PROTECTED MEMBRANE FLAT ROOFS

G. Christensen

ABSTRACT

Protected membrane flat roofs have been used for a number of years with foamed plastics mainly used as insulation materials. However, materials such as mineral wool are possible insulations to use in such roofs. Insulation systems based on both groups of materials can be used for new buildings, or as for additional insulation of existing flat roofs.

In a test house at the Danish Building Research Institute, the thermal resistance of four different insulation materials was measured when exposed to the natural climate during a winter period. For these measurements two plastic foam insulation materials were used and two types of mineral wool. The results for both types of materials showed a better thermal performance than previously assumed for such roofs. It should be mentioned that the winter climate in Denmark is not very different from that of the New England states in the U.S.

The test roof arrangement and the measurements are described as well as the results where these materials were used in the same thickness as traditional warm roofs in the test house.

INTRODUCTION

Protected membrane flat roofs - PMF-roofs - have been used in the US, Canada, and Europe for a number of years with generally good results. In most cases the insulation material has been a foamed plastic. The experiments reported here had two purposes:

1. To investigate if mineral wool is suitable for use in PMF-roofs.
2. To study the thermal performance of different insulation materials used in PMF-roofs.

G. Christensen, Head of Building Physics Division at the Danish Building Research Institute, Hørsholm, Denmark.

Climatic conditions

The Danish winter weather is fairly wet with long periods of rain and only short periods where the ground is covered with snow. This is a climate that is not the most favorable for the use of a PMF-roof, seen from a thermal insulation point of view. Consequently, it is important to study how much the insulation value of such roofs is influenced by the wet climate. Is is believed that this climate is not very different from that in the New England states of the U.S., or the Maritime Provinces of Canada.

Basic concept

The base concept of the PMF-roof is to protect the roof membrane from the influence of climatic factors such as rain, very high and low temperatures, and UV-radiation. This is achieved by placing the insulation material on top of the roof membrane, thus exposing the insulation material to the climate instead. Comparing this configuration with a traditional warm (unventilated) roof, the roof membrane and the insulation material change place. This kind of roof is also often called an upside down roof or an inverted roof, since the two layers are reversed compared to a traditional warm roof.

When rain falls on the PMF-roof, the major part is drained away from the surface. A small amount penetrates through the joints between the insulation boards and is directed to a drain in the protected roof membrane.

The small amounts of moisture that are trapped in the insulation material or the joints between the insulation boards will evaporate sooner or later, due to the heat flow going from the interior to the exterior in the roof. In a way this situation can be compared with the fur on animals. The fur is not watertight and the moisture penetrating the outer layers of the fur will evaporate due to the body heat from the animal. In Figures 1a and 1b are shown the principles of the PMF-roof and the warm roof. These two types of roofs were compared in this study.

It should be mentioned that it is a clear advantage that the thermal insulation protects the membrane from reaching high temperatures in a PMF-roof. In this way, degradation processes in the organic membrane are slowed down very much. It is also an advantage that a PMF-roof protects the membrane from low temperatures thus minimizing the risk of thermal shock and thermal stress caused by wide swings in temperature. In Figure 2 typical temperature variations are shown, as well as a typical day in the roofing membrane for each type of roof under Danish climatic conditions.

The primary aim of the investigation was to study the difference in thermal resistance (hereafter called insulance for brevity) between warm roofs and PMF-roofs built as identically as possible. This comparison was made for plastic foams as well as for mineral wools.

Cooperation

The tests were carried out in cooperation among a number of producers of insulation materials, the Danish roofing industry, and a consulting engineering firm. The tests were carried out on a building within the premises of the Danish Building Research Institute. Here, the test roofs were placed on the building exposed to the natural climate. Data acquisition and processing systems were available for making many temperature measurements and calculating the insulance of the different roofing systems.

