SNOW ACCUMULATION ON AND AROUND SOLAR COLLECTORS

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ABSTRACT

Studies of the accumulation of snow and ice on buildings with flat plate solar collectors were carried out during the winter of 1979. Although the studies were generally qualitative, prelimary guidelines for snow load criteria were developed. Observations identified two significant phenomena: the sliding of snow from collector surfaces and the drifting of snow around protruding collectors. It was found that only those collectors which are relatively steep (more than 50° from the horizontal) and are free of obstructions will shed snow reliably. The accumulation of snow sliding from collectors appears to be a significant load for roof structures. It was also found that collectors that protrude from roofs tend to create drifts, much as a snow fence. The common installation of several parallel rows of protruding collectors creates a situation somewhat like a "sawtooth" factory building roof and requires special attention in design of the roof structure. Further study of the problem is merited.

INTRODUCTION

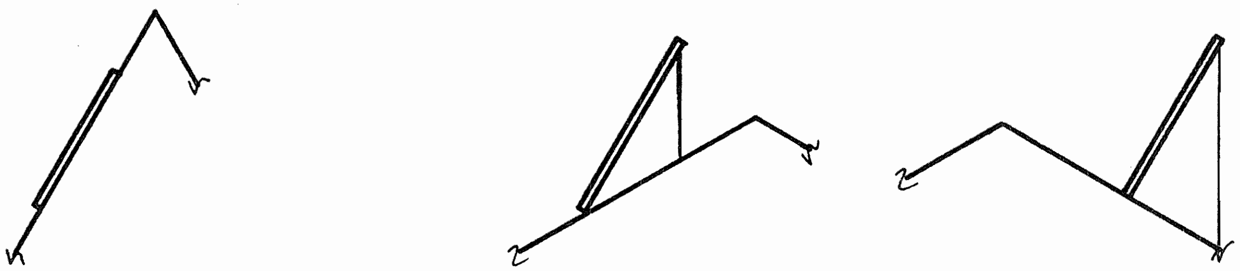
Flat plate solar collectors are becoming an increasingly common building component, both for new and existing structures. Most solar collectors are located on building roofs, and understanding is needed in order to develop more specific design criteria to provide safety in the event of large snowfall. This paper summarizes the findings of studies of snow accumulation around solar collectors conducted during the winter of 1978-79 and identifies areas of needed research. The objective of the study has been to understand the difference in snow accumulation caused by the solar collectors.

For the purposes of studying the accumulation of snow on roofs with flat plate solar collectors, roof surfaces can be categorized as sloped or flat and collectors can be categorized as flush or protruding. Protruding collectors may also be supported with a small or large clear space between them and the roof. Figure 1 shows several pertinent combinations of these factors commonly found at solar collector installations.

FINDINGS OF STUDIES CONDUCTED IN 1979

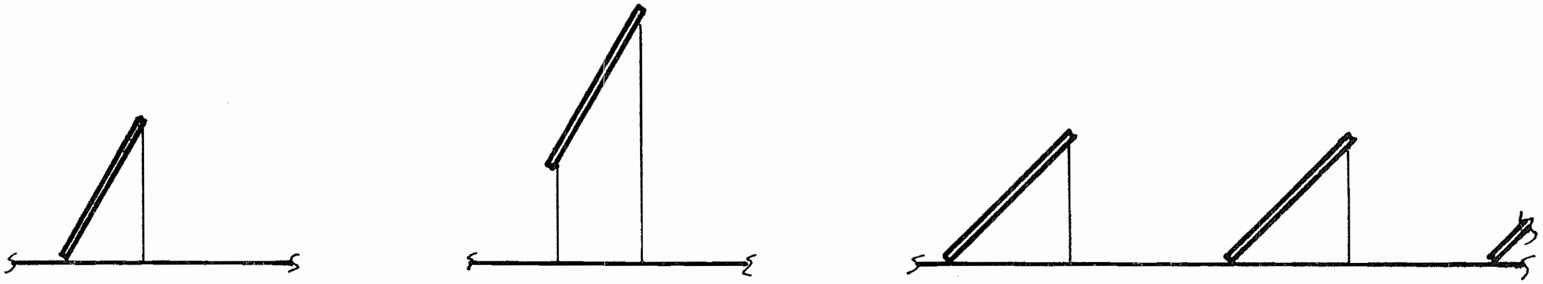
Two studies were conducted for the National Bureau of Standards during the winter of 1978-79, one in the vicinity of Albany, New York, and one in the Chicago area. Each is documented in a report available from the National Technical Information Service (one by Corotis et al, the other by O'Rourke). Twenty-six sites were studied, including a wide variety of configurations of flat plate collector systems. In addition, four sites in the Washington, D.C., area were observed by NBS personnel, and summaries of those observations are also included in this report.

There are two items of interest in the study of snow on and around solar collector systems: the amount (both volume and weight) of snow on the collector itself, as related to the amount of snow on the ground, and the <u>difference</u> in the amount of snow on the



a) Flush collector
on sloped roof

b) Protruding collectors on sloped roof



c) Protruding collector
on flat roof

d) Protruding collector
on flat roof with
large clear space

e) Multiple rows of protruding
collectors on flat roof

Figure 1: Common Configurations of Solar Collectors

building from what would exist if no solar collectors were present. The basic physics of the problem includes the mechanics of falling and drifting snow around solar collectors and the melting and sliding of snow from solar collector surfaces. The studies addressed these issues in a qualitative manner, although some quantitative analysis was carried out on the data collected around Albany.

