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INCREASING THERMAL PROTECTION WITH USE OF GREEN ROOF

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Abstract. The use of green roof is a great choice in case of climate change mitigation and reduction of urban heat islands. Positive aspects of green roofs during winter or the whole year round balance are often overlooked. The surface of highly insulated flat roof is overcooled during the night by the long wave sky radiation. This radiative cooling increases the thermal losses that are reduced by the existence of additional layers. The green roof composition layers also have their thermal resistance, which is not usually included within the calculation of thermal resistance using the EN ISO 6946. The presence of snow on the roof can also increase the resistance. This paper analyzes the measurement results of various experimental green roof fragments in Central Europe.

Keywords: Green roof, temperature, experimental, measurement, winter, snow.

1. Introduction

Hanging Gardens of Babylon are considered as the first use of green roof, dating back to around 600 years B.C. The riding school building has the oldest green roof in the former Czechoslovakia constructed in 1911. In 2005, most of the green roof layers were replaced by the new ones, but the waterproof membrane remained original [1]. In Slovakia, terraces of the Nitra Castle are one of the oldest examples of green roofs. Therefore, the use of the green roof is not a new idea. But in the Slovakia, they are nowadays in the center of public interest.

Green roofs have many benefits, for example: reducing the urban heat island intensity, reducing the summer overheating of interiors, rainwater retention and evapotranspiration, dust particles collection, fire safety, different architectural and aesthetic aspects etc. State of the art is provided by authors in [2, 3]. Measurements worldwide in this area differ in the aim and scale [4, 5]. Summer benefits are more often analyzed [2, 3, 5–7]. Different simulation approach [8], boundary conditions [9] and material parameters are analyzed in [10]. The winter regime is analyzed in these works [11–13]. Usual energy saving can be between 10–15 % depending highly on the thermal insulation thickness. Higher insulation has lower saving [14]. Water retention regime is also important part of the green roof research [15, 16].

Research in this area in Slovakia is limited to the experimental roof in Kosice [17]. Similar research is conducted in the Czechs UCEEB with more types of green roofs [18]. With its new measuring platform of green roofs, the University of Zilina was added to the international effort to mitigate the climate change [19, 20].

In this paper, part of the initial results of winter regime of the green (G) and non-green flat roof (R) is analyzed. The additional thermal resistance of the green roof layers and its influence on the thermal loss are also analyzed. Also, the planned and possible outcomes in the future are mentioned.

Figure 1. Aerial view during renovation work of the roof.

2. Test site and methodology

In the year 2019, one of the flat roofs in the campus of the University of Zilina was completely reconstructed (Figure 1) The whole structure up to the load-carrying concrete slab was removed. This enable the possibility for creation of testing platform (Figure 2). During the reconstruction, temperature/humidity sensors Sensirion SHT21 were incorporated within the roof structure in two places (Figure 3). These sensors are connected to the Raspberry PI with one-minute recording interval.

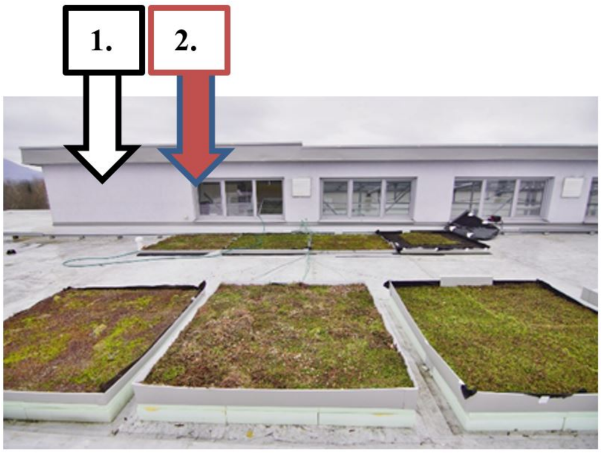

Figure 2. Front row for measuring the rainwater retention, the second one for temperature measurement (picture from autumn 2020). Marked position of compared compositions in this paper.

Figure 3. Incorporation the Sensirion SHT21 sensors during the reconstruction work.

