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THERMAL MEASUREMENT AND CALCULATION OF GREEN ROOF AND NORMAL FLAT ROOF

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Abstract: Installing green roofs on building tops is an important part of energetically conscious planning. This has many energetic advantages, while it is simply aesthetic. Opportunities of green roofs are in use in Western-Europe for a long time, and nowadays, more and more fine examples can be caught in Hungary, as well. In this article we present a specific series of measurement and computer calculation on a certain building, which has two different cover on the same roof surface. One part is green roof, the other is normal paved flat roof. We compare measured results with numerical calculation and draw conclusion for further examination.
Keywords: green roofs, measurements and computer calculations

1. INTRODUCTION

With a series of measurement we examined the change of temperature of each layer of a green roof, which belongs to a nursery school built in the 1970's. The roof is shown on Figure 1. Similar examples in [10].

On the picture we can see the green roof with the measuring equipment and the other side of the fence there is the paved flat roof.

During the series of measurement for almost a year we gathered temperature data of each layer of both roofs. This way both summer and winter data are available. Figure 1 shows the layers of the roof structures. We can see that lower layers are the same, only the covering layer is different.

Figure 1 - Green roof and normal flat roof

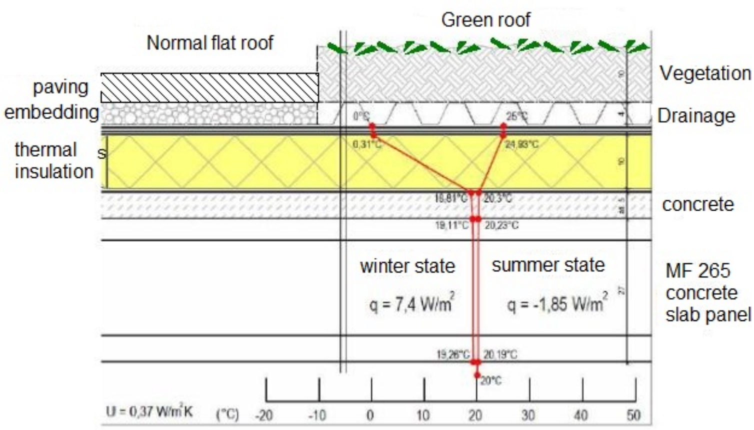

Figure 2 - Layers of normal and green roof and steady-state temperature distribution of green roof

Layers from inside: reinforced concrete slab panel, concrete inclination layer, moisture proofing, thermal insulation, 2 layers of waterproofing

- normal flat roof – broken stone embedding layer, concrete pavement
- green roof – plastic drainage layer with geotextile, 10 cm of soil (vegetation layer).

Green roof directives are defined in [3], [4] and [9].

On figure 2 we can see the temperature distribution of the green roof layers for both summer and winter conditions. The temperature values show a steady-state heat transport. However our real measured values show a much different temperature distribution.

2. MEASURING EQUIPMENT

The electronical unit had been installed with proper weather protection, which means a covering tile roof and base to avoid contact with the soil. This way we could keep it dry and protect from direct sunlight. This unit includes the probe to measure air temperature.

Figure 3 - Electronical unit with weather protection, battery, and wires

There had been installed two measuring units on the roof of the nursery school building. One to the green roof, the other to the paved roof. Eight measuring sensors had been attached on each units with wires in order to get a temperature map as wide as possible. These sensors had been put to the different layers of the structures.

We got temperature values from each points in every minute, and each value was calculated as an average of 20 measurements. The same measuring method was used in [6]. Accuracy of measuring was +/- 0,3°C.

We planned to measure temperature values not only inside the roof structures, but on the inside and outside of the walls of the building. This way we can calculate the whole heat transport of the building, so we get more precise data for the roofs.

The following elements had been used to build up the electronical measuring unit:

- PIC18F4550 type micro controller unit
- LM 35 thermistor, resistance based temperature measuring unit
- Micro SD memory card
- RS5C348 realtime clock, trigger
- CR2032 battery for the clock, 4 pcs of AA type batteries for measurement
- double layer galvanized printed circuit

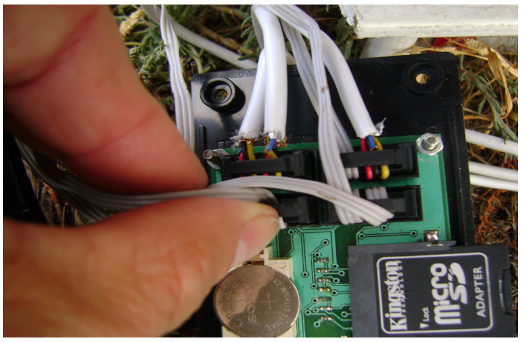

Figure 4 - PIC18F4550 type micro controller unit with wires, SD memory card and CR2032 battery for the clock

