Heat flow through green and tile roofs under winter conditions

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Abstract: In this study has been performed a comparative analysis of the heat flux through a green roof and a traditional tile roof under winter conditions. The study is based on two previously developed mathematical models, describing the heat exchange through the two roof constructions. A simulation has been carried out, using a specially developed software application, implementing the two models. The simulation uses the official climate data (temperature, humidity, wind speed, and cloudiness) during the months November 2010 - March 2011, for the city of Ruse, Bulgaria.

The results of the simulation are presented in a graphical form. They include the temperature variations of the two tile roof surfaces, oriented respectively southward and northward. Also is presented the temperature variation of the bottom soil layer of a green roof for two different soil substrate depths (10 cm and 30 cm). Using a sample temperature inside the house, are determined the heat fluxes through the two roof constructions for the investigated period and are calculated the total energy loses.

Keywords: green roof, tile roof, simulation, winter conditions.

Introduction

The minimization of the energy loses through the roof is an important problem for improving the buildings microclimate. There are a number of studies, showing the green roof could solve this issue by providing potential energy savings during the summer season. The reason for this is that they maintain low roof temperature, which reduces the energy expenses for climatization [2,4].

The climate in Ruse, Bulgaria is characterized with relatively cold winters with the air temperature reaching down to -20 $^\circ C$. The latitude is 43.8 N wherefore the sun position on the horizon during the winter season is relatively low, which leads to lower maximum value of the solar radiation – about 700 $W.m^{-2}$. The energy conservation which the green roof provides could lead to effective reduction in the energy loses. Still there is lack of information about the green roof performance under winter conditions as well as a comparison between a green and a tile roof.

The goal of this study is to perform a comparative analysis between the two roof construction types, using the model of heat exchange and accumulation of a green roof [1] and the model of heat exchange through a tile roof [2], for the winter conditions in the city of Ruse, Bulgaria.

Object of the investigation

In Bulgaria the most common roof construction covering is the classical clay tile roof. It reflects about 26% of the solar energy and the rest is accumulated in the form of heat. The green roofs with a well developed grass cover also reflect about 26% of the solar energy, but in the winter this percent is reduced because of the reduced vegetation quality. The energy balances of these two roof construction types has the following form (fig. 1) [1,2]:

$$Q_{env.tile} = Q_{solar} - Q_{refl} - Q_{rad} - Q_{conv}, \; W.m^{-2}, \quad (1)$$

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$$Q_{env.gr} = Q_{solar} - Q_{refl} - Q_{rad} - Q_{conv} - Q_{ET}, \; W.m^{-2}, \quad (2)$$

where $Q_{env.tile}$ is the energy flow of the accumulated heat energy in the roof tile, $W.m^{-2}$;

$Q_{env.gr}$ - the energy flow of the accumulated heat energy in the green roof, $W.m^{-2}$;

Q_{solar} - the solar energy flux, $W.m^{-2}$;

Q_{refl} - the reflected energy flux, $W.m^{-2}$;

Q_{rad} - the radiant heat transfer energy flux, $W.m^{-2}$;

Q_{conv} - the convective heat transfer energy flux, $W.m^{-2}$;

Q_{ET} - the evapotranspiration energy flux, $W.m^{-2}$.

