Moisture Behaviour of Protected Membrane Roofs with Greenery

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Abstract

Protected membrane roofs have a higher durability than conventional flat roofs because the roof membrane is protected by the insulation layer above. But the insulation material must fulfill special requirements due to the direct exposure to precipitation water. However, to stay sufficiently dry over a long period of time the insulation should undergo a drying process in summer. This process is influenced by the moisture behaviour of the layers above the insulation. Therefore the moisture conditions on top of the insulation slabs have been examined in different roof assemblies with the aid of temperature and dew-point sensors. The results show that conditions stay very moist beneath cover layers with greenery, while the widely used gravel cover dries out completely during spells without rain. Therefore, a long-term moisture accumulation in the insulation has to be taken into account when water retaining cover layers are used for protected membrane roofs. In contrast to a damaged conventional roof soaked with water the water content of such a protected membrane roof and its effect on thermal insulation is calculable and can be accounted for at the design stage.

1. Introduction

Protected membrane roofs, also called inverted roofs because the roof membrane is situated beneath the insulation layer, work well as practical experience over several decades has shown [1]. However, this is true only for inverted roofs with vapour permeable cover layers which show no water retention like gravel or ventilated slabs. If the roof is covered with greenery - an increasing tendency due to micro-climate and ecological aspects - the moisture conditions above the insulation are changed and calculations supported by measurements show that an accumulation of moisture in the insulation layer may result [2]. This accumulation can be explained by the prevailing boundary conditions. Precipitation water which penetrates the insulation leads to a permanent water film beneath the insulation slabs. Therefore the water content of the slabs increases in winter by vapour diffusion and condensation. In summer the condensate can dry out if the layers on top of the insulation are dry. If the summer dry-out is not sufficient a slow moisture accumulation will occur over the years. Fig. 1 shows the calculated [3] moisture behaviour of extruded polystyrene (XPS) slabs with a thickness between 6 and 8 cm depending on the mean relative humidity directly above the insulation layer. In order to avoid long-term moisture accumulation the mean relative humidity there should stay below 90 % in summer. The closer the conditions come to 100 % R.H. the faster moisture is accumulating. This is the reason why temperature and humidity on top of the insulation slabs have been measured in a field test on difference green roofs and on a standard inverted roof.

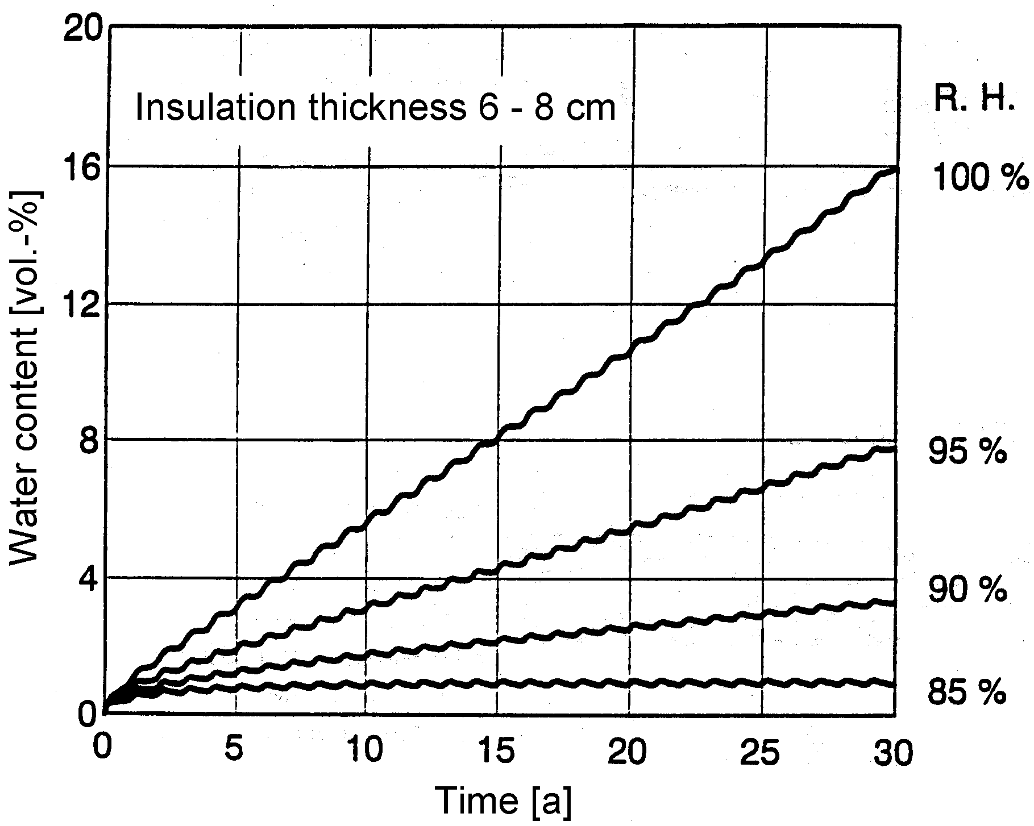

Fig. 1 Calculated Long-term moisture behaviour of extruded polystyrene insulation slabs in inverted roofs depending on the mean relative humidity in close vicinity of the upper surface of the slabs.

