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SOME FACTORS AFFECTING DRAINAGE OF MOISTURE FROM WET INSULATION IN FLAT ROOFS

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RÉSUMÉ

Les ruptures de toits sont plus souvent dues aux amoncellements de neige qu'aux surcharges de neige uniformément réparties. Les codes et les normes, en particulier la Norme A58 de l'American National Standards Institute et le Code national du bâtiment du Canada, contiennent des directives pour estimer les surcharges de neige sur les structures. Une bonne connaissance de la mécanique des fluides élémentaire et de phénomènes d'accumulation de la neige permet à l'ingénieur de prévoir les zones potentielles de forte surcharge de neige dans des situations non prévues par les codes. Cette étude fournit plusieurs principes de base, des exemples d'écoulement d'air autour des structures conventionnelles et les zones d'accumulation de la neige. Dans des cas compliqués on peut obtenir des renseignements qualitatifs sur l'accumulation de la neige au moyen de modèles. (Présentation des avantages et des limitations de cette méthode).

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Some Factors Affecting Drainage of Moisture from Wet Insulation in Flat Roofs

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ABSTRACT: Moisture often finds its way into flat roofs where it causes a reduction in the thermal resistance of the insulations and sometimes leads to the destruction of the roofing system. Various methods for removing moisture have been studied, but effective drying is usually difficult to achieve because the natural forces acting to remove moisture are small.

Some moisture may be drained from wet roofs, but because the slope is small or nonexistent and absorptive forces tend to retain moisture it is not usually an effective method. If the retentive forces can be overcome, however, drainage rates can be substantially increased.

In one outdoor study carried out on an experimental roof deck with 2 percent slope glass fiber, perlite-fiber, and wood fiber insulations were found to drain very slowly. Of the moisture contained in the insulation at the outset less than 25 percent drained out in the first 4 months of test.

In a second, laboratory study tests were carried out on a deck 2.4 m long with slopes of 2, 4, and 8 percent using a variety of underlays beneath wet glass fiber insulation. Drainage was slow when a plastic sheet underlay was used, but rates were higher with soil and vermiculite-asphalt underlays. The fourth underlay, polyester fabric, produced drainage rates that varied with deck, slope, and length of flap allowed to hang down at the end of the deck. This flap provides a suction force that increases the rate of moisture flow. As an example, moisture content was reduced from over 70 percent to less than 5 percent by volume in a period of 4 days with a slope of 2 percent and a 75 mm flap.

KEY WORDS: wet insulation, flat roofs, drainage, drying, thermal insulation, moisture

Moisture attack represents one of the chief threats to the proper performance of flat roofs. Dripping often provides the first indication that water

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has entered the roof system of a building, either in the form of water vapor from inside or as leakage water resulting from failure of the roofing membrane. In some cases the roof may remain wet without causing interior problems; if there is an effective vapor retarder the water may be trapped within the roof components. In this case its effect will not be so obvious, but it will cause an increase in the rate of heat transfer and may contribute to the eventual destruction of the roofing system.

One normally speaks of the need to keep roof systems dry. The problem might best be regarded as one of maintaining an acceptable moisture level or moisture balance, recognizing that gains are likely to occur at some time; they will cause a minimum of difficulty if they can be offset by moisture removal that maintains the moisture content at an acceptably low level.

Rational treatment of the question depends on consideration of the forces that act on moisture (both vapor and liquid) in flat roofs and the effect they have on its accumulation, retention, or removal. The forces may be described as due to vapor pressure, wicking, or absorption and gravity. By its nature the construction of a flat roof tends to favor accumulation and retention of moisture, providing little opportunity for these forces to cause it to escape.

For this analysis the roof can be considered to have two important dimensions: its thickness from top to bottom and its lateral dimensions, that is, the distance from any point in the roof to the edges or other points at which moisture can escape. This second dimension is made up of two components—horizontal and vertical. The size of the vertical component depends on the slope and represents the distance through which gravity force can act (Fig. 1).

Vapor pressure differences in the roof result from temperature gradients through it. In winter they tend to move moisture upward; in summer, with the effect of the sun on the roof membrane, the moisture tends to move downward. Upward escape, however, is prevented by the roof membrane and downward escape by the vapor retarder, if present. Vapor pressure differences have very little effect in moving moisture laterally. Further, the distance to an exit is long and paths available for vapor flow are of limited size.