Calibration measurement made between these two places was done with and without green roof and showed matching courses with slight differences caused by the shading of the higher part of the building showed also in Figure 1 and the fact that the pitched insulation layer is about 20 mm thick [19]. During the year 2020, four different green roof compositions were constructed. Each composition is made twice. The first one is for monitoring the temperatures, because it is placed on the original waterproof membrane. The second one is slightly elevated with additional pitched layer to increase the angle and add the possibility to use the tipping bucket rain gauge for measuring the amount of rainwater [19]. The complex view of both segments is shown in Figure 2. The winter period was with either total snow cover (Figure 4) or with partial powder snow cover.

The differences between the individual compositions are up to the manufacturers of the compositions: they differ from each other by the use of mineral wool for water retention and filtration or the use of different drainage layer. All compositions are commercially available. In this paper, only one composition is analyzed (marked in Figure 2) and compared to non-green roof.

Figure 4. Roof covered with snow.

In the green roof compositions, there are used PT100 sensors and sheathed thermocouples with capability of immersion into the water or for usage in humid environment. The recording time interval of Fluke Hydra datalogger is one minute. As it was stated before, monitoring of the outdoor climate is also important. There is a weather station on the site, on the roof of another building within the campus [21–23].

The sketch of the both roof compositions is in Figure 5 with marked positions of sensors used for comparison in this paper. The comparison is made for the temperature on the membrane, where also in the results graphs is this position named membrane (either only membrane for roof R or green roof membrane for roof G). Also, the temperature bellow the vegetation surface is measured, where the sensor is below the vegetation and covered with the layer of substrate as thin as possible.

The impact of the green roof on the thermal properties and thermal loss is analyzed in a simple steady state calculation with the use of measured outdoor climate temperature and also with the impact of surface temperatures, which were taken into account as air temperatures. Properties of individual materials within the regular roof and from the green roof composition are summarized in Table 1. Material properties of the snow differ [24] according to the state of the snow; if it is powder, or has several melt-froze cycles. Based on the observation after snowing two days before, there were properties of powder snow used in this case.

3. Results and discussion

3.1. In-situ temperature measurement

Results of initial temperature measurement of the samples are in Figures 6 and 7. From the longer time period, there were two 2 days periods chosen, which can show and demonstrate the impact of the green roof. Compared are the temperatures on the waterproof membrane show the selected temperature

material	thickness [m]	λ [W/(m · K)]	ρ [kg/m^3]
snow (powder, chosen)	0.15	0.029	100
soil (wet)	0.03	2.0	2000
green roll substrate (wet state)	0.05	0.2	50
mPVC membrane	0.0015	0.35	1470
EPS 150	-	0.035	30
vapor barrier	0.0035	0.21	1200
reinforced concrete	0.25	1.74	2500

Table 1. Material properties of used materials example [24].