THE TEST HOUSE

The test house had a roof area = 77.8 m^2 (7.20 m x 10.8 m), which consisted of 8 warm roofs and 8 PMF-roofs constructed as identically as possible. In order to study the effect of shading, half of the roofs were protected from direct radiation by means of a special shading arrangement, which allowed the rain to fall on the roof. All roof surfaces had a slope of 1:40 and all results are thus only valid for this particular slope. The lightweight load-bearing construction was built from wood joists and plywood as shown in Figure 3. On top of the plywood was placed a bituminous roofing membrane, PF 2000. Above this was placed a 45 mm PIR insulation material which was covered with two layers of bituminous roofing of the types PF 2000 and PF 4000. The letters PF stand for polyester reinforcement and the number shows the total weight in grams per square meter of the membrane. The top membrane, PF 4000, acts as support for the insulating material in the PMF-roof and is consequently also the water tight layer in the roof.

From previous experience, it was known that the insulance would be reduced when joints between the boards are placed directly above the thermocouples. Consequently, measurements were made under the joints between the insulation boards as well as in areas as far from the joints as possible. These two areas are called (for brevity) areas "with joints" and "without joints." In Figure 4 a plan of the roof is shown with a cross section showing the shading arrangement.

Materials

Four different insulation materials were placed on the roof as warm roofs or as PMF-roofs. The materials were:

1. Extruded polystyrene (EPS) (33 kg/m^3)
2. Rockwool (150 kg/m^3)
3. Glasswool (80 kg/m^3)
4. Polyisocyanurate (PIR) (36 kg/m^3).

Measurements

All the test roofs were built on top of a "base insulation" acting as a heat-flow meter. This base insulation could also be considered as the existing insulation if the new insulation systems were used to improve the insulance of an existing roof. The base insulation consists of 45 mm PIR plastic foam material, and the thermal conductivity of this material was established at different temperatures with a very high degree of accuracy in the thermal insulation laboratory of the Technical University of Denmark. Five thermocouples (Cu-Cn) were placed on both sides of the measuring areas having a dimension of 0.5 m x 0.5 m. In this way heat-flow meters are established. The areas where these heat-flow meters were placed are also shown in Figure 4. It should be noted that it was attempted to reach similar U-values for all test areas, and the target was 0.2 W/m^2C, which is a building code requirement for new roofs.

The air temperature on the north side of the building and the temperature at the bottom of the insulation material being tested were also used for the calculations. When the surface temperature of the exposed insulation material is not used it is because this temperature at that place may fluctuate in a very uncontrolled way due to ponding on the roof. It should be noted that no attempt was made to study the moisture content in the insulation materials.

The measurements were carried out during a period of 178 days in the winter of 1983-84 and were repeated during periods of the next winter in order to see if long-term effects could be detected. This was not found to be the case.

Calculations

In Figure 5 the location of the temperature points used for the calculations are shown. Values for t_u, t_1-t_2, and t_1 are automatically recorded as mean values during one hour. The value t_1 is based on a single measurement in the middle of the measurement area, while t_1-t_2 are mean values from the five measurement points as shown in Figure 5. As mentioned above, t_u is the air temperature (shielded) measured on the north side of the building. The same t_u is used for the calculation of the insulances for all areas.

The insulance of the insulation materials placed on top of the base insulation may be calculated from the following expression:

$$m_{insul} = m_{base} \times \frac{\Delta T}{\Delta t} - m_{base} - m_u - m_{memb} \tag{1}$$

where $\Delta T = t_1-t_u$ and $\Delta t = t_1-t_2$ and

$$m_{base} = \frac{d_{base}}{\lambda_{base}} \tag{2}$$

where d_{base} = 45 mm and λ_{base} is the thermal conductivity W/m °C.

λ_{base} is the thermal conductivity of the base insulation (t_m) and is calculated on the basis of λ_{20} and λ_{10}.