Wicking forces may exist in some organic fibrous and fine-pored insulations, but are almost absent in mineral fiber and closed-cell plastic insulations. The value of wicking as a drying force is doubtful since, on balance, it

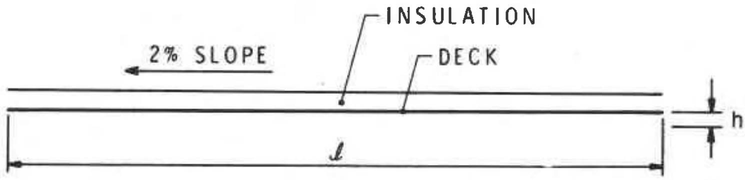

FIG. 1—*Sketch of flat roof system (to scale) showing relative sizes of horizontal distance* (l), *vertical fall* (h).

is more likely to contribute to retention of moisture than to its removal from the roof system.

The movement of moisture towards openings as a function of gravity can be regarded as acting in two steps. Moisture moves downward through the insulation, collecting at the bottom. From there, if there is no impermeable member, it may drip into the building or evaporate into the air. If the process can be prolonged the insulation may become dry, but it may inconvenience the occupants below.

If there is an impermeable member beneath the insulation, the water will collect on it or adhere to the bottom surface of the insulation. Forces for further movement by gravity are absent if the roof is absolutely flat and very limited even if there is some slope to a drain. Any gravity forces must overcome adhesive forces between the water and the roofing components, including wicking, and any unevenness of the surface will constitute a barrier to a liquid flow.

Past observations suggest that drying of roof insulation by forces normally active in roofs is, at best, a slow process. Many who have used them (though not all) have concluded that venting of flat roofs has little beneficial effect in removing moisture by vapor flow. This was the conclusion drawn from work at the Prairie Regional Station in Saskatoon, Sask., Canada, when wet insulation was sealed in polyethylene, placed in experimental roof panels 600 by 1200 by 50 mm, and provided with a vent at the middle of each panel so that vapor could escape. The insulation was weighed periodically. The results in Fig. 2 indicate that after almost 6 years several that had started with low moisture contents were nearly dry but that two were still quite wet. The small slopes indicate a slow removal of moisture.

Measurements of Drainage Rates

Two sets of measurements on moisture removal by drainage have been carried out at the Prairie Regional Station, Division of Building Research.

Field Test

One set of measurements was carried out at the outdoor test facility. An experimental roof deck with a 2 percent slope was maintained at about 21°C. Three kinds of insulation were used: glass fiber, wood fiber, and perlite-fiber. Two 1220 by 2440 mm panels of each insulation were prepared, the insulation pieces arranged on a large sheet of 0.15-mm-thick polyethylene sheet, which was folded over the insulation and sealed. Two arrangements were used for each insulation. In one, the insulation rested directly on the polyethylene; in the other, spacers were placed on the polyethylene to provide a 6-mm gap between the insulation and the underlying polyethylene.

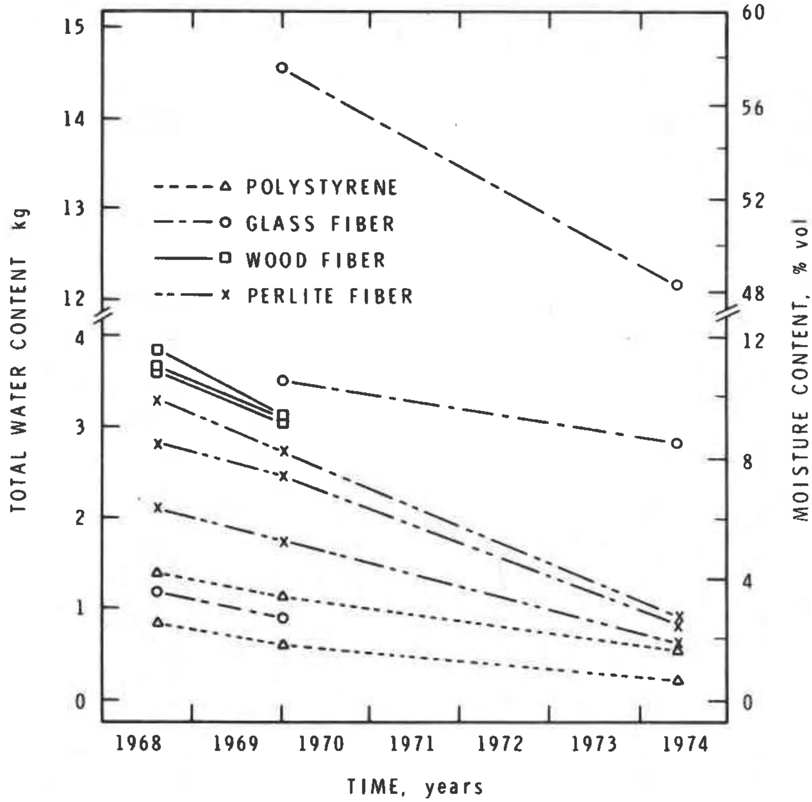

FIG. 2—*Total moisture in vented panels.*

The insulations were wetted before sealing. The panels contained the following amount of water: perlite-fiber (6-mm space) 24 kg, (no space) 20 kg; glass fiber (6-mm space) 23 kg, (no space) 23 kg; and wood fiber (6-mm space) 34 kg, (no space) 30 kg.