In most cases where observations were made during or shortly after snowfall, some snow was retained on the collector surfaces. This accumulation was generally small in comparison to the amount retained on other portions of the roof. Figures 2 and 3 illustrate light snow cover on the collectors following a snowfall of approximately six inches (150 mm). It is apparent that such snow cover would prevent the operation of a solar collector, and that it would impose some load on the collector unit itself. Intuitively, it could be expected that the snow would quickly melt and slide off the collector surface. If this were consistently true, the short loss of operation would not be serious, and the maximum weight on the collector would be that of a single storm. Observations both confirm and deny this intuition, depending on other cirumstances. Figure 4, taken within a few minutes of figure 3, shows the anticipated melting and sliding, even on an over-cast day. The circumstances preventing the melting and sliding are of immediate interest.

Observations made in the Washington, D.C, area by the National Bureau of Standards, as well as observations recorded by Corotis serve to define necessary conditions for dependable shedding of snow from collector surfaces. Of first importance is the slope of the surface; only those collectors at a steep angle, more than about 50° with the horizontal, could be counted on to shed snow. Of nearly equal importance is the presence of obstructions in the path of the sliding snow; only those collectors completely free of obstructions were completely uncovered by sliding. Figures 5 and 6 both show collectors that are flush with the roof and have no gutters below, only the slopes are different. Most of the snow slid off the steep collectors in figure 5, although about four inches (100 mm) of snow had fallen in the 24 hours before the photograph was taken. Considerable snow covers the collectors in figure 6, even though only one and one-half inches (38 mm) had fallen in the 24 hours before the photograph was taken. The two photographs were taken only one day apart in similar locations in the Chicago area.

For collectors that are mounted flush with the roof surface, the most dependable way of assuring slide-off is to extend the collectors to the bottom edge of the roof. A flattening of the roof slope beneath the collector, a change in the sliding resistance of the surface down the slope from the collector, or even a gutter may prevent the sliding action. Figure 7 illustrates the effect of a flatter slope below the collectors: those upper collectors above the lower roof are partially covered while the remaining upper collectors are clear. Figure 8 shows the effectiveness of a gutter below the collector in forming an ice dam and preventing sliding.

Interviews with owners in the Chicago area revealed that collectors were out of operation for extended periods, up to two months in some cases, unless the snow was manually removed from those collectors with unfavorable situations for clearance by sliding.

One further observation regarding the sliding of snow from solar collectors is that any structures beneath the solar collectors that might catch the sliding snow must be strong enough to withstand it. Measurements of piles of snow accumulation on flat roofs beneath protruding collectors in the Albany area indicated that well over twice as much load existed there as at other locations on the same roof.

Collectors that protrude from the surface of the roof alter the air currents that carry both falling and blowing snow. The effect is much like that of a snow fence. Several interesting observations were made concerning this effect. The presence of a row of protruding collectors oriented normal to the wind tends to reduce the effect of the wind in removing snow from the roof. Depending on the amount of clearance below the protruding collectors, they can also serve to initiate drifts. The presence of several parallel rows of protruding collectors creates a situation comparable to a "sawtooth" or "northlight" roof, in which the valleys tend to fill in with snow. Figure 9 shows a building with many such rows of collectors. Figures 10 and 11 show the drifting effect on this same building, with snow depths well over four feet (1.2 m) following an eighteen inch (450 mm) snow accompanied by a significant wind.

