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Extensive roof garden as a thermal insulator

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Abstract

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Extensive green roofs are established with thin layers of substrate exerting only small load to the roof. The construction of such a roof is relatively simple, low cost demanding, and, on the other hand, it is able to improve not only the ecological value of the concerned building but also the overall value of its surroundings. One of the requirements an extensive green roof is able to comply with is thermal insulation of the roof. The aim of our research was to find the extent of energy savings in case of a model green roof in climatic conditions of the Nitra town. The roof was built with standard materials with heat transmission coefficients refereed by the manufacturer. At the same time we evaluated, using the TEVLAKO software (software for heating systems and thermal protection of buildings), energy savings and losses corresponding to reduced thickness of thermo-insulating materials used for construction of the studied model extensive green roof. We obtained the following results:

1. An extensive green roof can represent lower costs thanks to reduction of the necessary thermo-insulation layer.
2. In summer, an extensive green roof can represent savings in energy necessary for cooling air in rooms situated immediately under the roof, because green roofs reduce the penetration of heat from solar radiation and can lower the inside temperature under the roof by 5–6 ºC.

Key words

extensive roof garden, green roof, roof insulation value, reduction in heating energy costs, reduction in summer cooling needs, reduction in thermo-insulating materials

Introduction

A roof, as a part of outer skeleton of a building, is sharing the control of the inner building climate, by reducing the effects of external factors. Each roof needs to comply with the given requirements (standards) dependent on the chemical and physical properties of the roof material. A green roof, particularly its vegetation layer, is modifying, to considerable extent, the thermal-insulation properties of the original roof.

One of profits cited in connection with positive impact of green roofs is their thermo-insulation effect. The roof gardens can provide thermal insulation in winter when they reduce the amount of escaping heat. In summer, by contrast, they can positively influence temperature in rooms placed immediately under the roof because they do not allow the accumulated solar energy to penetrate into the rooms. The thermal insulation is dependent on the thickness of roof-covering substrate and on the type of plant cover. Apart from these, there are also present effects of other green roof layers – water-proofing and drainage layer. According to Dürr (1995), the thermal-insulation efficiency of a green roof is not uniform, but it depends on actual climate, and, consequently, on the moisture pattern throughout the individual layers of the vegetation profile, on the water flow in the drainage layer and on the actual wind speed. Dürr (1995) also suggests that in summer, an evident cooling effect of roof gardens is exerted on rooms situated immediately under the roof whose temperatures are evidently lower compared to the temperatures under classic roofs. The mean summer temperature in rooms under flat roofs reaches about 25 ºC, in hot summer days even 30 ºC. Liesecke (1989) reports values decreased by 3–4 ºC after providing the roof with a green cover. Minke (2000) explains this fact as a positive effect of vegetation shading the soil, preventing it from over-heating, because a part of solar energy is absorbed in water evaporation from the soil, and the photosynthesising plants consume another part.

Various-oriented research has resulted in the finding that each vegetation cover is a very complex system, and that the measurements of heat amounts and losses between the plants, soil and atmosphere are intricate. The complete physical pattern of performance of these elements outlined up to now remains unsatisfying, in spite of well-sophisticated equipments and technology. However, the potential thermal-insulation effect of roof gardens has been commonly approved in the literature, primarily in case of rooms placed immediately under the roof.

Material and methods

Extensive roof gardens are limited with a load up to 300 kg m^{-2} (300 KN m^{-2}). Such load is considered in static design of residential buildings and also of many-storey facilities, which people live and work in. We may suggest that all the flat roofs of panel housing blocks constructed since the 1970s can comply with the load requirements of an extensive roof garden.

Some authors define extensive roof gardens as green roofs without artificial irrigation. This definition can turn contradictory in case of territories with higher regular natural precipitation because these conditions allow us to grow also mesophyte plants in thicker layers of soil growing media. In such a case, the load to the roof can even increase up to 1,000 kg m^{-2}.

Extensive roof gardens are in general established with thin layers of growing media, from 20 to 150 mm in thickness, usually on flat or moderately sloped roofs, up to 45º. Slopes exceeding 45º are rare, and they require a special technology to stabilise the layers against slide. The most frequent solution is planting in panels where each separate panel is attached to the roof construction (Šimek, 2004).

Extensive roof gardens are established with mineral growing media, the first are primarily important in areas poor in precipitation. An extensive roof garden can retain storm water and allow its gradual run-off from the roof, without overloading the local wastewater system.

According to the required amount of maintenance we distinguish between roof gardens:

- Extensive
- Semi-intensive.