All of the water that drained from the insulation was collected at the bottom of the slope and weighed (Fig. 3). Rates of drainage differed considerably. There was between 3 and 4 kg of water from the glass fiber and the wood fiber over a 4-month summer period, but the rates lessened thereafter. Rates of drainage were substantially smaller for the other panels.

The test extended over a period of nearly 5 years, and was somewhat rough in that amounts of moisture differed considerably at the outset. In all cases only a small fraction of it was removed by drainage. Final measurements of moisture content, based on weighing the insulations at the conclusion of the test, revealed that some moisture had been lost in ways other than drainage, for example, through leakage of vapor, faults in the seal, and permeation

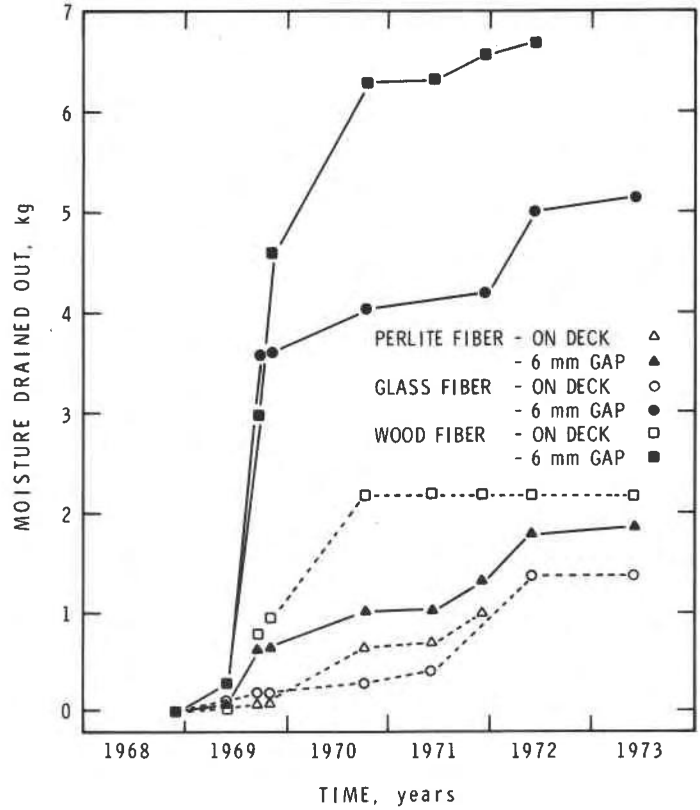

FIG. 3—*Amount of water drained from three insulations on a concrete slab at 21°C with a 2 percent slope.*

through the polyethylene. In any case the moisture contents exceeded 10 percent by volume at the end of the test, indicating that drainage did not stop for lack of moisture and was not a very effective way of drying the insulation.

Laboratory Studies

In the field test the underlay material was polyethylene. In most roofs it would be one of a number of materials used for vapor retarders on the roof deck. None has properties that promote drainage. A laboratory study therefore was carried out to assess the relative effects of several underlay materials in transporting water laterally along the bottom of the insulation to an exit.

A panel 1220 by 2440 mm was constructed and mounted on an axis so that its slope in the long direction could be adjusted as required (Fig. 4). The panel was divided lengthwise into four sections and a different underlay material placed in each. These were a 25-mm layer of an asphalt-vermiculite