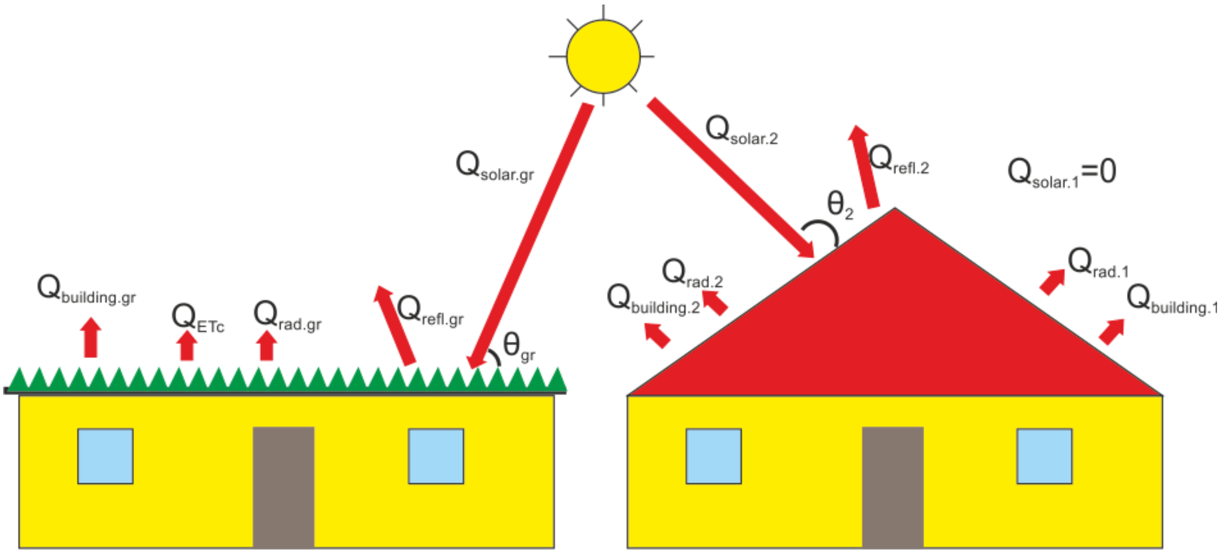


Fig. 1. Energy flow between the environment and green and tile roofs under winter conditions.

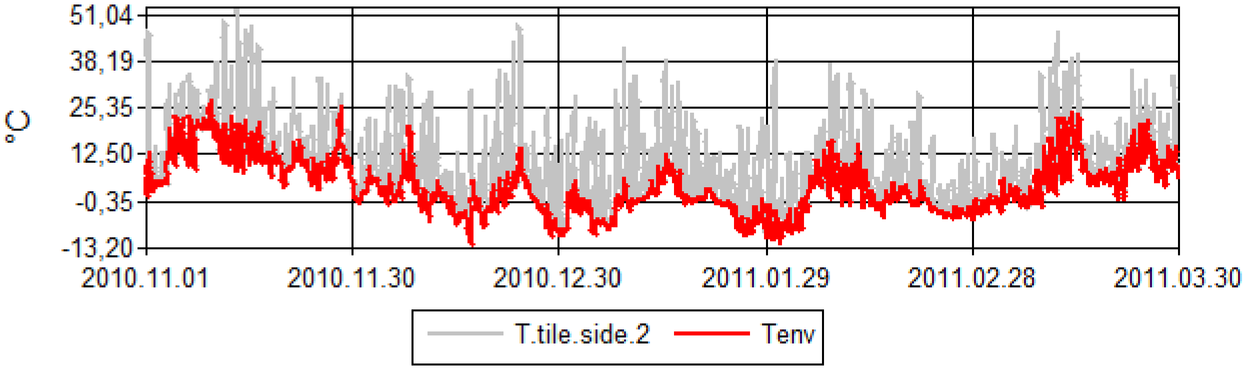
During the winter season the evapotranspiration energy flux has low influence because the air temperatures are low and the relative humidity – high. This makes the two energy balances almost identical but the roof characteristics differ. The first major difference is the roof surfaces. A flat green roof could have up to two times lower surface compared to a tile roof. Another difference is the solar energy angle. Considering the sloped roofs have two sides, if one of them is facing south and the other north, the solar energy flux falling on the north one is very limited during the winter months and includes mainly reflected energy.