Extensive roof gardens are established on thin layers of growing media planted with xerophyte plant communities consisting of mosses, lichens, sedum species or dwarf grasses. In this case it is not true that all the herbs with natural requirements appropriate for poor site conditions are suitable for this type of roof greenery. Krupka (1992) suggests that deep-rooting plants and perennial herbs from rock cracks and fissures are a positive exception. The plants provide the roof with a connected cover not allowing weeds (if any) to develop their roots. This green roof does not require almost any maintenance, except several checks a year and removing accidental natural seeding of woody plants that might cause damage (in spring when the precipitation is abundant) to the roof garden structure. The roof can either be contaminated with weeds just at the establishment when weed seeds are present in the applied growing medium or at the initial stage when the herbal stands have not yet created connected canopy.

In case when the growing medium layer is extremely thin (20–50 mm), neither natural seedling of the non-desired species can survive. These species can germinate in spring, they, however, get gradually dry with decreasing water supply and they cannot compete with the target species (Wagnerová, 1996). The plant species for extensive roof gardens are selected from sites with extreme drought and frosts, and they have a considerable capacity for regeneration (Liesecke et al., 1989). Feriancová (2002) defines an extensive vegetation as consisting of forms very close to nature, able, after having been established, to develop and self-sustain. The appropriate choice of the plant community well-fitting the natural local conditions (in other words as far as the chosen plant community is native to the ecological site) can ensure that even seedlings of other native species that are embedded into the natural vegetation dynamics cannot suppress the planted species because the last are almost identical with the surrounding vegetation (Kolb and Schwarz, 1999). The closer is the plant community consistent with the given ecological conditions, the higher is the probability that the roof garden will be well functioning under a minimum keep-up. We can say that the degree of extensiveness of a roof garden corresponds to the degree of ecological stability of the plant cover.

Semi-intensive green roofs are established with thicker substrate layers, from 80 mm to 350 mm, sometimes even more. These can only be constructed in areas with regular precipitation with the annual total exceeding 800 mm. This type of roof greenery comprises roof gardens with more sophisticated architecture, and higher-demanding design primarily consisting of higher plants (xerophytes and mesophytes perennial species, drought-tolerating dwarf woody plants, planted in beds, groups or regular lines).

The most common types of roof garden are designed as aesthetic but also recreational. The second case is connected with higher requirements for structural support (500 KN m^{-2} and more). The maintenance of this type of roof garden is given by the garden itself. When the roof is covered with a conventional lawn, regular mowing is necessary, together with other treatments required for keeping an intensive lawn. In case when the lawn is extensive, the maintenance only consists of moving once or more times yearly. Other necessary treatment comprises regular weed removal, re-planting and supplementary planting of perennial herbs, regular alterations in herbal beds, removal of dry flowers, fertilisation, etc. Shrub beds require weed removal, removal of dry branches and twigs, regeneration of old shrubs, pruning of regular and line plantations, etc. Most interventions are very similar to an ordinary garden.

Our research model was an extensive green roof situated in the town of Nitra with standard climatic conditions. The roof layers were prepared from materials for which the manufacturer assigns the heat transfer coefficient "U". The calculation was carried out with the aid of the "TEVLAKO" software used by designers of heating systems and thermal protection of buildings. At the same time, it was necessary to design the roof greenery in such a way as to ensure compliance of the designed layers with the minimum value of the thermal resistance of the roof stated by the standard STN 73 0540-2.

The calculation required doing the following:

- o Assembly the mean long-term climatic data for the town of Nitra.
- o Design the layers of the roof garden in such a way as to meet the thermo-insulation requirements for roof constructions set by the standard STN 73 0540-2, taking in consideration climate conditions of the Nitra town.
- o Determine the maximum possible reduction in the thermo-insulation layer of the roof top (under which the roof garden is situated) with included transmission heat loss coefficient of the extensive roof garden.
- o Provide the TEVLAKO software with the obtained data and perform the evaluation.

Results and discussion

From materials fit for building hydro-thermal insulation layers for roof gardens, with the values of thermal resistance declared by the manufacturer, we selected, as suitable for our climatic conditions, two types of hydro-insulating boards produced by ZinCo: Floratherm WD 65-H and Floratherm WD 120-H. The first type has a thickness of 65 mm, the second 120 mm (Table 1).

The standard STN 73 0540-2 requires for new buildings the coefficient of thermal transmittance U lower or equal to 0.2 W m^2 K^{-1}, where W is watt, unit of electric power in the SI system, m^{-2} is the surface area unit and K^{-1} is the unit of difference in temperature.