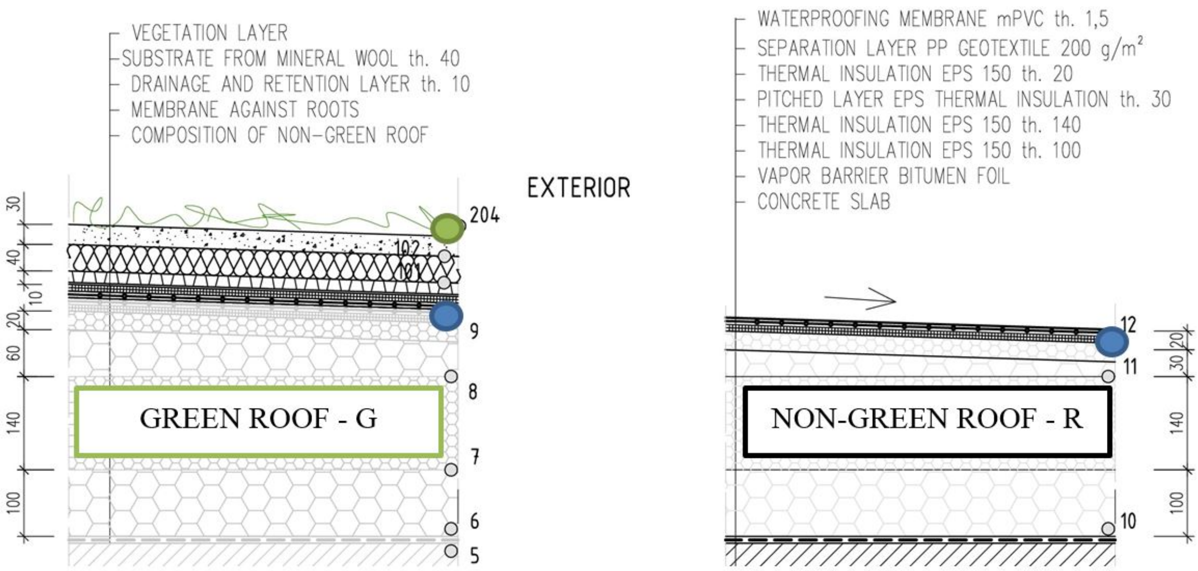

Figure 5. Detail of compared roof compositions with installed sensors – color-marked ones are used in the results graphs.

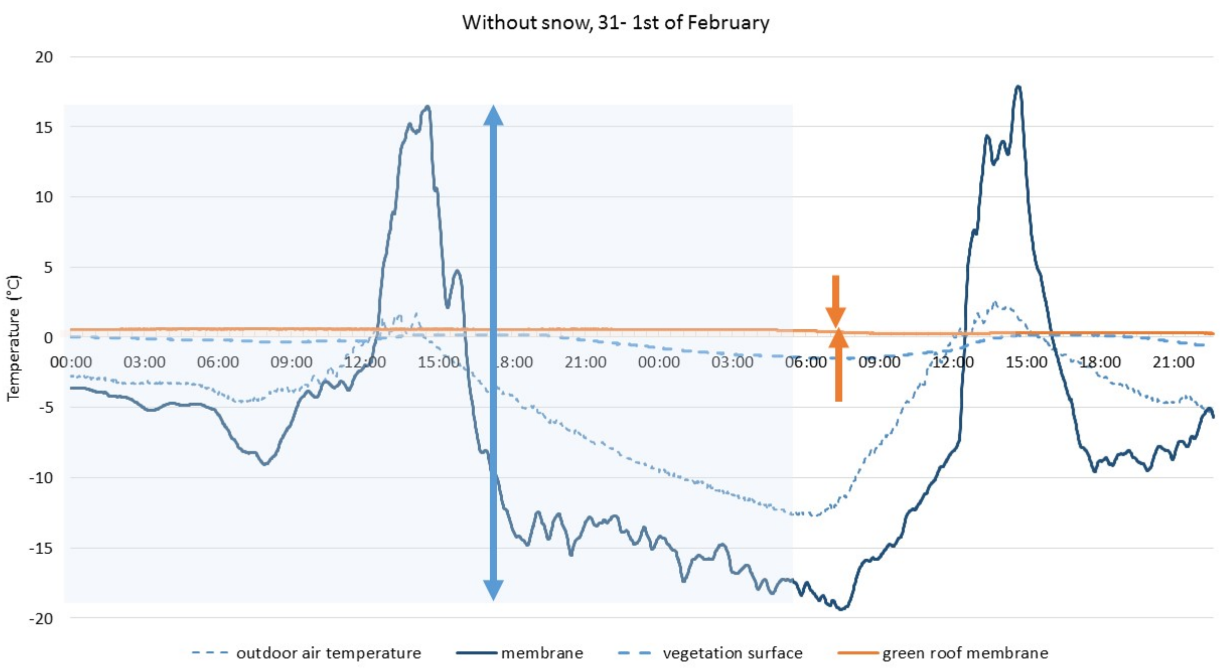

Figure 6. Temperature courses for two days without snow on the roof. Daily difference on the membrane is 37 °C, green roof membrane 0.4 °C. Air temperature difference is 15.5 °C.