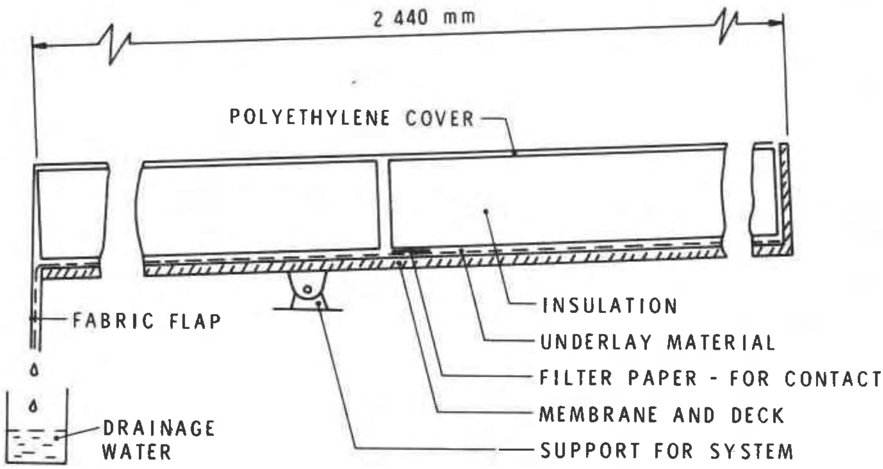

FIG. 4—*Drainage panel for laboratory study. Fabric flap and filter paper contact were not used in first series of tests. (Vermiculite-asphalt, butyl rubber, and black soil also were used as underlays.)*

mixture, a 25-mm layer of soil, a butyl membrane, and a sheet of polyester fabric that terminated at the bottom of the slope.

The object of the work was to study the principles involved in moving water substantial distances when there is little or no slope. The underlay materials were selected without considering the practical questions regarding their application in flat roofs as they are constructed normally.

Four sections of rigid glass fiber insulations each 270 by 600 by 50 mm thick were placed on each type of underlay. Glass fiber retains water but does not hold it very strongly. It is probable that this method would not be very successful in removing water from insulations with much stronger absorptive forces than glass fiber. On the other hand, if water lies in butt joints and other spaces, as may be the case with closed cell insulations, removal would be relatively easy.

Water was added to the glass fiber to bring its moisture contents up to 80 percent by volume at the beginning of each run. Runs were made with slopes of 2, 4, and 8 percent. The water flowing out at the lower end of each section was captured and weighed. Individual insulation specimens also were weighed periodically. The average moisture contents for each set were calculated and plotted against time (Figs. 5, 6, 7, and 8).

After 36 days the moisture content of the insulation on polyester, asphalt-vermiculite, and soil on 2 percent slope was still about 20 percent by volume. That of the insulation on a butyl underlay was over 30 percent for the same slope. Moisture contents were lower in each case for an 8 percent slope than for the 2 percent slope.

The position of the insulation section affected its rate of moisture loss. The

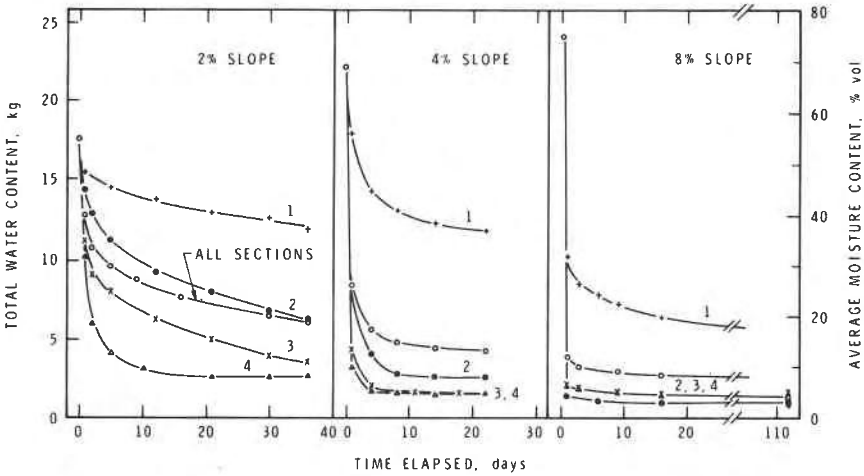

FIG. 5—*Drainage with polyester fabric underlay with 2, 4, and 8 percent slopes. Moisture contents given for each section, numbered from 1 at bottom of slope. Open circles denote all sections.*

specimens farthest down the slope usually lost moisture at the slowest rate. This effect was most marked for the fabric underlay; its effect on the moisture contents of the individual sections of insulations is shown in Fig. 5. At 2 percent slope the loss from the lowest section was very slow, nearly 40 percent moisture being retained after 35 days. The other sections lost weight more rapidly, but even the topmost section had 8 percent moisture after 35 days. For 4 percent slope the drainage from all but the bottom section was more rapid. At 8 percent slope the moisture content of the top three sections reached 5 percent within 1 day. The lowest section lagged behind, but had reached 5 percent moisture after 110 days.