The classic flat roof with a water-vapour-tight layer was designed in the following way: 1. viewed-from-below layer, 2. roof deck, 3. water-vapour-tight layer, 4. equalising and sloping layer, 5. thermo-insulating layer, 6. protective layer.

The materials proposed for the separate layers, namely the roof garden and underlying layers: 1. vegetation cover of sedum species, 2. mineral substrate in a thickness of 50 mm consisting of 80% keramzite and 20% peat, 3. geo-textile filtration layer 4. drainage-accumulation layer Floratherm WD 120-H with water retaining capacity up to 13 l per 1 m^2, 5. root-protection layer, 2 mm in thickness (eg IIR), (Fig. 1).

The thermal performance of both roofs was compared using the TEVLAKO software.

The aim of the first calculation was to find out whether there were possible savings in material necessary for the roof thermo-insulation in case when the roof was extensive green. According to our results, it is possible to reduce the thickness of the Nobasil layer (in compliance with the standard) under the conditions in concern. While the climate conditions of the Nitra town require for Nobasil a thickness of 160 mm in case of a classic flat roof, the corresponding green roof only requires 100 mm, to reach the same thermal insulation.

Table 1. Parameters of the used hydro-insulating boards produced by ZinCo

Hydro-insulating board	Thickness (mm)	Thermal resistance R (m^2 K W^{-1})	
		Non-saturared with water	Saturated with water
Floratherm WD 65-H	65	0.90	0.65
Floratherm WD 1205-H	120	2.15	1.20

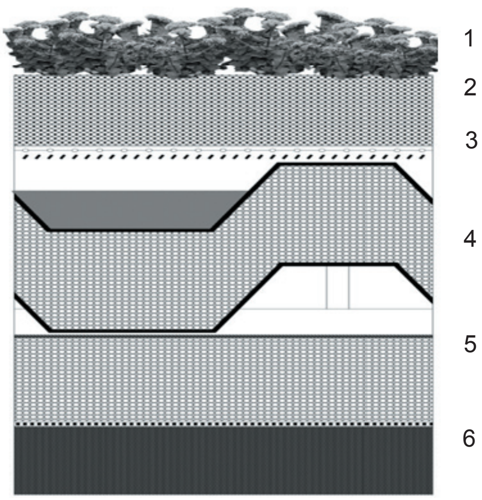

Fig. 1. Cross-section of roof garden layers
1. vegetation cover of sedum species
2. mineral substrate in a thickness
3. geo-textile filtration layer
4. drainage-accumulation (layer Floratherm WD 120-H)
5. root-protection layer
6. roof housing layers

In the first case we compared heat losses between the classic flat roof and the roof garden for the commonly recommended Nobasil thickness of 160 mm, in the second, the same comparison was done for the thickness of 100 mm (reduction by 60 mm). The calculation using the TEVLAKO software was focussed on roof heat losses for:

- o Layers non-saturated with water
- o Layers fully saturated with water.

The calculation followed the formulae:

1. Thermal (heat) loss of the roof was obtained using the relation:

$$Q = S \times U \times \Delta t \text{ (W)},$$

$$\Delta t = t_i - t_e \text{ (ºC)},$$

where Q is the thermal loss of the roof (W) according to STN, S is the roof surface in m^2, U is the coefficient of thermal transmittance (W m^{-2} K^{-1}), t_i is the mean temperature inside the building (ºC) set for residential houses, t_e is calculated (the lowest) temperature of the external environment (ºC), Δt is the difference between the mean temperature inside the building and the mean calculated external temperature.

2. The overall annual heat loss of the roof was obtained according to the following formula:

$$E_t = 24 \times 3{,}600 \times f_i \times Q \times d \times (t_i - t_{es}) / (t_i - t_e) \text{ (J)},$$

where E_t is the annual thermal loss of the roof (J), when heating period is supposed to be 217 days, f_i is the correction of annual dumping, for residential houses being 0.85 according to STN 73 0540-2, d is the number of days in the heating period, according to a fifty and a thirty-year mean (ºC), t_{es} is the mean external air temperature in the heating period, according to the fifty and the thirty-year mean (ºC).

Comparison of heat losses between the flat roof without root garden and the roof garden for the normal thickness of 160 mm of the thermo-insulation material Nobasil (under presumption that the heating period has 217 days)

Basic roof layers with insulation of standard thickness (we calculated heat losses of the roof throughout the heating period in compliance with the requirements set by the standard and under presumption that the heating period length is 217 days):

1. The annual thermal (heat) loss of the flat roof without greenery cover was found to be E_t = 51.36 MJ.
2. The annual thermal loss of the green roof in dry conditions was E_t = 35.755 MJ.
3. The annual thermal loss of the green roof in wet conditions was E_t = 42.80 MJ.