Simulation and analysis

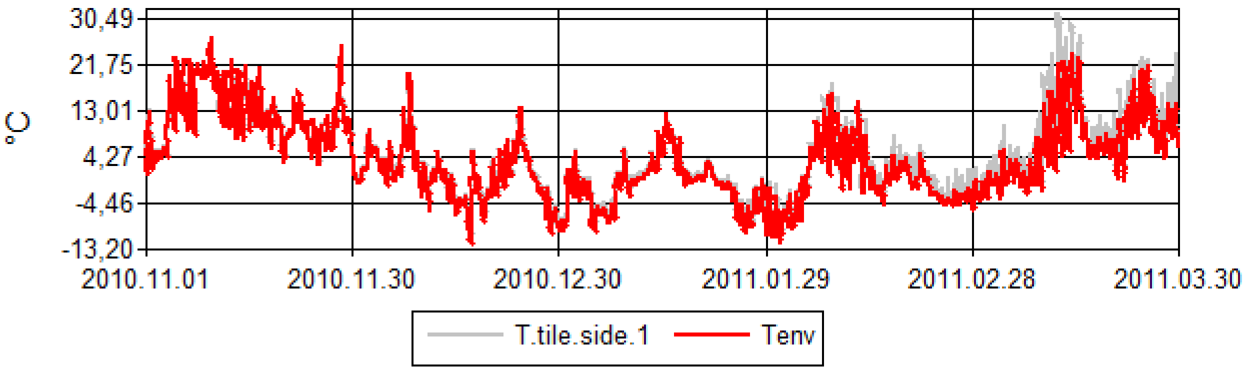
A specialized software application has been developed in the Visual Studio 2010 environment, implementing the models developed in [1] and [2]. It has been used to perform a simulation of the energy flow through two roof constructions, which basic characteristics are presented in table 1 [3,5]. In the simulation has also been used the meteorological data in the city of Ruse for the months November 2010 – March 2011, particularly the environment temperature and relative humidity, the wind speed and the cloudiness. The results from the simulation have been presented on figures 2, 3 and 4.

The temperature variation of the north and south tile roof surfaces have been presented on figures 2. From the graph could be seen that during the months November, December, January and February almost no solar energy falls on the north oriented surface. Low levels of solar energy could be noticed only in March, when the surface temperature is higher than the environment one. The temperature gradient between the south roof surface and the environment does not surpass 30 $°C$ during sunny conditions and is close to zero during most of the time.

The temperature variation of the bottom soil layer of the green roof is presented on figure 3. It could be seen that for a 10 cm soil substrate the temperature of the bottom layer is averagely 5 $°C$ higher than the environment, while for a 30 cm soil substrate this gradient reaches 10 $°C$.

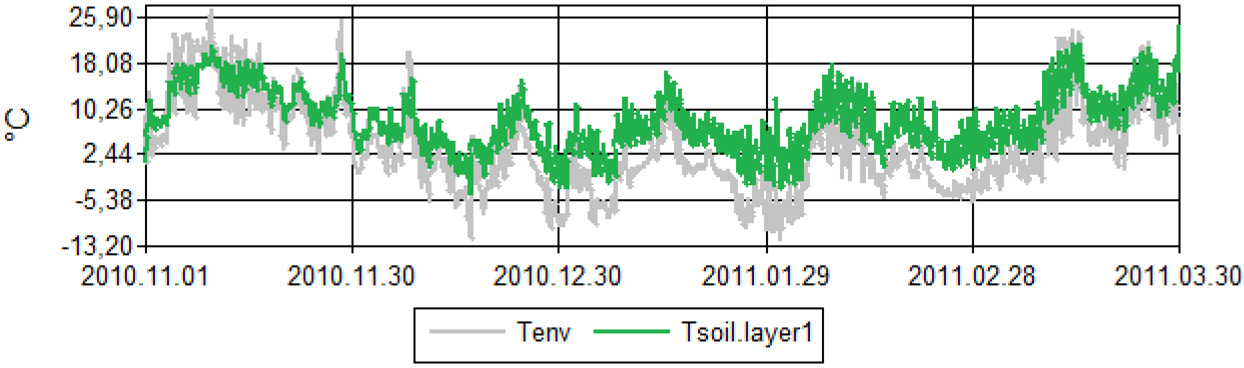


(a)