It appears that with these arrangements the moisture is held by absorptive forces and prevented from escaping from the lowest section. In subsequent tests, done mainly with polyester fabric, the fabric underlay was extended beyond the end of the test bed and allowed to hang down. This can be expected to exert a suction effect and partly offset the retention forces that otherwise would prevent water from escaping.

Glass fiber insulation has some ability to retain liquids against the force of gravity. The force of retention is small, however, and can be overcome by certain underlay materials wherever the two make contact. If the specimen or underlay is uneven, the former may be supported toward its middle and the lower part, cantilevered above the underlay, may trap water. To avoid this event, a 50-mm-wide piece of 1-mm-thick filter paper was placed under the bottom edge of each glass fiber piece in some tests to ensure contact at that point (Fig. 4).

Figure 9 shows moisture content versus time for a run with a 2 percent

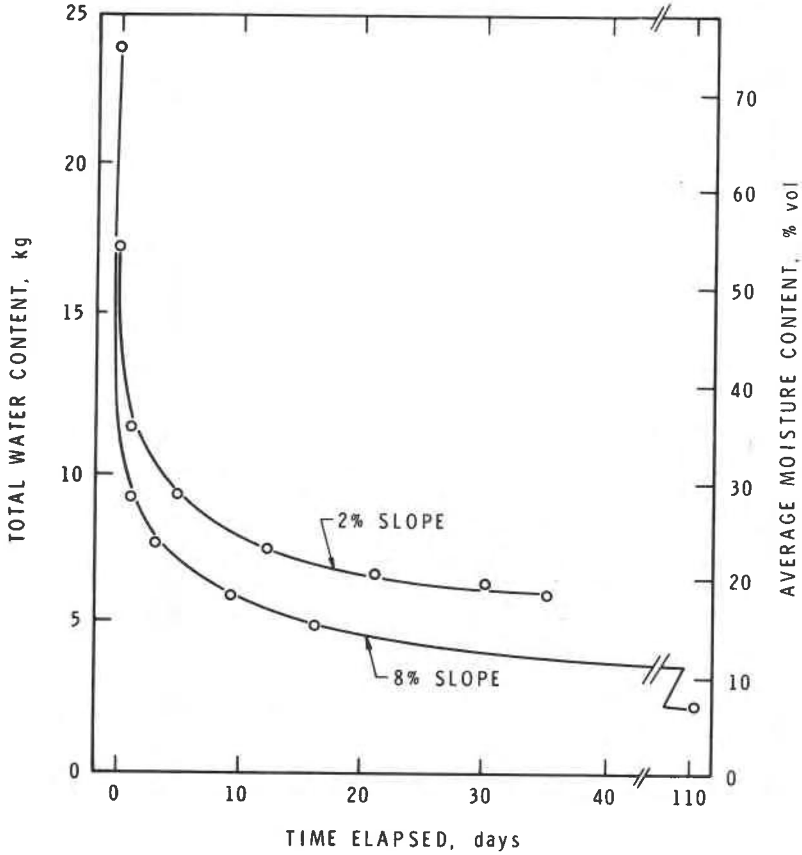

FIG. 6—*Drainage with vermiculite-asphalt mix underlay.*

slope and a 75-mm flap. The results are typical for tests made under these conditions. Rates of flow varied, with moisture contents of about 5 percent reached in 4 days.

The effect of suction for a deck slope of 2 percent is illustrated in Fig. 10, which shows water flow rates for flap lengths ranging from 30 to 300 mm. All values were obtained while the moisture content of the insulation was above 30 percent by volume. Rates of flow ranged from a low of about 1 kg to over 4 kg/h. Rates are affected by a variety of other factors and these values should be regarded as illustrative of the suction effect, which at other times might produce substantially different results under nominally the same conditions.

Probably more important than an accurate measure of flow rate is the moisture content reached within the first few days. It appeared to be affected by flap length. This is illustrated in Fig. 11, where the first part of the run was done with no flap and the moisture content fell to about 14 kg in 6 days.