λ_{base} is calculated from the following expression:

$$\lambda_{base} = \lambda_{20} - (\lambda_{20} - \lambda_{10})\ (20 - t_m):10 \tag{3}$$

where

$$\left.\begin{array}{l}\lambda_{20} = 24.9 \times 10^{-3}\ W/m^{o}C \\ \\ \lambda_{10} = 23.0 \times 10^{-3}\ W/m^{o}C\end{array}\right\} \text{ } \lambda_{20} \text{ resp. } \lambda_{10} \text{ are averages from seven calibration measurements}$$

The following insulances are considered as constants:

$m_u = 0.1\ m^2\ {}^oC/W$ (exterior surface insulance)

$m_{memb} = 0.04\ m^2\ {}^oC/W$ (roofing membrane)

When inserting in Equation (1) the insulance of the tested insulation materials becomes

$$m_{insul} = \left[\frac{45}{24.9 - 0.19\ (20-t_m)} \times \left(\frac{\Delta T}{\Delta t} - 1\right) - 0.14\right] m^2\ {}^oC/W \qquad (4)$$

RESULTS AND DISCUSSION

In Figures 6-9 results are shown from the measurements taken during the winter of 1983-84. It can be seen that the insulances of the PMF-roofs are reduced 5%-24% compared to similar warm roofs. However, the areas "without joints" show small reductions of insulance. It was expected that the insulances were reduced in the shaded roof areas because drying conditions were less favorable. This theory was not confirmed, since the values from both areas were about the same. The reason is believed to be that the shading arrangement acts as a shield toward radiation to the sky, thus acting as a kind of "additional insulation" that counteracts the effect of a higher moisture content in the insulation material.

CONCLUSION

Measurements on a number of PMF-roofs have shown that the reduction in insulance compared to warm roofs, is much less than the 30% previously assumed under Danish climatic conditions. It has also been shown (rather surprisingly) that open-pored materials such as mineral wool are also suitable as insulation materials in PMF-roofs. It should be mentioned that other experiments have shown that such open-pored materials do not need a ballast to prevent uplift from the wind. It must be emphasized that for the test roofs a slope of 1:40 was providing good drainage, both from the top surface as well as for the protected membrane under the insulation material. The same positive result is not expected from horizontal roofs or roofs where ponding will often occur.

REFERENCES

Christensen, G.; Prebensen, K.; Vesterløkke, M. 1984. "Warm roofs and PMF-roofs." COWIconsult report 492 (in Danish).

Heirsted, T.; Nielsen, A.; Poulsen, E. 1984. "Upside down roofs." TFP-report. Norwegian Building Research Institute, Trondheim, Norway (in Norwegian).

PMF-roof. 1984. Norwegian Building Research Institute. Building Detail Sheet (in Norwegian).

Petersson, B.Å. 1980. Publication 8:6. "Upside down roofs." Chalmers Tekniska Högskola, Gothenburg, Sweden (in English).

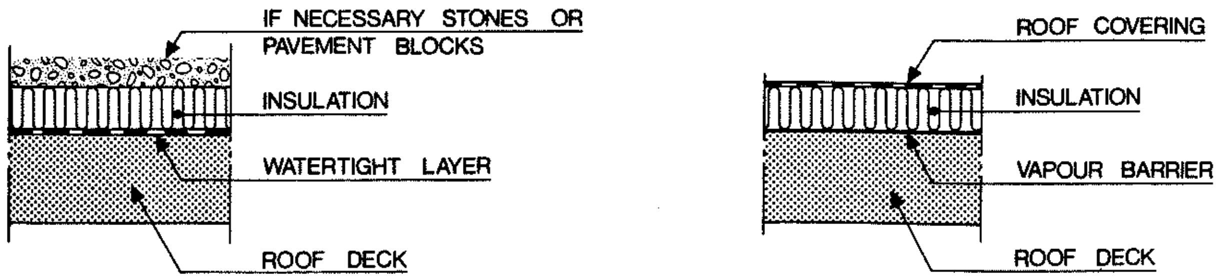

Figure 1. Example on PMF roof (left) and warm roof (right)

