valleys and at roof/wall intersections. Eaves would remain blocked and the ridge cap would be reconfigured as discussed previously.

**The "cold roof" alternative**

During the on-site inspection, the alternative of changing the warm roofs of this building to cold roofs was discussed. A cold roof permits a significant amount of cold air to flow above the insulation and keeps the roof cladding relatively cold, thereby minimizing problems caused by meltwater, slush and ice. A building with insulation in the ceiling and a cold ventilated attic above has a cold roof. Air flow in the narrow space above the insulation in the Chevak school roof (Fig. 3) is not enough to cool the roof cladding significantly. In this building a cold roof could be created by installing a vapor barrier and insulation along the bottom of the roof trusses or at the level of the suspended ceiling, and then opening the gable ends and the ridge of each roof to allow cold outside air to cool this area. With appropriate baffling of air intakes, snow infiltration into this space could be minimized.

For the gymnasium, this approach seemed worth considering. It would have involved removal and replacement of the lights and heating system ducts attached to the lower chord of the trusses, but this did not appear to be a complex undertaking. The use of urea formaldehyde (UF) foamed-in-place insulation was considered for this application. UF foam is not normally recommended for attics because of expense and possible degradation by excessive summer heat. However, it would have been an effective way to insulate this roof in among the lower chord members of the trusses. Because the upper roof is reflective metal and contains insulation, and because this attic space would be ventilated, it would not have become warm enough to deteriorate the UF foam.

The ingredients of UF foam insulation are shipped to a job as liquids, thereby providing some logistical advantages for remote areas over other insulations that leave the factory in rather bulky forms. However, the cost of transporting a skilled UF foam applicator to Chevak might have outweighed such logistical advantages.

For the "school" and "locker rooms," a cold roof seemed difficult to install because of the equipment suspended from the lower chord of the trusses and the location of the warm air heating ducts above the suspended ceiling.

## REPAIRS AND MODIFICATIONS

During the summer of 1979 a crew of Eskimos from the village repaired and modified the heating system and the roofs of the Chevak school under the direction of James Goddard of the Bureau of Indian Affairs. The roofs were repaired and modified from the exterior. Once the plywood deck was exposed by removing the corrugated metal roofing, insulation and purlins, a multilayer vapor barrier was installed. First, all joints in the plywood deck were sealed, and then a layer of kraft paper-backed aluminum foil was *adhered* to the deck. This was then covered with a coating of asphalt emulsion, a layer of 40-lb roofing felt and a second coating of asphalt emulsion. The original purlins and insulation were then reinstalled. An extra 1-½ in. of polystyrene insulation was added to the existing insulation before the original metal roofing was reinstalled.

New 4 ft-wide valley flashing was installed, with extra effort devoted to sealing between the flashing, the new closure strips and the corrugated metal using silicone sealant. Heat tapes were then installed in the valleys.

When the corrugated metal roofing was removed it was found that flashing had not been installed along the upper 4 ft of the roof at the gymnasium wall/locker room roof intersection. Water draining from the gymnasium roof found easy entry into the building because of this construction deficiency. Flashing was installed.

The ventilated ridge cap was replaced with a solid ridge cap vented every 20 ft with an inverted J.

The exterior work proved to be simple and effective. It was easily handled by a crew of construction laborers. By working from the exterior they avoided complications of dealing with internal equipment such as electrical, plumbing, heating and ventilating systems.

The repairs and modifications have been effective in eliminating the roof leaks at the school.

## SUMMARY AND CONCLUSIONS

Four types of roof leaks occurred at the BIA school in Chevak, Alaska.

1. *Leaks by snow infiltration,* which were eliminated by blocking eave ventilation features.

2. *Leaks caused by slush and ice in the valleys,* which resulted from meltwater overtopping the valley flashing.

3. *Leaks due to a missing section of flashing* at the locker room/gymnasium intersection, which were solved with new flashing. Although simple construction deficiencies (e.g. the missing section of roof-wall flashing on this roof) explain some problems, it was often difficult to establish their existence until portions of the structure were opened for repair.

4. *Major condensation leaks,* which occurred in many areas of the building, were caused by the absence of a vapor barrier in the roof. Without it, vast quantities of warm moist air

from within the building entered the roof and the water vapor condensed as frost on the inside of the corrugated metal roofing. During warmer periods, the frost melted and subsequently leaked back into the building. To eliminate these leaks, the roof was disassembled from the exterior down to the plywood deck, a multilayer vapor barrier was adhered to the plywood, and the roof was reassembled. In the process, insulation was added, valley flashings were widened and a new robust ventilated ridge cap was installed. Collectively, the above actions appear to have solved the roof leak problems.

The Chevak study supports the following general conclusions about sloping roofs in cold regions:

1. In cold areas that experience significant amounts of blowing snow, the snow infilitration problems associated with conventionally-designed warm roof ventilation systems can be significant.

2. Valleys in corrugated metal roofs in cold regions should be avoided. Where valleys occur, designers and maintenance people must ensure a clear passage for meltwater down the valley during all seasons.

3. When the valley of a warm roof drains onto a cold roof, significant icing problems should be expected.

4. Air exfiltration through gaps in wooden roof decks can cause significant moisture problems in very cold regions if no separate air leakage barrier is present on the warm side of the insulation.

5. Roofs in cold regions require warm-side moisture barriers to retard outward movement of water vapor by diffusion and by air leakage. Air leakage at seams and gaps in the barrier can transmit vast quantities of moisture past a barrier with an otherwise low permeability.

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