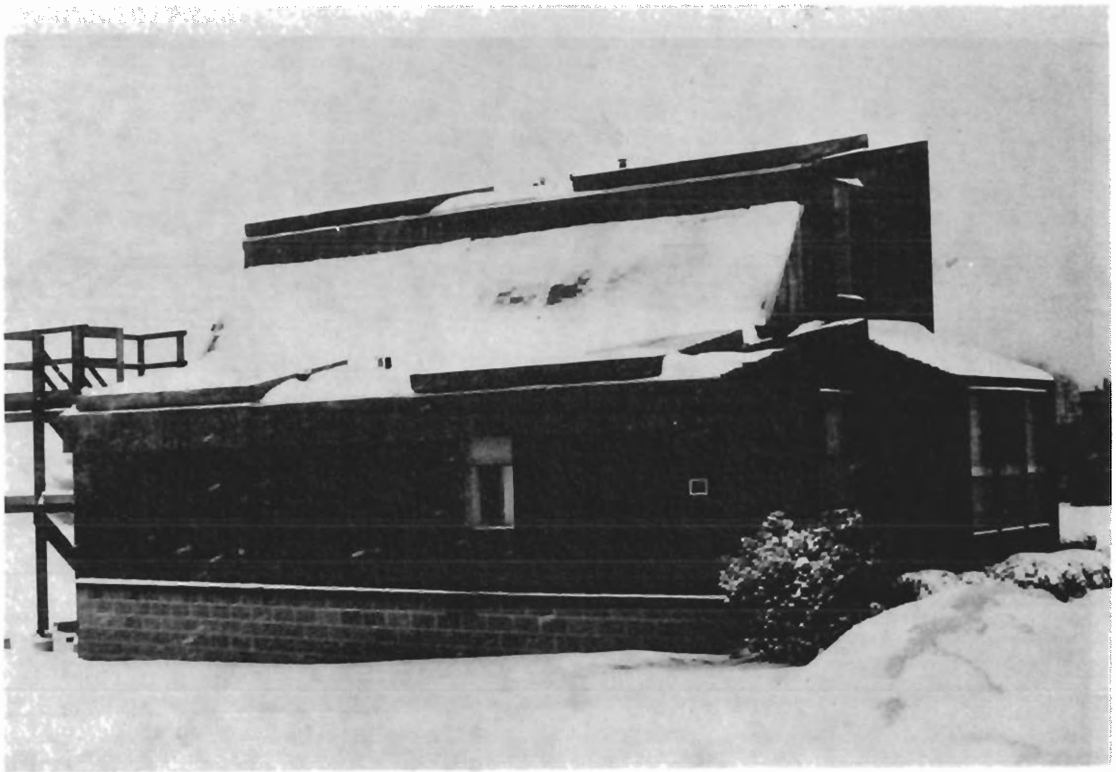


Figure 2: Light Snow Cover on Collectors during Snowfall

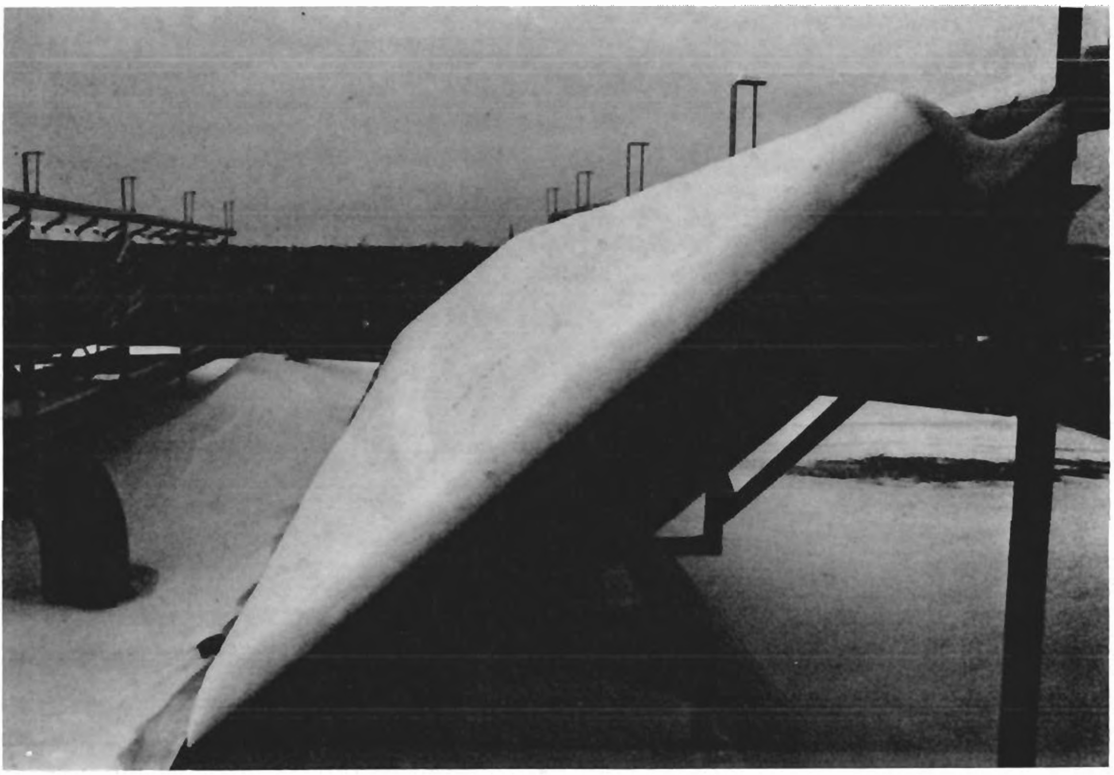


Figure 3: Light Snow Cover on Collectors after 6" (150 mm) Snow

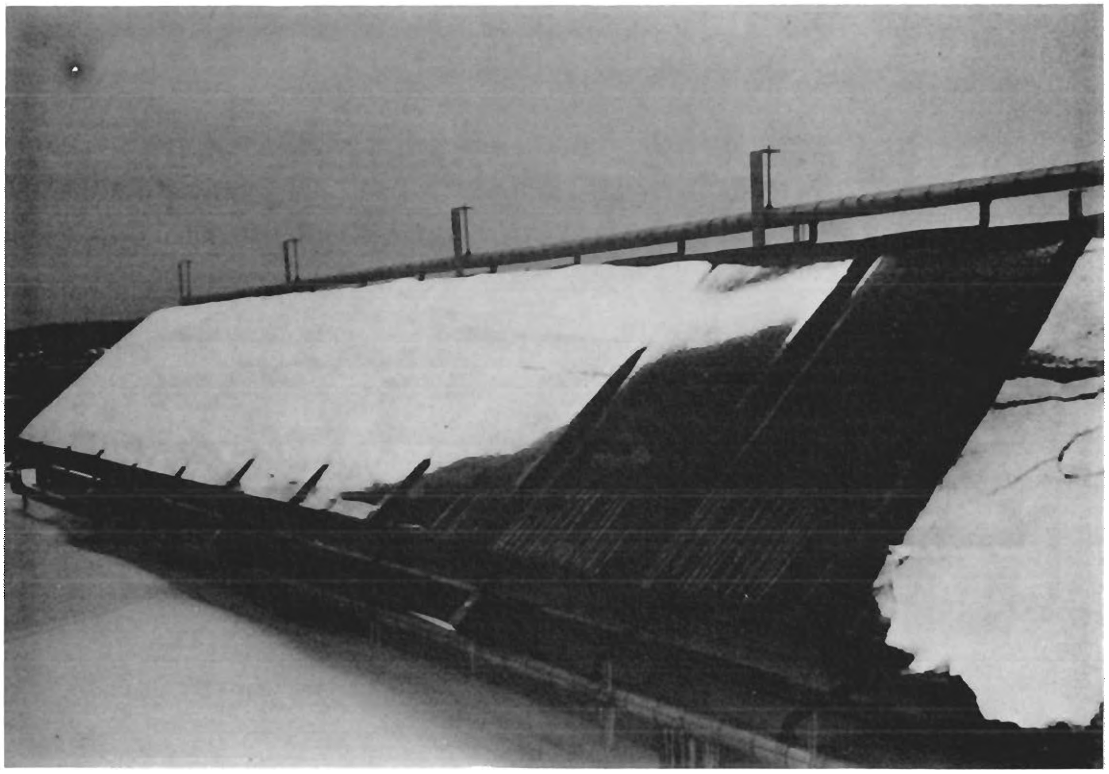


Figure 4: Melting and Sliding of Snow