3. TEMPERATURE SENSOR AND ACCURACY

LM35 IC type thermistor had been built in to each measuring point. Main properties of this sensor made by Texas Instrument are the following:

Output voltage of this sensor is linear to measured temperature in celsius degree. It do not need any calibration, tipical accuracy is ±0,25°C on room temperature and ±0,75°C on the whole scale between -55°C + 150°C. The sensor has low output impedance, linear characteristics, relatively simple controller circuit. LM35 requires only 60 μA of currency, therefore several units can be put on one single battery. This way it has only 0,1 °C of self heating in calm circumstances. Accuracy is less influenced by the length of the wire. This means that with a proper wire this length can be almost 100 m without any substantial loss of accuracy. Temperature values had been gathered throughout a whole year with this unit.

Figure 5 - LM35 thermistor

There had been also performed a computer simulation of the measured values, which is presented in the following chapter.

4. MATHEMATICAL MODEL

Equation 1 shows the law of conservation of energy in mathematical form, which is a partial differential equation about the energy transport. We considered all of the thermal parameters (ρ , λ , c_p) of the equation steady for all materials (concrete, thermal insulation, broken stone embedding) except soil which has varying density, heat capacity and heat conductivity depending mainly on the water content. This is altering by evaporation and precipitation. Evaporation is also an inside heat source of soil. In present essay we are negligent of the change of these parameters during a one-day examination. We consider density and heat capacity steady, but heat conductivity is regarded as varying in time. This serves to model the cooling effect of the vegetation. In summer conditions this can be considered as a better thermal insulation. Similar theory than in [1].

$$\frac{\partial}{\partial t}(\rho c_P T) = \frac{\partial}{\partial x_i}\left(\lambda\left(\frac{\partial T}{\partial x_i}\right)\right) + q_v \quad (1)$$

We used the following constants for the equation to get the heat conductivity,

$$\lambda = \begin{cases} c_1 & 0 \le t < 7 \\ c_2 & 7 \le t < 19 \\ c_1 & 19 \le t < 24 \end{cases},$$ where t is time in hour unit.

Validating the model, night heat conductivity value proved to be $c_1 = 0.03$ W/mK, day value $c_2 = 0.1$ W/mK.

Before performing numerical calculations, we generated numerical grid for each layer of the roof structure. All of these grids are flat except the one on the slab panel, which is shown on Figure 6. These flat grids had been generated with a relatively small resolution, and these grids were pulled out vertically. This was necessary to be able to decrease the number of lattice points and cells. We used the fact that only the vertical derivative value is considered as a big number.

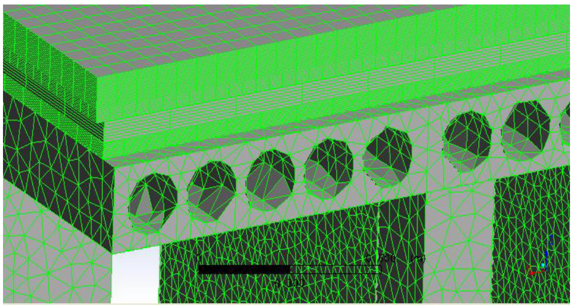

Figure 6 – Generated numerical grid of the roof structure

$$\frac{\partial T}{\partial x} \cong 0, \quad \frac{\partial T}{\partial y} \cong 0, \quad \left|\frac{\partial T}{\partial z}\right| > 0.$$

5. MEASURING RESULTS

Firstly, without any specific explanation we present a series of measurements during a week. First eight diagrams show temperature values of green roof layers, the last five diagrams show the same values of the normal flat roof.

Based on this summer diagram we can make several important statements comparing green and paved roof.

Top layer temperature of both roofs follows the change of outside ambient temperature. Top layer of green roof (red line) is much warmer in daytime and much cooler at night than outside air, which is caused by radiation. On the other hand the pavement is warmer than air, both day and night. This is because the black grade of soil is higher than of concrete.

We can see the better thermal insulation property of the soil comparing the temperature values of the layer under the soil on the green roof and the broken stone embedding on the paved roof. The rest of the structure contains the same layers of both types of roof.