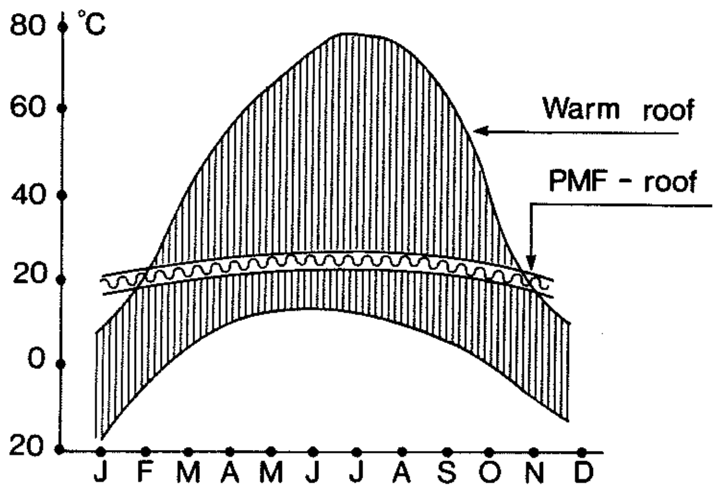

Figure 2. Temperature variations in watertight layers for the two types of roofs

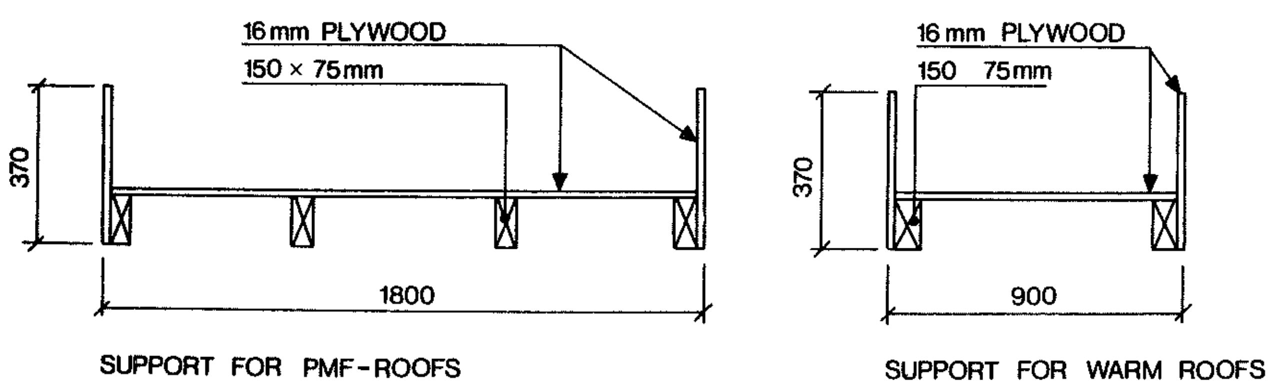