2. Experimental set-up

On the concrete ceiling above a heated laboratory an inverted roof structure with different test fields has been installed. The composition of the test fields which are 3 x 3 m² large is shown in Fig. 2. The heat conductivity of the insulation material lies below 0.035 W/mK which means that the U-value of the green roofs amounts to 0.37 W/m²K and of the reference roof to 0.44 W/m²K both including a ΔU-value of 0.05 W/m²K to account for the precipitation heat losses [4]. This difference in the U-value has, however, very little effect on the temperature and moisture conditions above the insulation. Since the solar radiation has a much greater influence on the surface temperature than the heat transmission from the room, the fact that the reference roof has a somewhat lower insulation thickness is negligible.

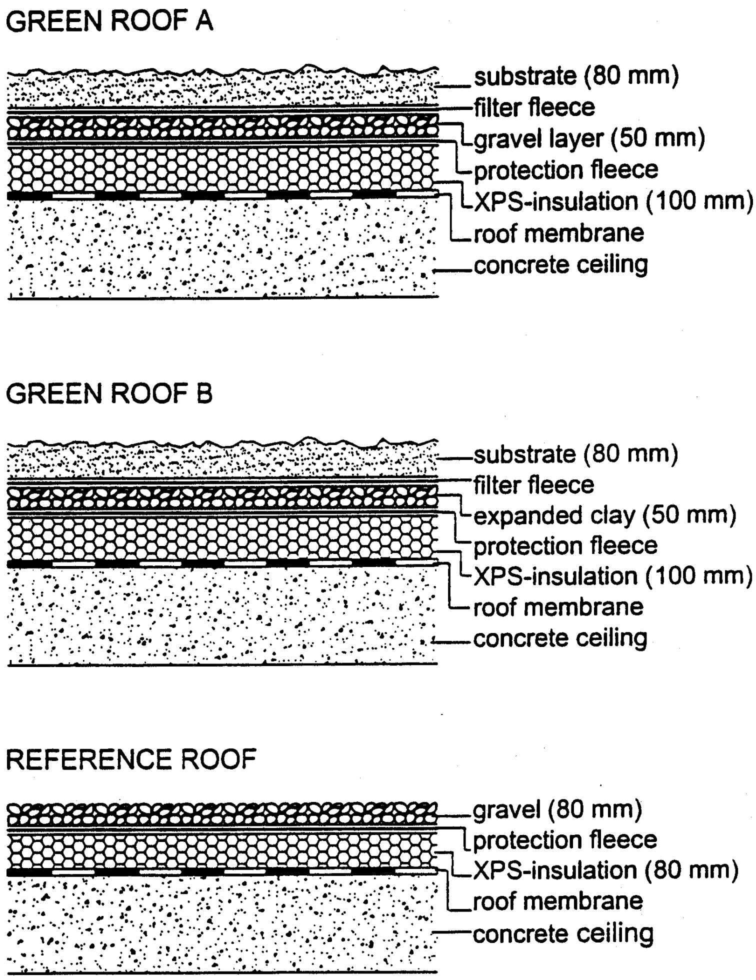

Fig. 2 Composition of the inverted roofs with greenery which have a drainage layer of gravel (A) or expanded clay (B) above the insulation and composition of the reference roof.

To determine the temperature and humidity directly on top of the insulation slabs, temperature and dew point sensors have been installed in the middle of the test fields as illustrated in Fig. 3. As temperature sensors serve Pt 100 class A with an accuracy of ± 0.25 K. The dew point is measured with Lithiumchloride sensors installed in a vapour tight plastic tube which is open at the bottom end, thermally insulated and protected against solar radiation by an aluminium shield. The dew point sensors have an accuracy of ± 0.75 K. The measurements were carried out continuously over a period of one year with regular calibrations of the sensors. The dew point sensors have to be regenerated from time to time because creeping of the LiCl-film due to high humidity changes can lead to lower readings.