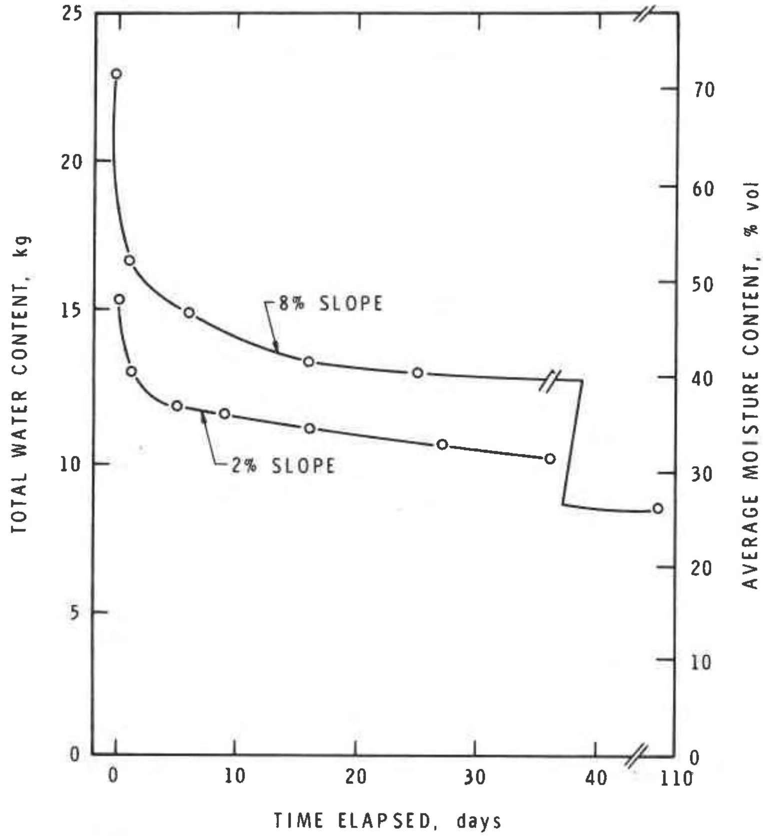

FIG. 7—*Drainage with butyl rubber underlay.*

When a 75-mm flap was attached, flow resumed and the water content was reduced to 2.6 kg in the next 3 days. This pattern was repeated in other runs, with up to 20 kg remaining if no flap was used but only 1 to 2.5 kg if a flap 75 mm or longer was used.

The foregoing tests were made with high initial moisture contents, which may produce conditions that favor rapid moisture removal. In a single test at 2 percent slope and starting with dry fabric, all of the insulation sections were left dry except for the topmost one, which was wetted to about 30 percent by volume (2.4 kg). Approximately 30 h elapsed before moisture began to drip out of the system. A total of about 1.05 kg was removed in this way; 0.75 kg remained in the wetted section and the remainder was in the fabric 5 days after the start of the test.

The reason for introducing a drainage layer would be to improve the overall thermal performance of the roof system. It should be noted that the drainage layer becomes part of the system and its thermal conductivity may

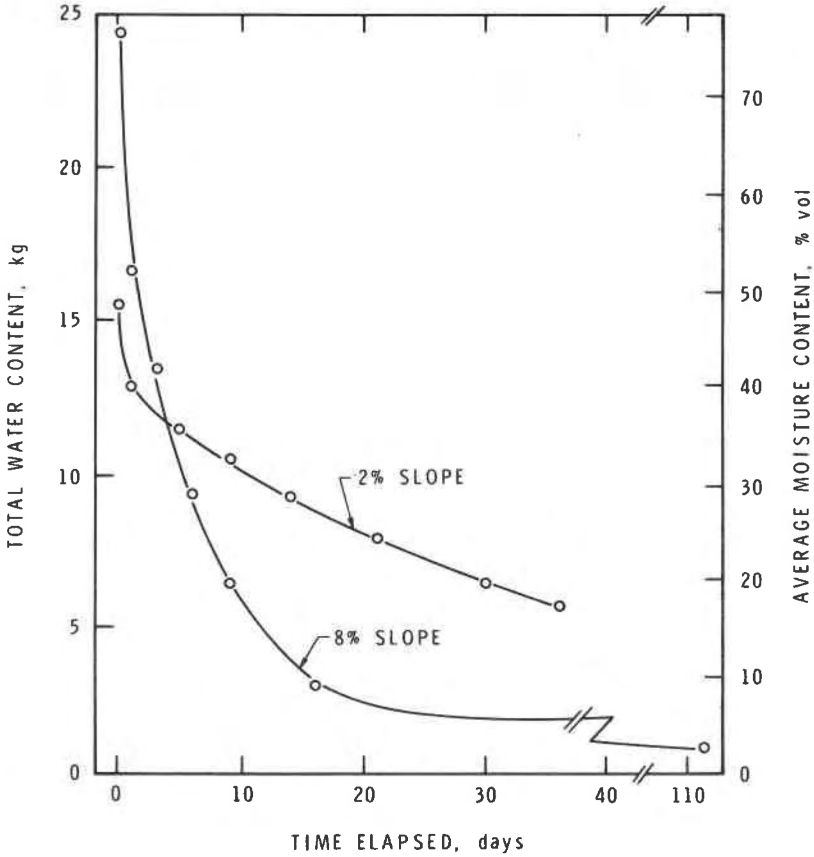

FIG. 8—*Drainage with 25-mm soil underlay.*

play a part; if it is dry it will add to the thermal resistance, if it is wet it could increase lateral heat flow to butt joints, thus having an undesirable effect.