Figure 3. Cross section of supporting roof structure

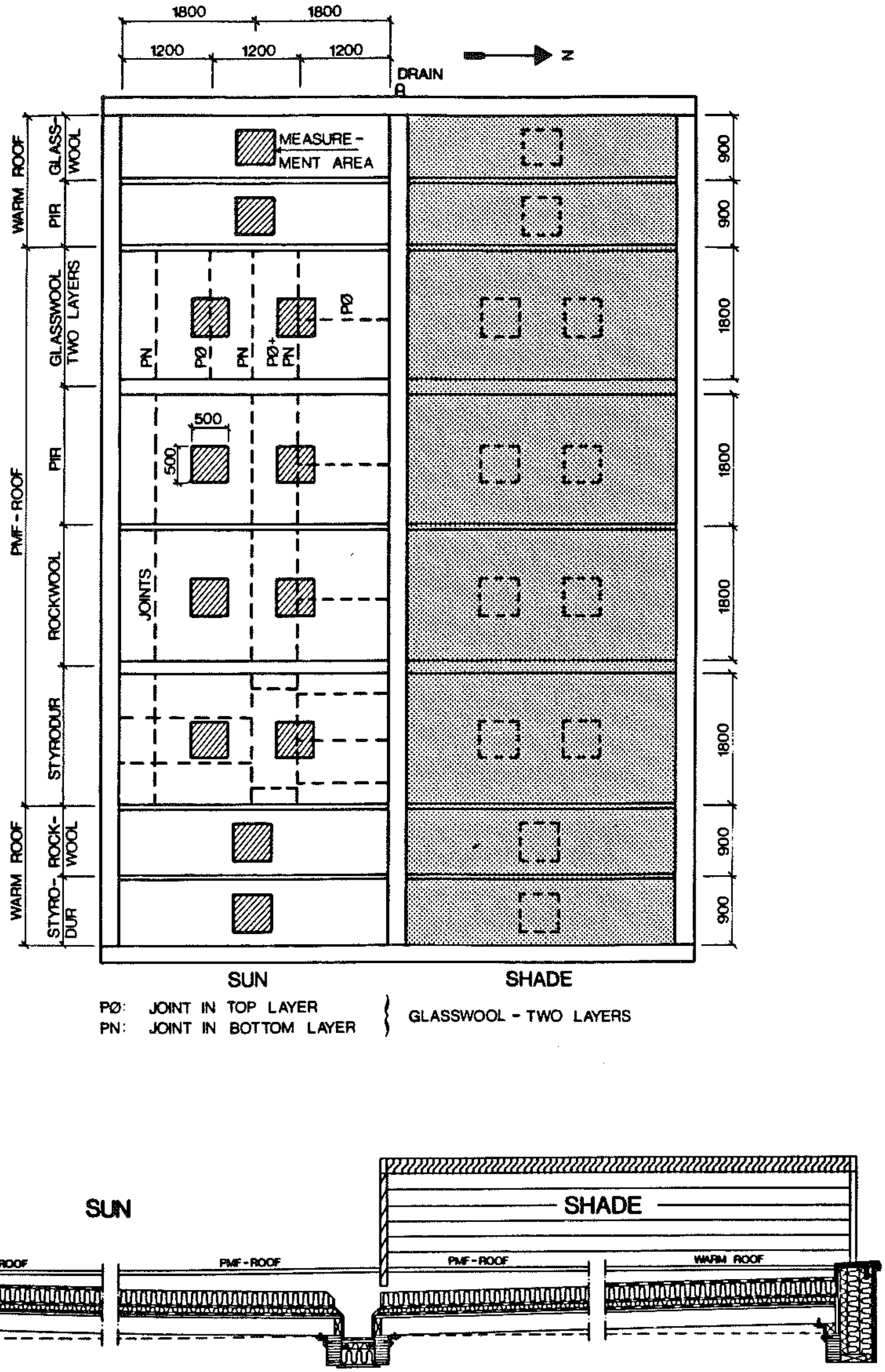

Figure 4. Plan and section of test roof

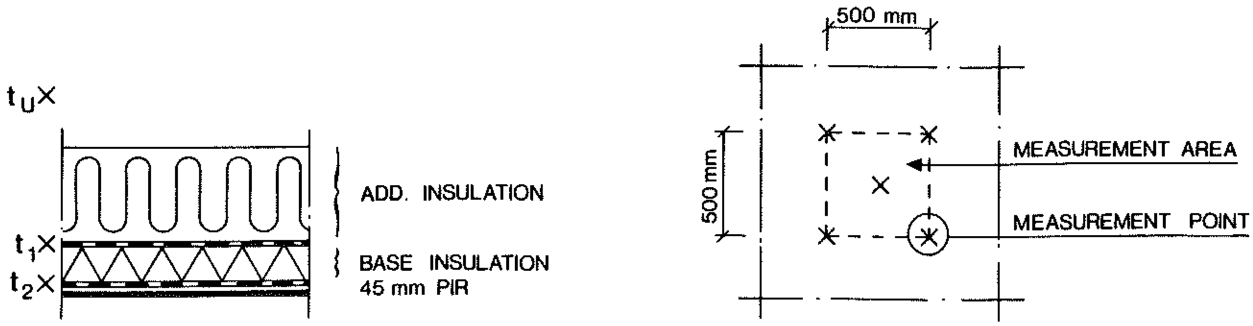