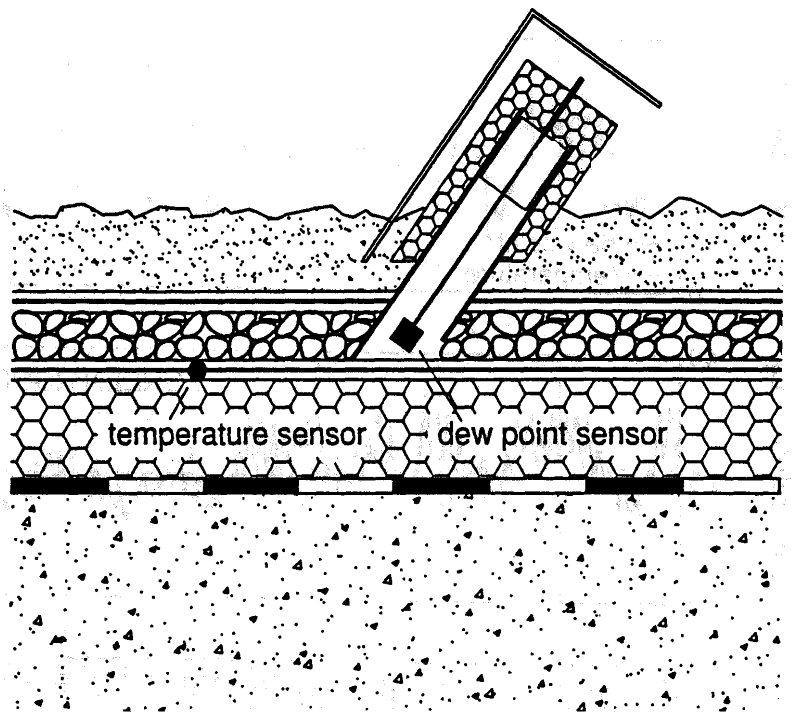

Fig. 3 Schematic picture of the installation of the sensors in the green roof.

3. Experimental results

The best drying conditions prevail in July and August when outdoor temperatures and insolation reach their maximum values. In the year 1995, July was particularly warm (monthly mean 19.2 °C) and dry (total amount of precipitation 40 mm) for the climate in Holzkirchen (680 m above sea level close to the Bavarian Alps), while August (15.7 °C, 230 mm) came close to average conditions. Fig. 4 shows the courses of the