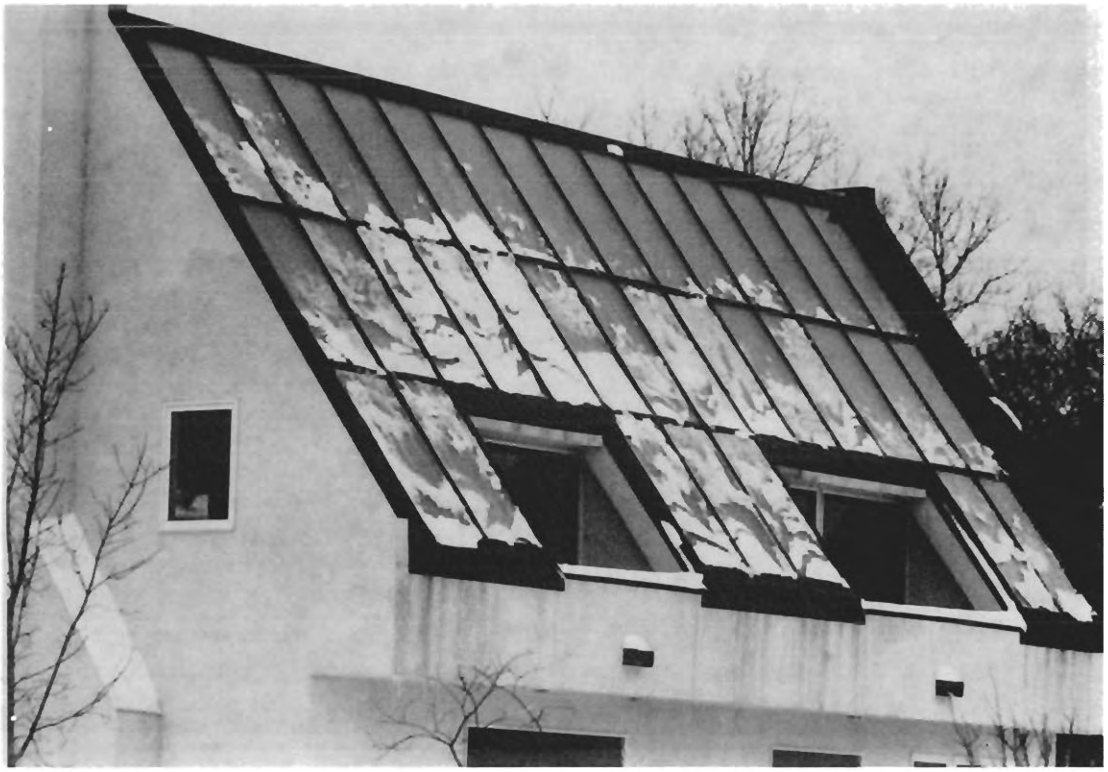


Figure 5: Snow Sliding off Steep Collectors

Figure 6: Snow Retention on Shallow Collectors

Figure 7: Obstruction below Steep Collectors

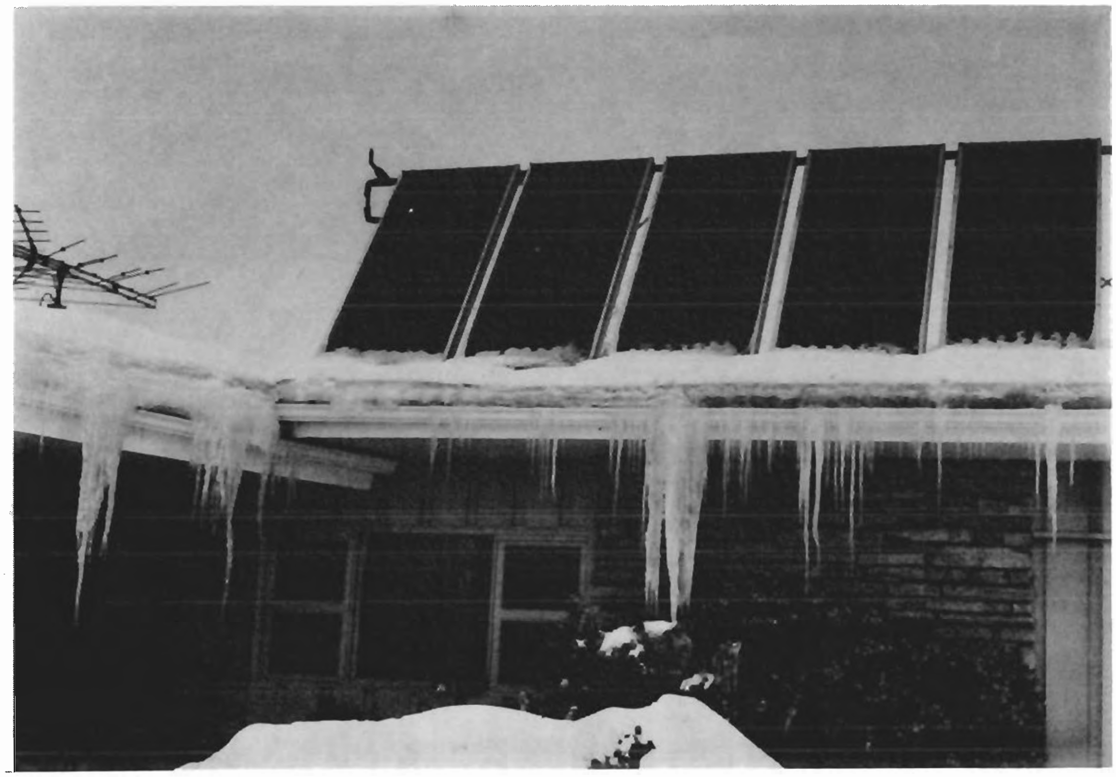


Figure 8: Ice Dam at Gutter and Icicles below Collectors

