THE EFFECT OF PHASE CHANGE OF WATER IN THE GREEN ROOF COMPOSITION ON THE HEAT TRANSFER COEFFICIENT

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Abstract
The water saturated substrate layer has a significant impact on the basic requirements of buildings in the green roof composition. Apart from the impact on stability, fire safety, noise protection, etc., this research is mainly concerned with the impact on energy saving and thermal technical parameters of these structures. A current problem is that the substrate layer is neglected in the assessment of green roofs in terms of heat transfer, while the ice crystals in the substrate are beneficial as an insulating layer in winter. Therefore, the effort is to prove that in the winter months it is possible to consider a significantly higher temperature under the substrate layer than is considered in traditional calculations where the substrate is neglected.

Keywords
Green roofs, substrate layer, phase shift, thermal parameters, temperature oscillation

1 INTRODUCTION

Green roofs are becoming more and more established constructions and are almost a standard design structures in the civil engineering. These constructions deal with urban heat island, air and noise pollution, water pollution and green gas emissions. Presence of greenery has a significant impact on psychological well-being and building aesthetics which leads to raising the value of property development [1].

Green roofs have impact on the basic requirements of buildings. Apart from the impact on stability, fire safety, noise protection, etc., this research is mainly concerned with the impact on energy saving and thermal technical parameters of these structures [2].

For example, in France there are study cases, that were evaluated the effects of various urban greening scenarios based on urban climate simulations across the Paris area. The scenarios tested consist of extending ground vegetation or implementing green roofs on compatible buildings, or a combination of both. Results show that increasing the ground cover has a stronger cooling impact than implementing green roofs on street temperatures, and even more, so when the greening rate and the proportion of trees are important. However, green roofs are the most effective way to reduce energy consumption, not only in summer but also all year round. [3].

Another researches are to study the thermal effect of blue-green roofs in order to assess their potential for shielding the indoor environment from outdoor temperature extremes (cold- and heat-waves). Temperature sensor values show that the outdoor surface temperatures of blue-green roofs are lower in summer and fluctuate less throughout the year than those of conventional roofs. [4].

What is important in this study is the effect of the substrate layer on the temperature underneath and the time it takes for the temperature from the outside to show up under the substrate layer.

In Slovakia it has been studied, that the spatiotemporal distribution of water in the substrate of a vegetated roof fundamentally influences the thermal-moisture behaviour of the roof [5]. Water content in the substrate of green structures is a variable phenomenon throughout a year. During this period, it has a strong influence on the building's hygrothermal behaviour. The presented simulation scenarios are aimed at assessing the effect of water in the green roof substrate on the waterproof membrane temperature and heat flux variations through the roof during the summer period (from 1 June to 31 August). The presence of water and its movement through capillary forces is a fundamental aspect of hygrothermal behaviour and cannot be neglected in the simulation. Water in the green roof substrate tested reduced the average daily heat flux through the roof by 11%, which contributed significantly to reducing its summer overheating. [6].

The soil substrate can influence the performance of the whole structure in terms of the assessment of the Heat Transfer Coefficient [7]. When the water approaches the freezing point (below 3.98 °C), the bond between the

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hydrogen atoms becomes less strong, the molecules expand, take up more space and the water becomes less dense. Consequently, water just before freezing is the best insulator and has the highest heat capacity.

2 METHODOLOGY

What is important in this study is the effect of the substrate layer on the temperature underneath and the time it takes for the temperature from the outside to show up under the substrate layer.

This phenomenon is called the phase shift of the temperature oscillation and it is the time difference between the maximum temperature on the inner surface of the structure and the maximum temperature of the outside air [8].

$$\psi = \tau_{Ax} - \tau_{Ae} \quad (1)$$

where is ψ phase shift of the temperature oscillation in hours, τ_{Ax} time of occurrence of maximum temperature in the structure and τ_{Ae} is a time of occurrence of maximum outdoor air temperature. In Fig. 1 you can see the sinusoid of temperature fluctuations as described above (1).