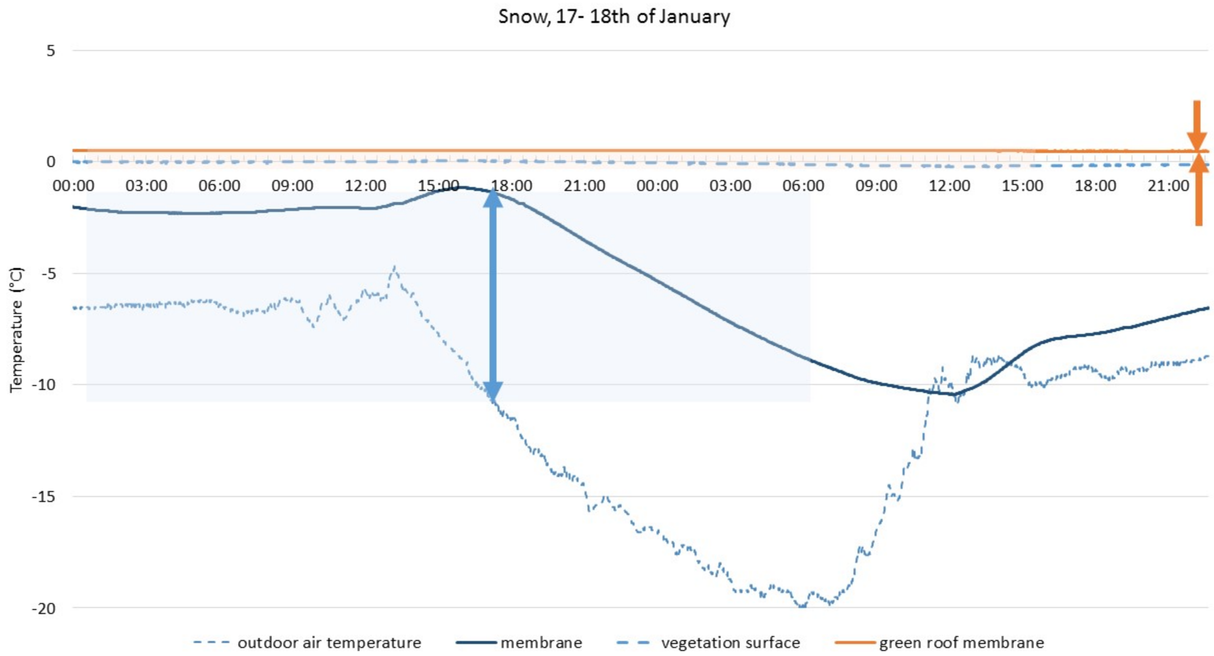

Figure 7. Temperature courses for two days with roof covered by snow. Daily difference on the membrane is 9.2 °C, green roof membrane 0.5 °C. Air temperature difference is 15.3 °C.

courses in the green roof compared to the non-green roof. The difference between membrane temperature and outdoor air temperature is important and can be almost the same or much bigger during the clean night sky. The first comparison is for the roof without snow (Figure 6) and two winter days with freezing and with sunny weather during the day. Although the air temperature during the day barely reached zero, the non-covered membrane had temperature higher than 15 °C. So also during winter, the daily variance of temperature on the membrane is higher than 30 °C, which can influence the durability. However, the more important fact in this case is that the surface of the roof is highly overcooled during the night. Night radiative cooling overcooled the surface of the non-green roof by around 5 °C.

Benefits of the green roof can be clearly seen. The daily course for the green roof is without significant peaks. Daily variations affect the durability of membrane. The green roof also protects the membrane against UV radiation. There is also time shift in the temperature peaks, which is not such significant nowadays with highly insulated structures [25–27]. The temperature course for the G membrane is supported by the other findings [12, 13]. The measured temperature below the vegetation is close to the membrane temperature, which can be influenced by the thermal inertia of the substrate, insulation effect of the plants or partly by shading of the elevated part of a building next to the samples (Figures 1 and 2). However, the overcooling of the R membrane will also be influenced in this case. There is a correlation between the air temperature course and the vegetation surface course, but the difference is up to 10 °C. This finding will be evaluated in later research.

In the case of the roof covered with snow, the surface is not overcooled as in the case without snow (Figure 7), where the non-green roof surface is much cooler than the outdoor air. Powder snow has a very good thermal conductance coefficient [24], so it creates relatively good insulating layer of the non-green roof (Figure 7). Snow also serves as the protective layer against the long-wave radiation from the cold sky during the night. Snow on the roof can effectively reduce the surface temperature of R membrane. The difference in this case is up to 9.5 °C. In the G roof case, the membrane temperature course is without any visible change or correlation with the outdoor air temperature.