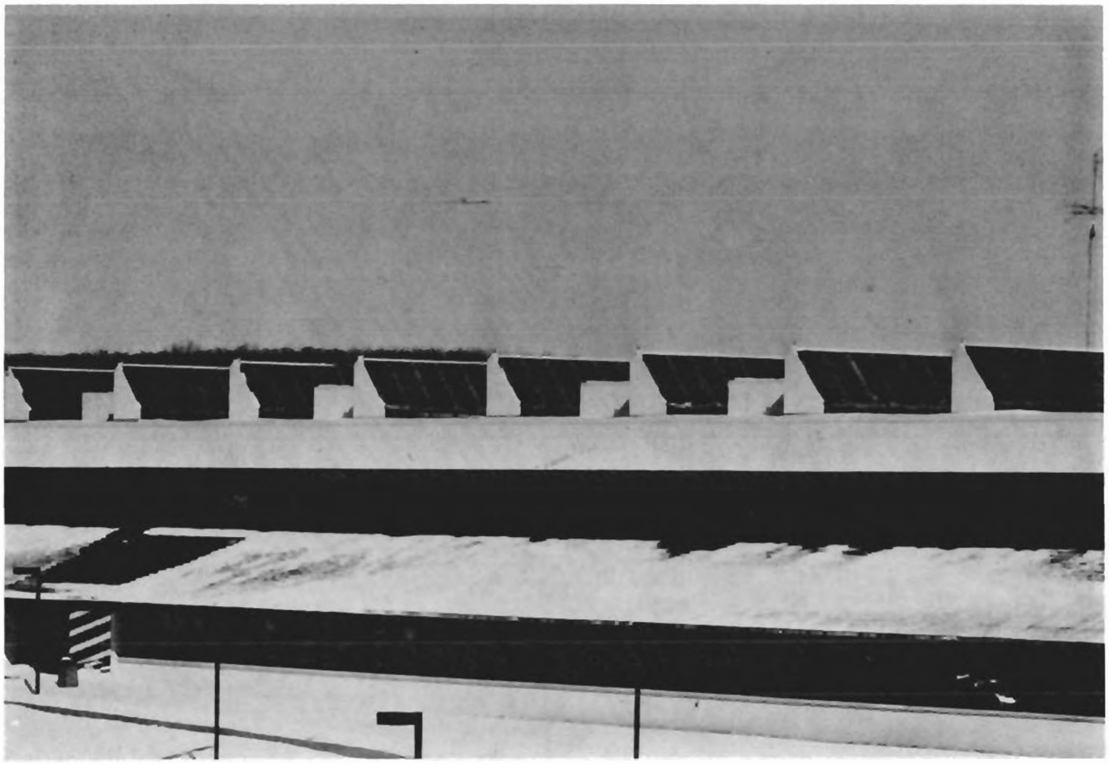


Figure 9: Building with Multiple Rows of Collectors

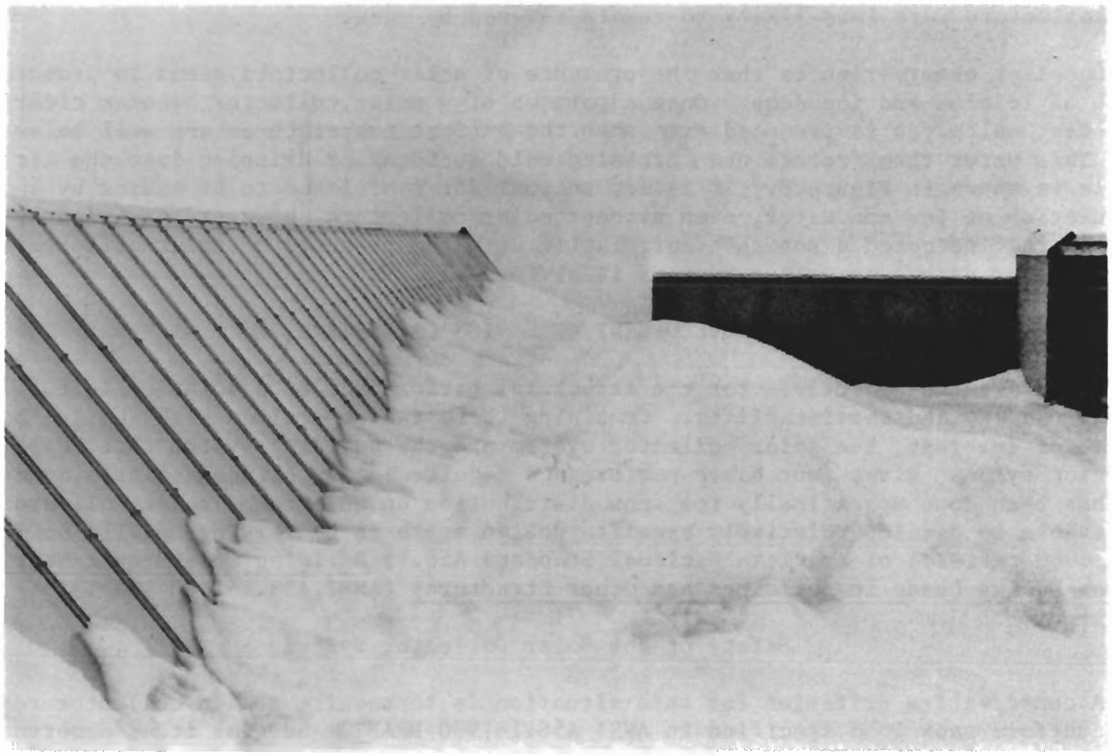


Figure 10: Drift between Parallel Rows

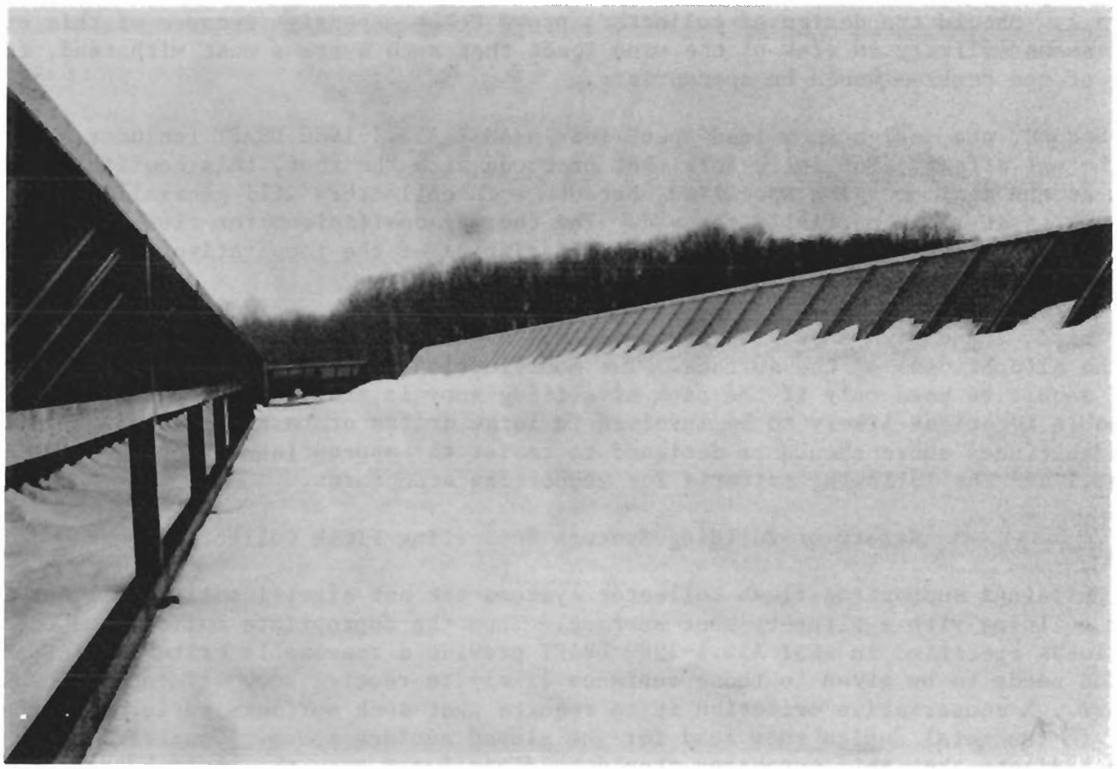


Figure 11: Drift between Parallel Rows

Protruding collectors mounted with a significant clear space between the roof surface and the bottom edge of the collector were observed to have less of an effect on the formation of drifts. Also, because this clear space presented no obstructions to sliding, such collectors were less likely to remain covered by snow.