Figure 5. Location of temperature measurements

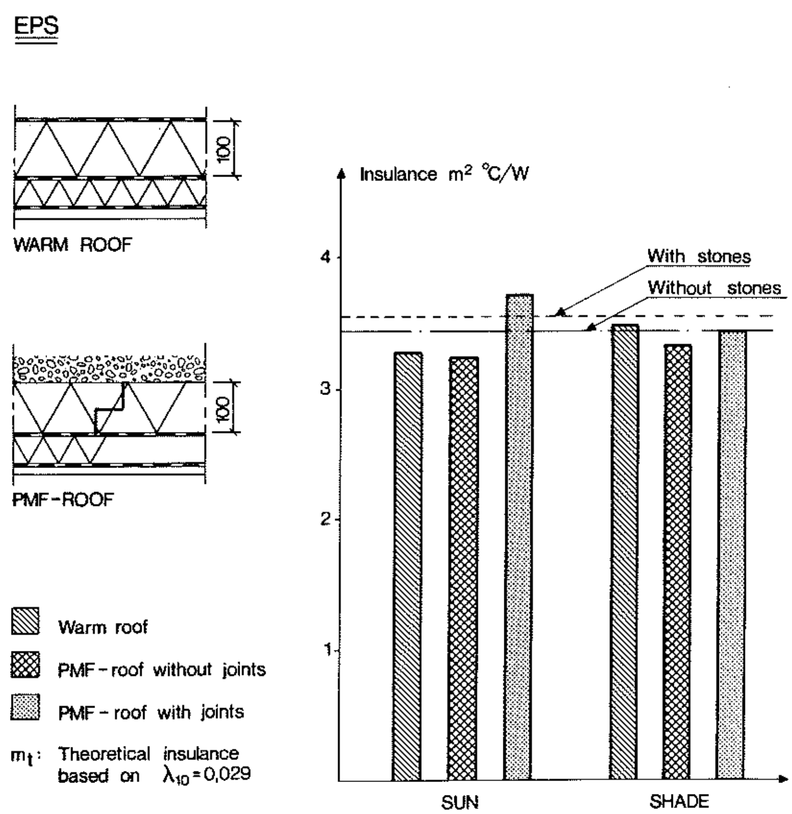

Figure 6. Extruded polystyrene, test results as an average over 178 days