We can read the daily rate of temperature change on Figure 7. It can be clearly seen that at the same level of each roof, at the top of the heat insulation, this daily change is substantially lower in case of the green roof. While the daily maximum temperature difference on the paved roof is 25°C, on the green roof this value is only 15°C. On the diagram both values are black.

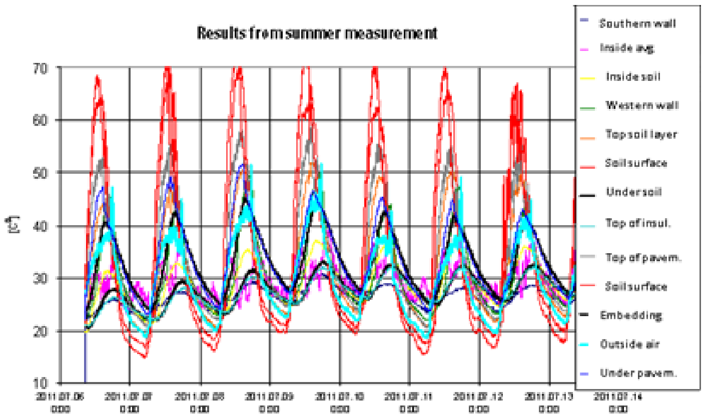

Figure 7 – Synoptic diagram with all values of green and paved roof

This difference is caused on one hand by the mass of the soil, which can be described with the heat capacity, which depends on the water content as we mentioned above. Also a big quantity of air is inside the soil, which enhances thermal insulation ability.

On the other hand, cooling effect of the evapotranspiration of the vegetation cannot be neglected either, when examining the green roof thermal properties. [2]

Bottom of the soil layer remains 3-5°C cooler at night than the bottom of the pavement. Green roof layer is a more effective thermal insulator than the concrete pavement with the broken stone layer. The bigger difference is between the daily temperature values, when it can be 10-15°C. As a conclusion we can declare that green roof is an effective insulation in the summer period.

6. COMPARING MEASUREMENT AND CALCULATION

We performed a temperature simulation for one single day of summer. For the calculation we took the temperature values of the top of the green roof and inside the building as boundary conditions. For the other layers calculated temperature values have been compared to measured values. Calculation resulted in varying isotherms in time, as well. We chose three representative measuring points – on the top of the soil, inside the soil and under the drainage layer. This way we practically got the thermal insulation and heat balancing effect of the green roof, which is shown on Figure 8.

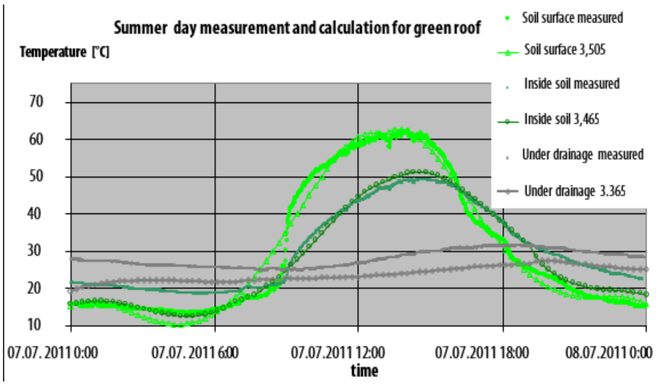

Figure 8 – Comparing measurement and calculation on a sunny summer day

We used thermal parameters of chapter 3 for the calculation. It is clear that calculation result follows measured values both on the top of the green roof and inside the soil layer.

We know that heat conductivity of day and night soil is different. During the validation of this parameter we experienced that green roof behaves different at night than during the day, therefore we had to set different values in order to get appropriate results from calculation. The main cause of this phenomenon is that the evaporation of vegetation is much stronger at daytime under heavy sun radiation. This means that thermal parameters of green roof are varying in time. [7], [8]

On behalf of further refinement of mathematical model we have to declare that green roof heat conductivity is varying not only in time but along thickness, as well. Inside the top layer of soil, where evaporation of the vegetation distracts much more heat than deeper layers, we have to calculate with a less value of heat conductivity. On Figure 8 we can see the difference of the grey lines, which proves this declaration.

7. SUMMARY

It can be settled that both measuring instrument and mathematical model are useful for the examination of thermal properties of green roofs. Measuring unit shows appropriate results for the changing temperature of roof structure while the model follows pretty well these values. The soil layer cannot be handled as simple as other structural elements and materials, which have their own single value of heat conductivity. This has to be varying both in time and in thickness. Change of water content makes this more complicated, which is going to be the topic of further examinations.

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