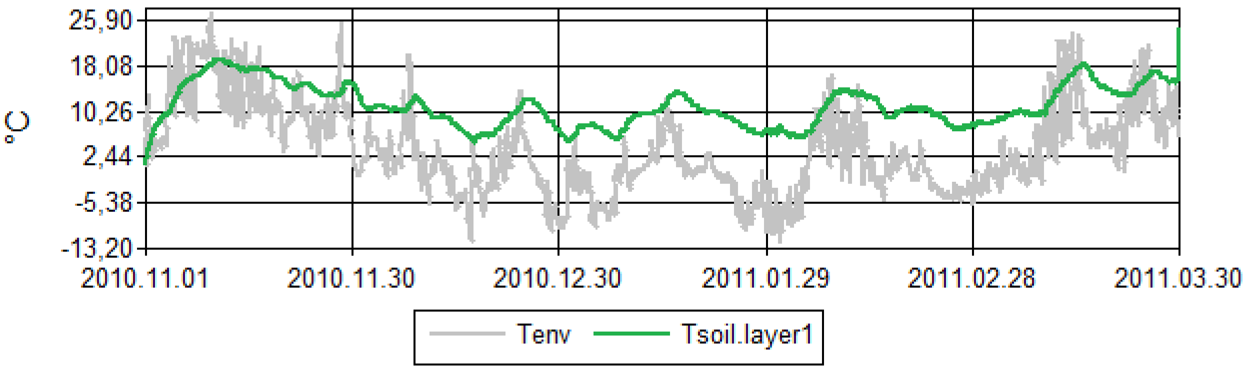


(b)

Fig. 2. Temperatures of the environment and the:
a) southern tile roof surface; b) northern tile roof surface.



(a)



(b)

Fig. 3. Temperatures of the environment and the bottom soil layer for:
a) 10 *cm* soil substrate; b) 30 *cm* soil substrate.