One last observation is that the presence of solar collectors seems to promote the growth of icicles and ice dams. Once a portion of a solar collector becomes clear on a sunny day, meltwater is produced even when the ambient temperatures are well below freezing. This water then freezes upon crossing cold surfaces or dripping into the air. An example is shown in Figure 8. It is not unusual for roof leaks to be caused by such an accumulation of ice and water, even without solar collectors, however some reports in the Chicago area indicated a possible correlation with the presence of solar collectors. The potential for damage to gutter systems is obvious.

DEVELOPMENT OF DESIGN CRITERIA

There are two objectives for the structural performance of a solar collector installation: safety and serviceability. Combining these two objectives with the two basic systems of interest, the solar collector system and the building system that supports the collector system, gives four basic performance requirements. Although little quantitative work has been done specifically for snow distribution on and around solar collectors, it is possible to develop relatively specific design criteria by relying heavily on the proposed 1980 revision of American National Standard A58.1, <u>Building Code Requirements for Minimum Design Loads in Buildings and Other Structures</u> (ANSI A58.1-1980 DRAFT).

Safety of the Solar Collector System

A conservative criterion for this situation is to require that a collector resist the basic uniform snow load specified in ANSI A58.1-1980 DRAFT. Several items deserve comment with respect to this approach. First, in those cold regions where the design snow load represents a winter-long accumulation of many snowfalls rather than a single large storm, the criterion is likely to be conservative because of the tendency for snow to disappear from collectors more rapidly than from the adjoining roof. But because snow has been observed to remain on collectors for months at a time during a severe winter, it does not appear appropriate to base the design of the collectors on statistics for a single large snowfall. Should the design of collectors prove to be expensive because of this criterion, which seems unlikely in view of the wind loads that such systems must withstand, further study of the problem would be appropriate.

Second, the design snow load specified in ANSI A58.1-1980 DRAFT includes a coefficient for thermal effect. For collectors that protrude from the roof, this coefficient should be taken as the maximum value specified, because such collectors will generally be cold until the snow is at least partially removed. The thermal coefficient for flush collectors would depend on the insulation and thermal characteristics of the inoperative collector, the structure, and the space below.

Third, the design snow load given in ANSI A58.1-1980 DRAFT is modified for the slope and the slipperiness of the surface. The modification for an "unobstructed slippery surface" should be used only if the path of sliding snow is truly unobstructed. Collectors placed in locations likely to be involved in large drifts or to receive snow sliding from sloped surfaces above should be designed to resist the appropriate surcharges, as defined in A58.1 and the following criteria for supporting structures.

Safety of Building Systems Supporting Flush Collectors

Buildings supporting flush collector systems are not significantly different that any other building with a slippery roof surface. Thus the appropriate uniform and unbalanced snow loads specified in ANSI A58.1-1980 DRAFT provide a reasonable criterion. Special attention needs to be given to those surfaces likely to receive snow sliding from solar collectors. A conservative criterion is to require that such surfaces resist a surcharge equal to the total design snow load for the sloped surface above. Observation and intuition indicate that this surcharge should be distributed over the lower surface in a strip along the lower edge of the upper sloped surface with a width equal to one-half of the horizontal projection of the upper sloped surface.

Safety of Building Systems Supporting Protruding Collectors

Protruding collectors alter the air currents that carry falling and blowing snow, much like a snowfence. The design snow load in ANSI A58.1-1980 DRAFT includes a coefficient for exposure, that is the effectiveness of wind in removing snow from a roof. It is possibile to account for the snowfence effect of protruding collectors by increasing this coefficient for those buildings that have a relatively open exposure (i.e., changing their exposure category from open to sheltered). This approach is intuitively attractive and seems justified based on the limited data from the studies.

Protruding collectors tend to be more free of snow as the clear space between them and the roof increases, particularly if they are high enough to avoid any involvement with drifts on the roof. Building systems supporting protruding collectors with more than some minimum clear space need to resist the appropriate uniform and unbalanced snow loads speciin ANSI A58.1-1980 DRAFT and the sliding surcharge described previously. It is not possible to derive the magnitude of this minimum clear space from the limited studies made so far, and it should be the subject of further study. One pertinent source of information is the design of "blower type" snow fences (snow fences designed to use the wind to keep an area clear of snow by funneling wind across a surface at a higher velocity). Such designs are based on a minimum clear space of four feet (Mellor, 1965). Also, it appears reasonable that the minimum clear height depends on the anticipated height of snowpack for the maximum ground load at the location.