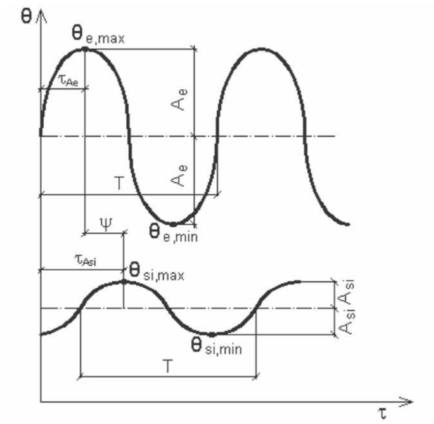
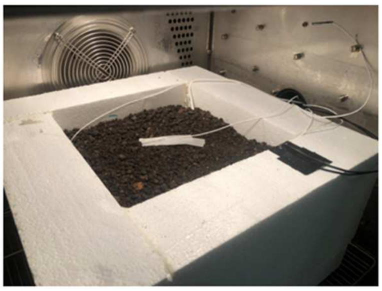
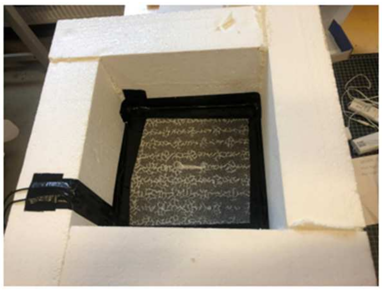


Fig. 1 Diagram of harmonic temperature variations on the surface and inside the structure [8].

1. In this research we will focus on temperature oscillations that take place only in the roof substrate layer. For outdoor conditions, the date of 10 February 2023 was chosen.
2. The measurements were made in a 0.5 × 0.5 × 0.28 m polystyrene mould, which was placed in a test climate chamber (Climate test chamber Memmert CTC 256). We can see in Fig. 2a. On the bottom of the mould was placed a ceramic tile on which is stretched a heating electric wire (Fig. 2b). The wire is routed on the tile so that the layer is evenly heated (Fig. 3a). A thermal switching sensor was placed on the surface of the tile and then the substrate was poured into the mould in 5 cm layers with the sensor inserted. The total thickness of the substrate is 15 cm. The substrate was saturated with water to about 30% moisture. This was determined by drying a sample of substrate (Fig. 3b).
3. The temperature in the climate chamber was simulated for 10. 2. 2023 and it was a day with temperatures both below and above 0 °C. This day was repeated several times in a row.
4. The data was recorded at the control panel (Monitoring system MS6-Rack), which downloaded the data in 15minute increments.



a)



b)

Fig. 2 a) testing pattern in climatic chamber, b) the tile with heating wire on the bottom.

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a) b)

Fig. 3 a) heating wire on tile, b) hot air sterilizer.

3 RESULTS

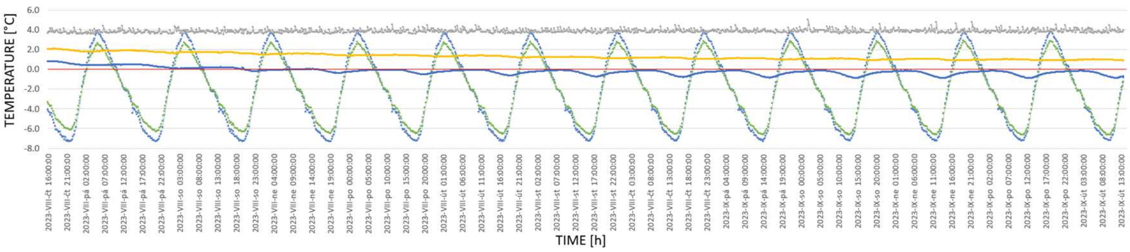

Fig. 4 Scheme of overall temperature measurement.