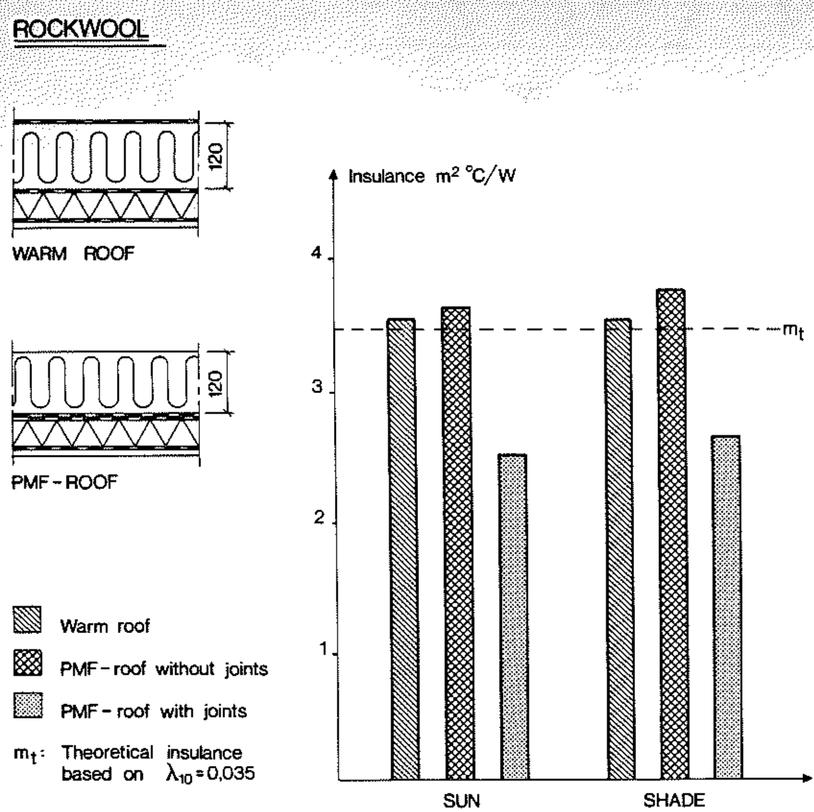

Figure 7. Rockwool, test results as an average over 178 days

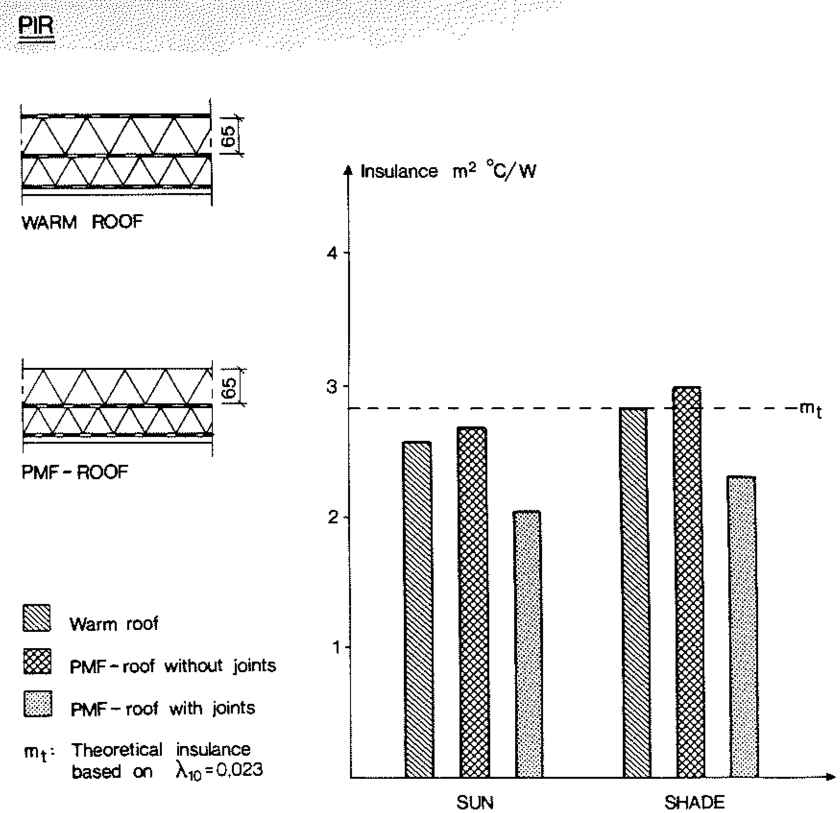