Protruding collectors that do not have a high enough clear space tend to become involved in drifts. Figure 12 indicates the shapes of drifts observed in the studies and the shapes of appropriate load distributions taken from ANSI A58.1-1980 DRAFT. Not enough data exists to confirm that the distribution or the magnitudes of drift loads specified in A58.1 apply to solar collectors, but the loads appear to be adequate for design purposes until more information is available. The common situation of several parallel rows of collectors tends to cause a load distribution similar to that specified for sawtooth roofs in A58.1. Once the drifts begin to form, the geometrical difference between rows of protruding collectors on a flat roof and a sawtooth roof begin to disappear. For the design of structural members that are normal to the rows and have spans longer than the row spacing, the sawtooth load distribution may be replaced by a uniform distribution equal to the average of the peak and valley loads.

Serviceability Criteria

There appears to be little concern with the structural serviceability of either collector systems or building systems as far as snow is concerned. However, the studies did raise two other serviceablity concerns that deserve at least passing mention. First, any collector sloped less that about 50° or located without the minimum clear space mentioned previously should be designed to account for extended loss of operation due to snow cover or provision for manual removal of snow should be made. Removal plans should include consideration of dumping areas, accessibility, and the resistance of the solar collector components and the roof surface to damage.

Second, the ice and meltwater caused by the presence of solar collectors should be accounted for by assuring the adequacy of the moisture barrier under adverse conditions and by avoiding details likely to promote the accumulation of large quantities of ice or likely to be damaged by the weight or expansive action of ice.

RESEARCH NEEDS

The lack of quantified data prevents any rigorous analysis in the development of design criteria. Thus the obvious need is for future studies designed to collect numerical data on the accumulation of snow at solar collector installations. Initial efforts should focus on two areas. First, the minimum clear space and other geometrical factors necessary to assure that protruding collectors do not become involved in drifts--that is, that the

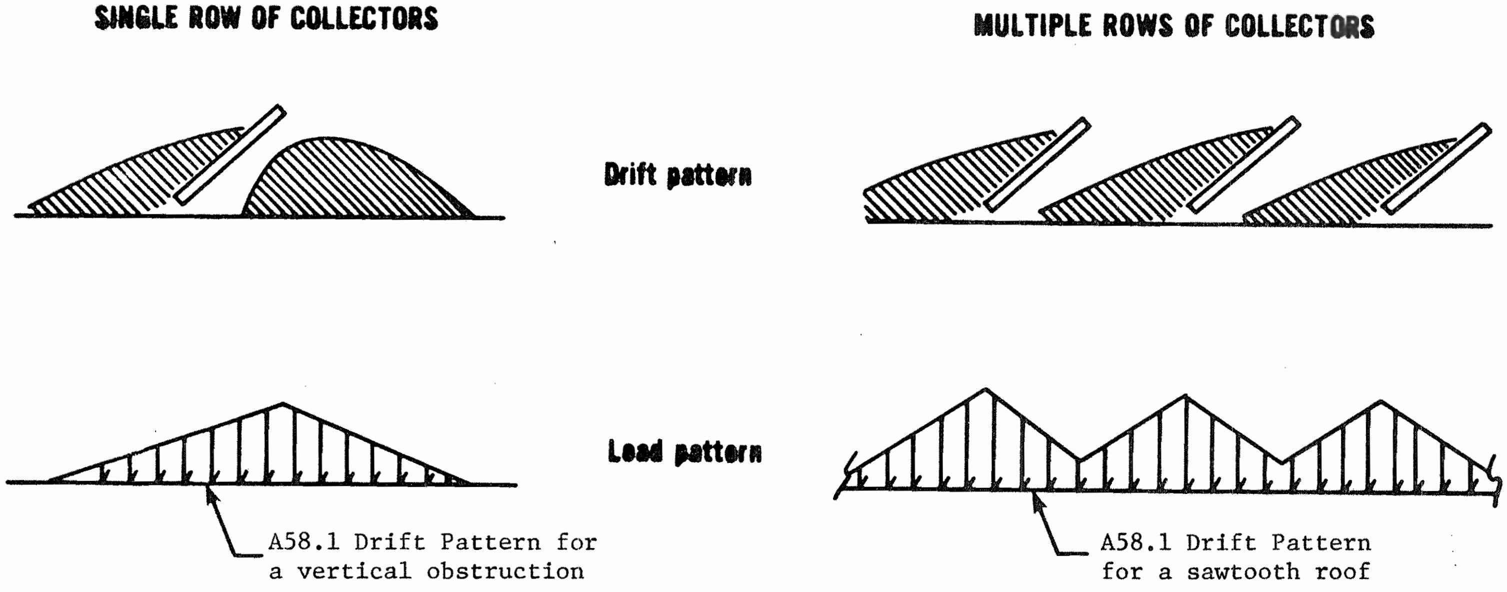


Figure 12: Load Patterns for Protruding Collectors Close to the Roof

collector functions like a "blower type" of snow fence rather than a conventional snow fence. Second, the important factors determining the drifting of snow around parallel rows of protruding collectors need to be studied. This is not meant to imply that studies of other aspects of the problem are not worthwhile. Rather, it is more an indication of the confidence level in the various portions of the tentative design criteria developed in this study.

It appears that future research should consist of a coordinated program of laboratory model studies and field control observations, because it is unlikely that a suitable amount of data on the desired range of geometric configurations could be found in the field. Thus a first priority would be the selection of modeling techniques. Both wind tunnels and water flumes offer potential tools.

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