Summary and Conclusions

If moisture enters conventional flat roofs, the natural forces tending to remove it may be ineffective either because they are too small or because they do not act in the direction that produces drying. Thus, even with fairly low rates of gain the moisture balance may reach undesirably high levels. This study has concentrated on the effects of slope and underlay material on drainage of moisture from insulation placed on low slopes.

1. Tests run with 1220 by 2440-mm panels and 2 percent slope indicated that a 6-mm space beneath the insulation will result in an increased rate of flow. Weighing of individual insulation pieces showed that moisture had

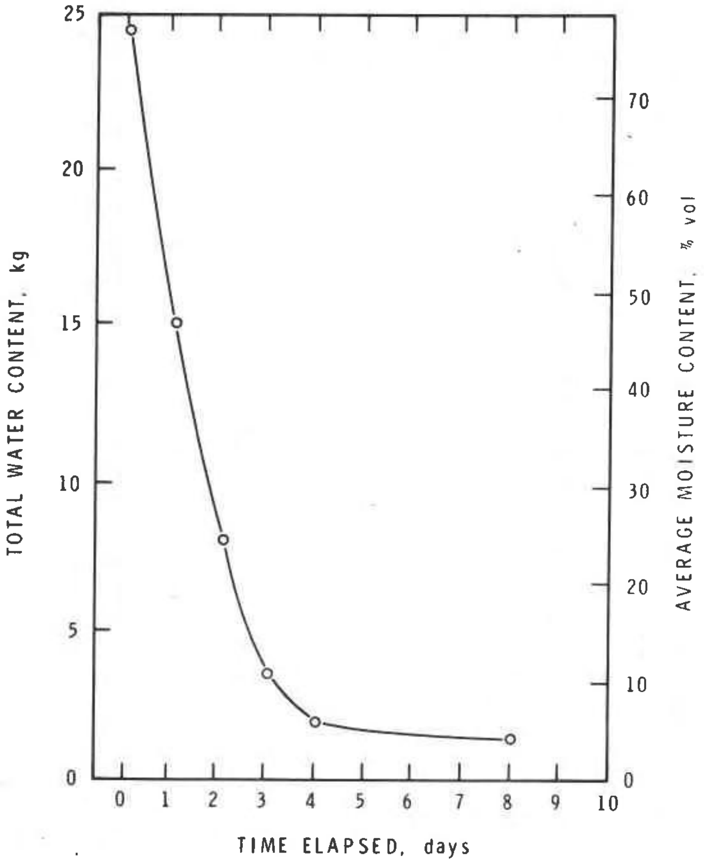

FIG. 9—*Average moisture content and total water content remaining in insulation versus time elapsed from start of test (2 percent slope and 75-mm flap).*

moved down the slope to accumulate in the section at the bottom. The amount of moisture drained from the panels ranged from about 1.4 to 6.8 kg, but in all cases substantial amounts of moisture remained in the insulation.

2. Laboratory tests were run using 270 by 2440-mm areas at slopes ranging up to 8 percent, with most at 2 percent slope. In one series of tests four different underlay materials were used to assess their effect on drainage rates. The slowest movement occurred with a butyl rubber underlay. Slope of the deck had a significant effect on drainage rate, that for an 8 percent slope being much more rapid and bringing insulation down to lower moisture contents than for 4 or 2 percent slopes.

3. The majority of the work was carried out with polyester fabric as the underlay material. With a 2 percent slope, moisture contents of glass fiber insulation could be brought from 70 percent moisture content by volume