Figure 8. PIR, test results as an average over 178 days

GLASSWOOL

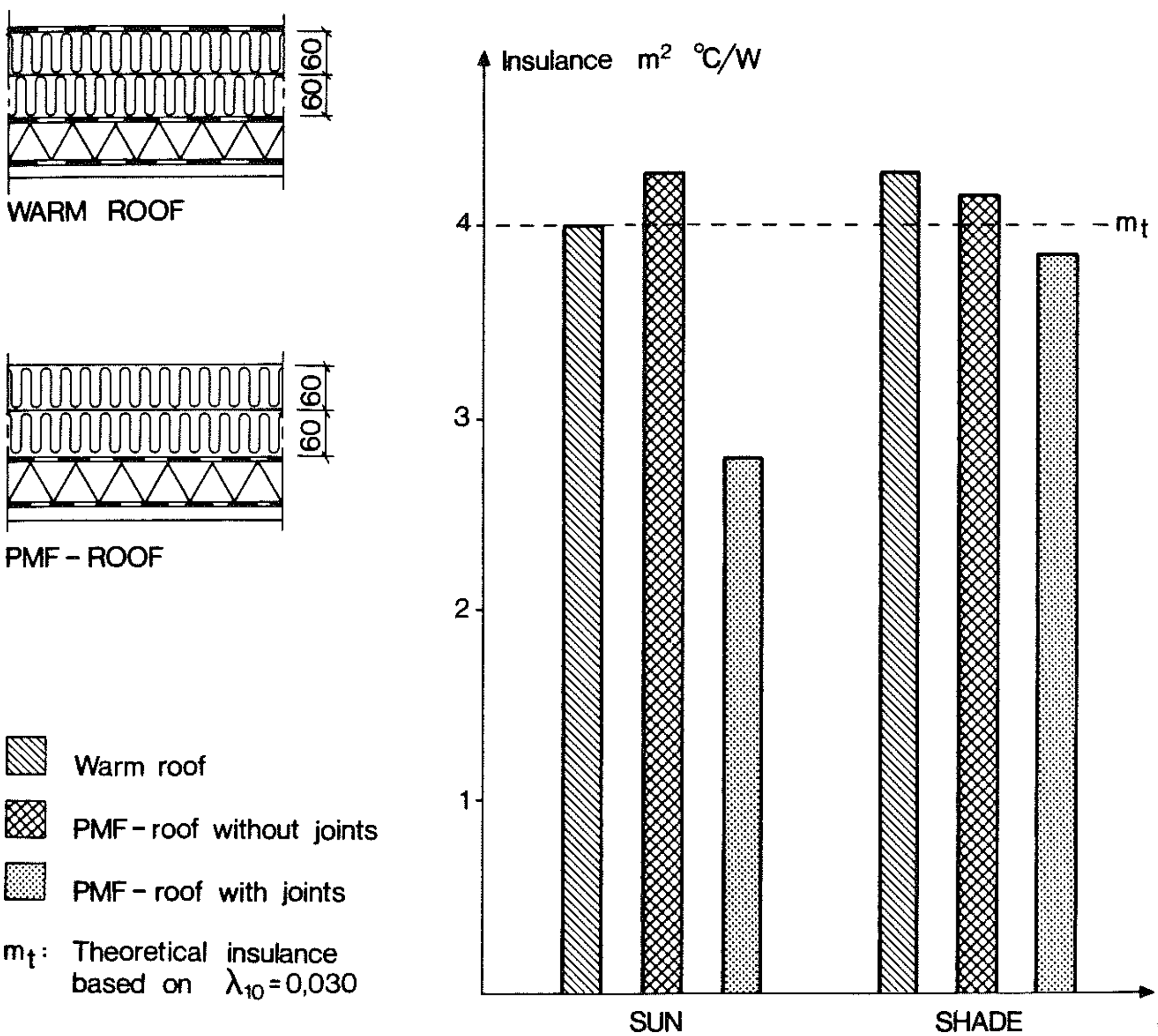

Figure 9. Glasswool, test results as an average over 178 days