The lowest heat loss was found in case of the green roof and dry wetter (2.)

Comparison between heat losses for the Nobasil thickness reduced to 100 mm, in compliance with the requirements set by the standard (presumed heating period length is 217 days)

1. The annual thermal loss of the green roof in dry conditions was E_t = 42.80 MJ.
2. The annual thermal loss of the green roof in dry conditions was E_t = 51.36 MJ.

The roof with reduced Nobasil thickness had lower heat losses when the conditions were dry (1). Note: MJ = Mega Joule (Joule = unit of energy and work).

Comparison of thermal losses between the conventional flat roof and the roof garden, both provided with Nobasil in the normal thickness of 160 mm, under dry and wet conditions.

Thermal losses under dry conditions

Subtracting from the heat loss value for the conventional flat roof uncovered with greenery the corresponding value for the green roof in dry conditions, that means 51.36 MJ; 35.755 MJ, we obtain 15.6049 MJ, representing the savings in heat loss by transmission in case of the dry green roof. If in 2006 was the price of 1 m^3 of natural gas 14 Sk, and the savings represented 6.40 Sk per 1 m^2 roof area in case of the extensive roof garden in dry conditions in comparison with the conventional roof.

Thermal losses under wet conditions

Subtracting from the heat loss value for the conventional flat roof uncovered with greenery the corresponding value for the green roof in wet conditions, that means 51.36 MJ – 42.80 MJ, we obtain 8.56. The savings in this case represented only 3.50 Sk per 1 m^2 roof area in profit of the extensive green roof in wet conditions in comparison with the conventional roof.

Comparison of heat losses between the conventional roof and the roof garden for the reduced Nobasil thickness of 100 mm

Thermal losses under dry conditions

Subtracting from the heat loss value for the conventional flat roof uncovered with greenery the corresponding value for the green roof in wet conditions, that means 51.36 MJ – 42.80 MJ, we obtain 8.56 MJ. The value of cost reducing by 3.50 Sk per 1 m^2 roof area in profit of the extensive green roof in wet conditions compared with the corresponding conventional roof is the same as it was in case of the extensive green roof with normal insulation thickness in wet conditions.

Thermal losses under wet conditions

If the layers of green roof are wet, no savings in energy are obtained in case of reduced thermo-insulating layer. However, an aspect is dramatically important. The reduction in the thermo-insulating layer compared to the conventional model can only bring heat savings when the roof is "relatively" dry, that means in summer. When the roof layers are wet (what is common in spring, autumn and winter), there are no savings and, on the other hand, no losses compared to the conventional roof.

More important than savings in thermal energy in case when the usual thickness of thermo-insulating layer is maintained, is namely the reduction in the insulating material thickness. In our model using Nobasil SPE, we supposed savings of 301 Sk per one m^2 at costs actual in year 2006. This model should also provide annual (one heating period) savings in heating oil consumption representing three litres per 1 m^2 of roof surface, what is a non-negligible value.

Another savings are possible in summer air-cooling in rooms under the roof. The roof garden reduces heat penetration into the rooms and lowers their internal temperature by 4–5 °C, which is a remarkable improvement in the comfort.

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Extenzívna strešná záhrada ako tepelný izolátor

Súhrn

Cieľom výskumnej úlohy bolo zistiť, ako sa na simulovanej strešnej záhrade v klimatických podmienkach mesta Nitra prejaví šetrenie s tepelnou energiou s použitím konkrétnych materiálov, pri ktorých výrobca udáva koeficient prestupu tepla. Zároveň bolo cieľom vyhodnotiť pomocou počítačového programu TEVLAKO (ktorý je určený pre profesiu vykurovacie systémy a tepelné ochrany budov) úsporu alebo stratu tepla pri zníženej hrúbke tepelnoizolačných materiálov strechy s použitím extenzívnej strešnej záhrady.

Výsledkom šetrenia boli nasledovné zistenia:

1. Pri použití extenzívnej strešnej záhrady môžeme ušetriť náklady na zníženej hrúbke tepelnoizolačného materiálu.
2. Pri použití extenzívnej strešnej záhrady v letnom období môžeme ušetriť energiu na chladenie vzduchu v miestnostiach pod strechou, pretože strešná záhrada zabraňuje prieniku tepla zo slnečného žiarenia cez strechu, a dokáže znížiť teplotný rozdiel až o 5–6 ºC.

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