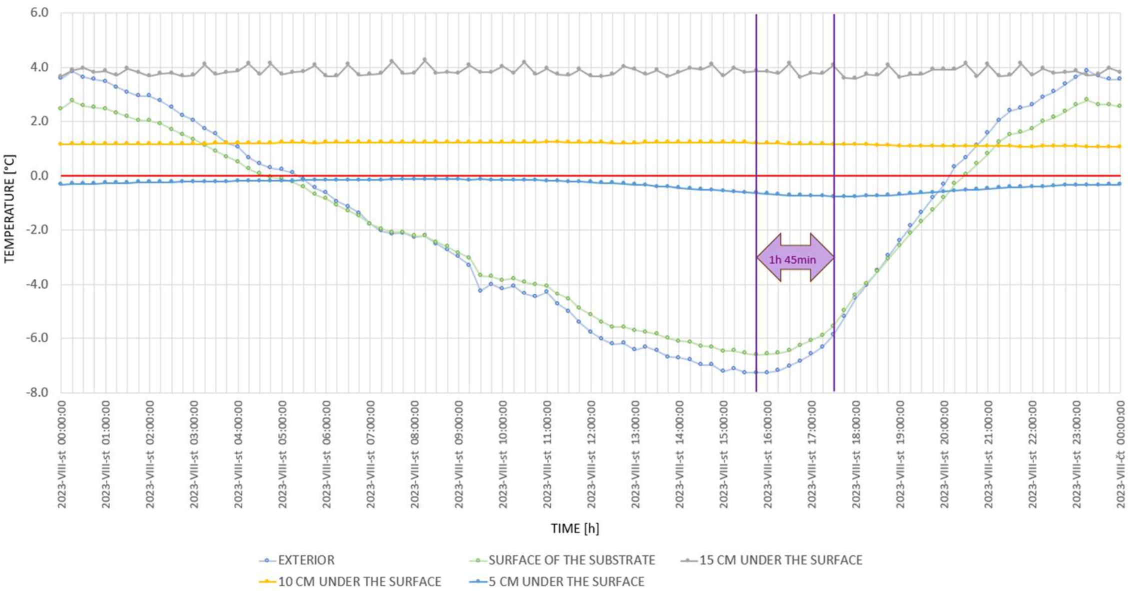

Fig. 5 Section of one-day measurement.

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The substrate samples were collected in two trays and dried before measurement to determine their moisture content by weight.

An important parameter that was monitored was the phase shift in the substrate layers after 5 cm. The water layer of the substrate has insulating properties in freezing temperatures and therefore it was observed over what time period the lowest temperature of the day would occur in each substrate layer.

The tile layer simulates a layer of waterproof membrane and has been estimated to be 5 °C. This hypothesis was then confirmed by measurements where the ceiling layer was simulated on another sample.

4 DISCUSSION

In Chapter 3, the results are shown in Fig. 4, a graph that captures the 12 measured days. The resulting temperature on the water roof membrane simulated by the temperature on the tile was 4 °C.

Of these 12 days, one day has been shown for better clarity (Fig. 5), on which the phase shift of the temperature oscillation is more clearly visible. Major changes in the temperature oscillation can be observed in the layer 5 cm below the surface. The temperature 10 cm below the surface and 15 cm below the surface is almost constant and there are no significant temperature differences.

The temperature in the monitored layer 5 cm below the surface is at a minimum of -0.8 °C, while the temperature in the exterior is at a minimum of -7.3 °C. The temperature 10 cm below the substrate surface is then already in the positive range.

The moisture content of the substrate sample was determined using the equation (2) and was measured in the device shown in Fig. 3b.

$$w = \frac{m - m_d}{m_d} \times 100\% \tag{2}$$

where m is the mass of the whole sample in the tray, the mass m_d is the mass of the sample after drying. W is the moisture content by mass of the sample taken. The exact moisture by weight is 30.75%.

5 CONCLUSION

The time it takes for the minimum outdoor temperature to appear in a layer 5 cm below the surface in the substrate is 1 hour and 45 minutes. In the layer 10 cm below the surface, the temperature is almost constant. The measurements show that a 5 cm layer of roofing substrate can eliminate outdoor temperatures around -7 °C to temperatures close to 0 °C.

The minimum daily temperature was reached in the substrate layer 5 cm below the surface in 1 hour and 45 minutes.

This measurement will continue with additional samples at different humidities and different outdoor temperatures. The aim of this measurement is to prove that the temperature under the substrate on the waterproof membrane does not reach the temperature in the exterior and therefore it will be an effort to determine some way to account for this in the heat transfer coefficient calculations.

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