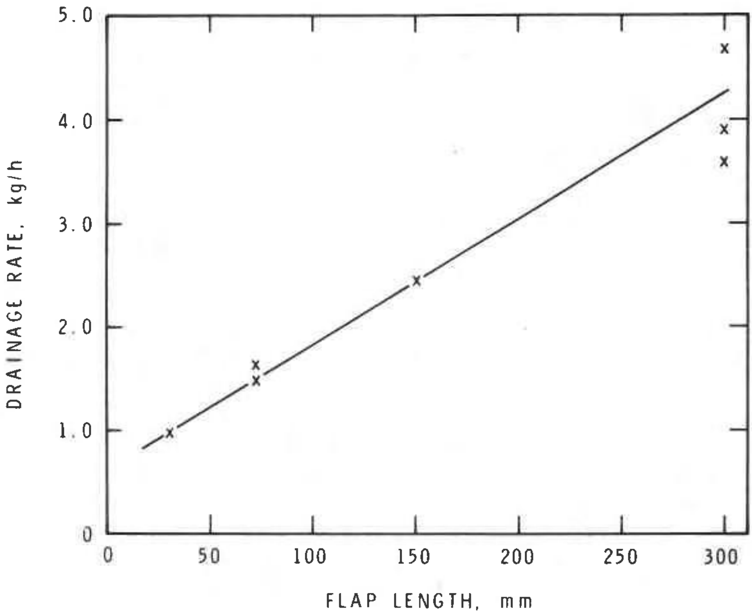

FIG. 10—*Rate of drainage versus flap length.*

down to approximately 5 percent in about 4 days. It was necessary to ensure that a continuous drainage path existed so that the water would not be trapped in the insulation. This included a flap of fabric at the bottom of the slope to apply a small amount of suction to the system (Fig. 4).

4. Glass fiber insulation was used in the tests, since it represents insulation with the ability to hold moisture, though with a weak absorptive effect. It would be expected that drainage could be obtained in roofing systems with closed cell insulations since they would exert only small forces to retain the moisture. For insulations with stronger absorptive or wicking properties the value of underlay materials in promoting drainage would probably be less successful.

5. Practical application of under-drainage for moisture removal requires design and construction techniques that will not result in damage to the material or impede the flow of water to it.

6. In the present experiments the moisture content of the glass fiber insulation could be drawn down to about 5 percent by volume in some cases. In others, where conditions were less favorable, the moisture probably would be removed, although at a slow rate. Even a 5 percent moisture content produces a significant decrease in the thermal resistance of insulation, and it cannot be considered dry.

7. The polyester fabric promotes moisture movement from wet areas, but with local wetting it could transport some moisture into previously dry areas.

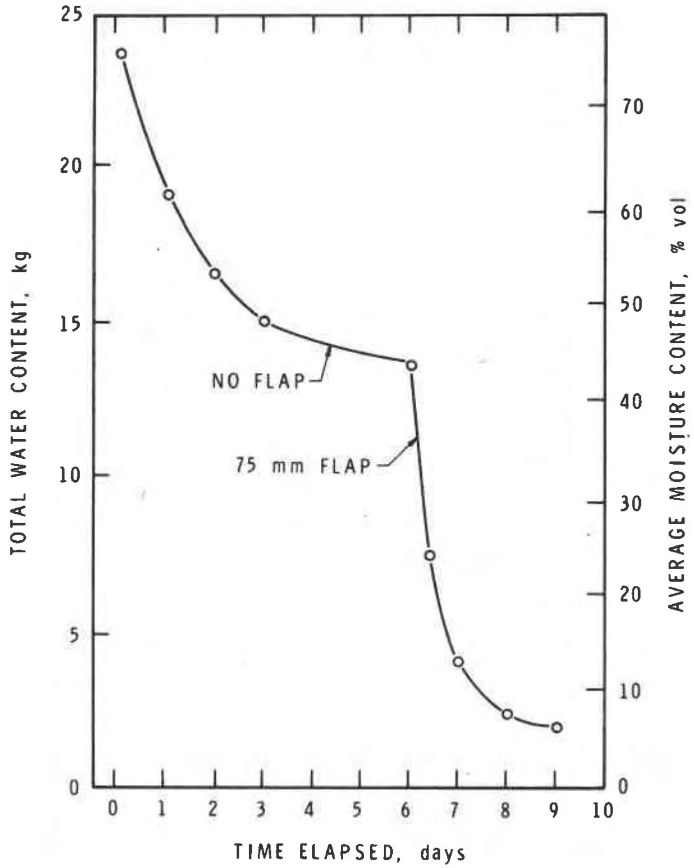

FIG. 11—*Average moisture content and total water remaining in insulation versus time elapsed from start of test. No flap used for first 6 days, 75-mm flap thereafter.*

In the test on local wetting reported previously, a substantial amount of moisture was drained from the system. A part of it, however, was retained in fabric that had been dry at the outset: for example, on the slope below the wetted section of insulation. In a practical situation it might move from there into the overlying insulation in a vapor-condensation mode.

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