3.2. Thermal loss calculation

Based on the measurement findings, the measured air temperatures were used as boundary temperatures for numerical thermal loss calculation. Calculated U-values for the analyzed roofs based on the material properties from Table 1 are in Table 2. Direct comparison is made for the same thickness of thermal insulation (the pitch of the roof is made from polystyrene; the difference between the two samples in situ is 30 mm). Therefore, the calculation is made for the same thermal insulation thickness and only with added green roof layers, based on the thermal insulation thicknesses of position 2. With the measured outdoor air temperature (-12.8 °C), the thermal loss through the fragment is 8 % lower.

Table 3 gives the calculated values with the influence of the vegetation and night sky radiation – the temperature was measured below the surface of the

Roof type	U [W /(m²K)]	thermal loss without snow [W/m²] $\Delta\theta = 30.8\,\mathrm{K}$	thermal loss with snow [W/m²] $\Delta\theta = 35.9\,\mathrm{K}$
non-green roof (position 1)	0.127	3.92	4.56
non-green roof with the same thermal insulation thickness as green roof – theoretical (position 2)	0.116	3.57	4.16
green roof (position 2)	0.107	3.30 (-8 %)	3.84 (-8 %)

TABLE 2. Calculated U-values and thermal loss based on climate temperatures (θ_{ai} and θ_{ae}) .

Roof type	U	thermal loss without snow	
	[W /(m²K)]	$\boldsymbol{\Delta\theta}$ [K]	[W/m²]
non-green roof (position 1)	0.127	37.4	4.75
non-green roof with the same thermal insulation thickness as green roof – theoretical (position 2)	0.116	37.4	4.34
green roof (position 2)	0.107	19.5	2.09 (-52 %)

TABLE 3. Calculated thermal loss without snow based on the measured surface temperatures (Figure 8).

vegetation during the same night -1.5 °C and for non-green membrane -19.4 °C. These two temperatures were considered as outdoor air temperature and the indoor – outdoor air temperature difference was calculated with them. The high surface temperature differences showed extremely high thermal loss, with the difference up to 52 %.

Calculated temperature courses within the compositions are in Figure 8. Left picture is for the roof without snow. The red line represents results from Table 2; the other two lines represent results based on Table 3.

Table 4 shows calculated results for snow-covered roofs. Steady state temperature courses are again in Figure 8. Because there were no surface temperatures on the snow measured, only outdoor air temperature can be taken into account. Snow with the thickness of 150 mm was added for U-values of the regular compositions measured on 18th January in the morning (Figure 5). Thermal conductance is used from [24]. Heat loss is 5 % lower for the green roof. Snow decreases the sky radiation cooling potential for both roofs.

4. CONCLUSIONS

Experimental setup for measuring the properties of the extensive green roof was briefly described in this paper with a closer look at the chosen two different days. As this is considered as the initial evaluation results, potential of the green roof during winter is drawn.

Results of the two days winter periods showed a clear benefit of the green roof. The green roof can decrease the peaks of the thermal loss through the fragment up to 50 %, which are during the freezing weather with the clear night sky. Also during the other times, the additional layers decrease the loss. Normal or usual benefit could be around 8 %. As stated in the introduction, the difference is influenced by the U value of the roof and nowadays, required values in Slovakia are lower than 0.15 and recommended lower than 0.1. The analyzed roof is between these values. The reduction of the losses supported the findings by [12–14]. The correlation between the courses of the membrane temperature and outdoor air course is almost none, which is also confirmation of [13].

If the roof is covered with snow, the difference is not so high. The waterproofing membrane has other crucial benefits such as protection against UV radiation. The temperature variances are also very low; they are almost constant during the analyzed days. This is due to the higher thermal capacity of the vegetation, soil etc. compared to the flat roof with EPS. This also minimizes the radiation overcooling in the night.

The snow layer more influences the thermal loss of the non-green roof, where the snow increases the membrane temperature by 9 °C in this case by thermal resistance of the snow layer itself and also by protection against the night sky radiation. This is valid for the case of powder snow, as presented in this paper.