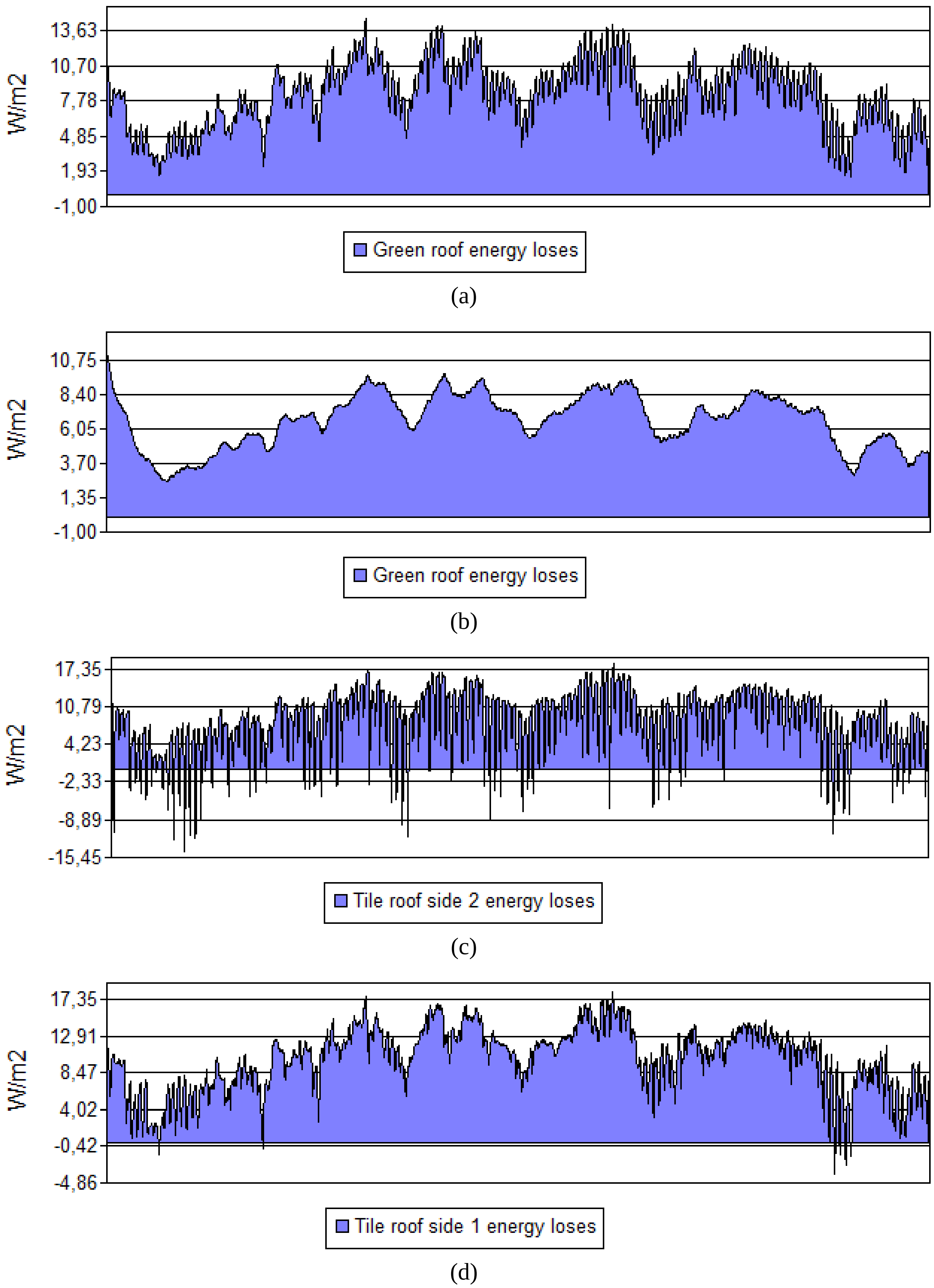


Fig. 4. Heat flux through: a) a 10 *cm* green roof; b) a 30 *cm* green roof; c) the southern side of a tile roof; d) the northern side of a tile roof.

Table 1.

Values of some of the roofs characteristics used in the simulation.

Thermal conductivity of Chernozem soil	0.31 $W.m^{-1}.K^{-1}$
Specific heat capacity of Chernozem soil	1041 $J.kg^{-1}.K^{-1}$
Albedo of green grass	0.26
Density of Chernozem soil	1290 $kg.m^{-3}$
Specific heat capacity of clay roof tile	920 $J.kg^{-1}.K^{-1}$
Albedo of clay roof tile	0.26
Mass of 1 roof tile	5.5 kg
Number of roof tiles per square meter	10
Surface of the roof surface	100 m^2
Width of the concrete plate	0.15 m
Thermal conductivity of concrete	1.63 $W.m^{-1}.K^{-1}$
Insulation depth	0.05 m
Thermal conductivity of the insulation	0.03 $W.m^{-1}.K^{-1}$
Orientation of the tile roof	North – South
Slope of the tile roof	60 °

On figure 4 are presented the energy loses through the two roof constructions. It could be seen that the heat flux through a 30 cm soil substrate (fig. 4b) is lower than through a 10 cm one (fig. 4a). Nonetheless the difference between them is not significant. The total energy loses for the whole period through a 10 cm and 30 cm green roofs are 2913 $kW.h$ and 2310 $kW.h$ respectively.

The heat fluxes through the southern and northern sides of a tile roof are presented on fig. 4c and 4d respectively. It could be seen that although the southern surface gets much more solar energy and reaches higher temperatures, the difference between them is not that great. The total energy loses through the tile roof for the whole period are 6799 $kW.h$.

Conclusions

A specialized software application has been created in the Visual Studio 2010 environment, implementing the developed in [1] and [2] models of heat exchange and accumulation processes in a green roof and the heat exchange processes in a tile roof. It has been used to perform a simulation of the heat flux through the two roof constructions, using the meteorological data in Ruse, Bulgaria for the period November 2010 – March 2011. The results have been presented in a graphical form.

The temperature variation of a southern and northern tile roof surfaces and a green roof with 10 cm and 30 cm soil substrate have been visualized. It could be seen that a 10 cm green roof has 2.3 times less energy loses, compared to a tile roof, while for a 30 cm green roof they are 2.9 times less. This means that the green roof could reduce significantly the energy loses in the winter conditions of Ruse. It could be seen that the difference in the energy loses between a 10 cm and a 30 cm green roofs is not significant, while the difference in the construction cost would be significant because the soil mass of a 30 cm roof would be 3 times higher. The conclusion is that for the winter climate conditions of Ruse, Bulgaria, the optimal soil substrate depth is 10 cm.

It should also be noted that in this simulation has not be considered the snow cover, which would offer additional decrease in the energy loses through a green roof.

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