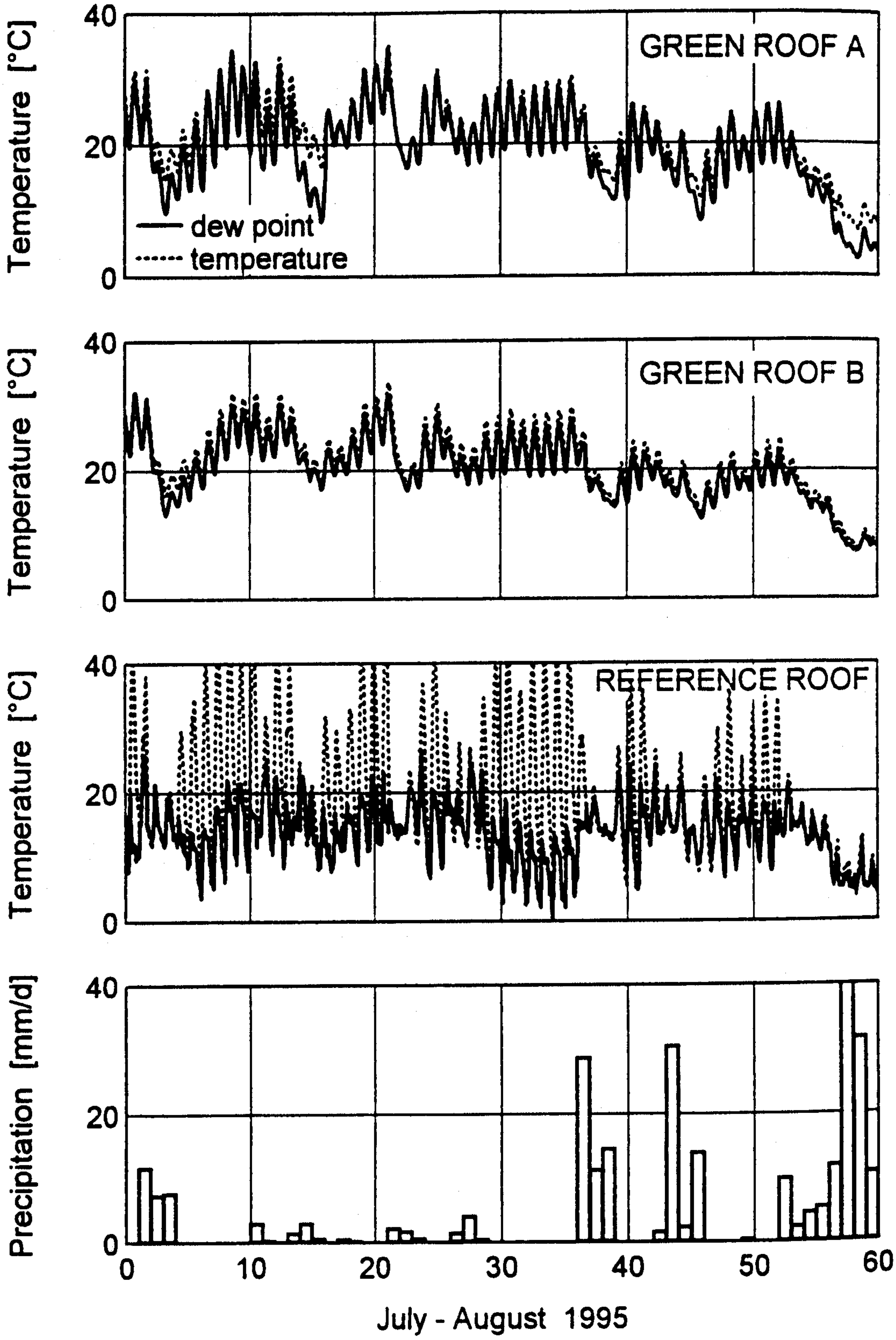

Fig. 4 Temperatures and dew point temperatures measured above the insulation layer in the test roofs as well as daily precipitation values in the period of July and August 1995.

temperature (broken line) and dew point temperature (solid line) at the outer surface of the insulation in the different test fields and the daily amount of precipitation during these two months. In the green roof structures the temperature and dew point temperature coincide most of the time even during periods of very little rain. This means that the relative humidity there is close to 100 %. If the dew point temperature falls below the temperature as in the case of the reference roof the relative humidity falls accordingly and signals drying conditions next to the insulation slabs. In the reference roof dew point and temperature coincide only during periods of heavy rain but most of the time the dew point temperature is much lower than in the green roof structures. The temperature at the surface of the insulation in the reference roof is higher than in the green roofs despite the fact that the substrate has a higher short wave absorptivity than the gravel. This is probably due to the evaporative cooling by the water retained in the substrate and the shading effect of the plants. The gravel do not retain the rain water and consequently dry out quickly by sunshine or wind.

4. Discussion and conclusions

The field test shows that contrary to the standard gravel cover water retaining cover layers like substrate with greenery prevent the drying of the layer next to the top surface of the insulation slabs. These results which were obtained under the unfavourable climate conditions in Holzkirchen can probably be transferred to other regions in Central Europe because even during the very warm and dry July 1995 no persistent drying of the considered layer was observed. A long-term dry out of the substrate would also lead to an unintended withering of the plants. As long as the substrate provides water to the plants its relative humidity must be above 99 % (i.e. a capillary pressure below 15 bar) because otherwise plants cannot extract any water. This means that the humidity of the layer next to the top of the insulation would not differ significantly from that condition even if drainage layers as in the tested roofs are introduced because the mean temperature gradient in the hot summer months leads to a vapour diffusion from top to bottom. This means that the summer drying of the insulation of protected membrane roofs is severely reduced or prevented when a substrate with greenery is applied instead of a gravel layer.

The consequences are a continuous accumulation of moisture in the insulation slabs and a reduction of their thermal resistance. Probing of such roofs [5] [6] have shown values which correspond to the course in Fig. 1 with a prevailing relative humidity of 100 %. It is, however, possible to slow the accumulation process by reducing the condensation in winter. This can be done by lowering the temperature at the warm side (e.g. by an additional insulation below the roof membrane) or by choosing a higher insulation thickness which reduces the temperature gradient. Insulation slabs with a higher vapour diffusion resistance, especially of the surface skins [7] or additional vapour retarding layers integrated at the bottom side of the slabs, will also do a better job. In any case the long-term moisture accumulation can be calculated introducing the respective parameters into modern computer codes e.g. Match [8] or WUFI [9]. This allows to account for the long-term loss in thermal resistance of the roof by increasing the designed insulation thickness accordingly. Thus a protected membrane roof with greenery will work as projected. This is a great advantage compared to conventional flat roofs with greenery where the membrane is prone to damages because it is not protected by the insulation layer.

5. References

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