The measurements are suited as long-term and are constantly running. Therefore, these initial results will be supported by more measurements and more G roof compositions. Some results, such as big difference between the air and vegetation surface differences will

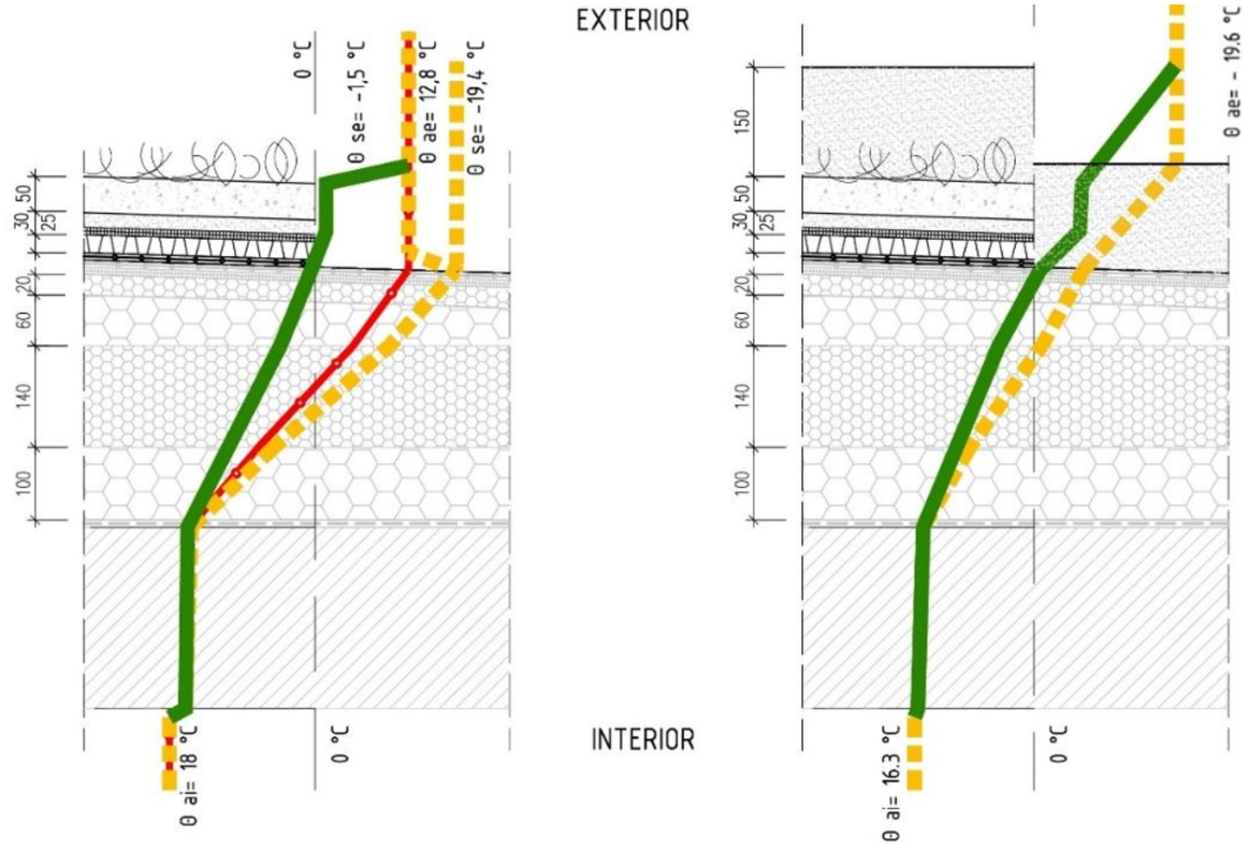

Figure 8. Steady state calculations of temperature courses within the roof not covered by snow (left) and with snow (right).

Roof type	U [W /(m²K)]	thermal loss with snow Δθ [K]	 [W/m²]
non-green roof (position 1)	0.073	35.9	2.62
non-green roof with the same thermal insulation thickness as green roof – theoretical (position 2)	0.069	35.9	2.48
green roof (position 2)	0.066	35.9	2.37 (-5 %)

Table 4. Calculated thermal loss with snow based on the measured surface temperatures (Figure 8).

be analyzed. In the future, the summer season and the rainwater retention will be analyzed. Other roof compositions are also upon completion. Heat flux measurement will be added (nowadays it is only in one composition). Measurement of the water content is highly problematic, because there is a limited use of regular soil substrate in most compositions.

Acknowledgements

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