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Construction and design requirements of green buildings' roofs in Saudi Arabia depending on thermal conductivity principle

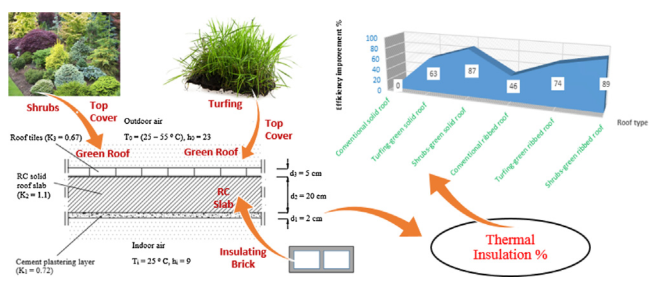
Amjad Khabaz

Civil Engineering Department, School of Engineering, Hasan Kalyoncu University, Gaziantep, Turkey

HIGHLIGHTS

- Conventional reinforced concrete roofs have high thermal conductivity.
- Thermal bridges reduce the efficiency of RC roofs-with air spaces.
- The use of only turfing on green roofs is insufficient at all thermal zones of KSA.
- The use of shrubs on green roofs is acceptable at the second and third thermal zones.
- Recommendation to use a manufactured thermal insulation layer at the first zone of KSA.

GRAPHICAL ABSTRACT



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ABSTRACT

Green buildings aim to promote the positive role of buildings in the community service, and to reduce the negative impact of buildings on the natural environment, as well as to support the national economy. This research showed the inefficiency of conventional roofs, especially those of residential buildings, against heat transfer at different geographical zones of KSA – Kingdom of Saudi Arabia. Thermal analysis of different computational models also led to improvements reached to 89% on roof performance regarding its thermal insulation. These improvements were obtained by converting those conventional concrete roofs into green roofs. In this study, details of several scenarios were shown, and analytical calculations were conducted for different types of green roofs compared to conventional roofs in two main cases, air absence and air presence inside it. According to these scenarios, the impact of vegetation cover on the building roof was determined using thermal models of roof slab in two sub-cases of vegetation cover, one when using the turfing and second when using the shrubs. The results showed that the use of turfing as a vegetation cover is insufficient at all thermal climatic zones of KSA, and the use of air spaces technique increased the efficiency of turfing-solid roof by 87% compared to conventional-solid roof. The use of shrubs in addition to air spaces technique increased the efficiency to acceptable level at most thermal climatic zones. The results also led to recommendations to use a manufactured thermal insulation layer, in addition to shrubs and air spaces, at the first thermal climatic zone of KSA.

1. Introduction

The roof of building is the main structural element that determines the relationship of the building with the surrounding nature. In the summer, in a temperate French climate the fluctuation amplitude of the roof slab temperature was found to be reduced by 30 °C due to the green roof. With a green roof, the summer indoor air temperature was decreased by 2 °C, and the annual energy demand was reduced by 6%, as well as in the winter, the green roof reduced roof heat losses during cold days [1]. Green

E-mail address: amjad.khabaz@hku.edu.tr

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roofs are a passive cooling technique that stop incoming solar radiation from reaching the building structure below. Therefore older buildings will take more benefits from green roofs, especially in countries where over than half of the existing buildings are old such as those in United Kingdom [2].

Despite of that the roof of building is the most exposed part to the summer sun radiation, it is also the part of building that receives the rain and the snow in winter, and a large amount of research has been published in German on the reduction of rainwater runoff for different types of roof greening. Studies showed that the annual rainfall–runoff relationship for green roofs is strongly determined by the depth of the substrate layer. The retention of rainwater on green roofs is lower in winter than in summer. An annual relationship for the region of Brussels was derived and showed that extensive roof greening on just 10% of the buildings would already results in a runoff reduction of 2.7% for the region and of 54% for the individual buildings. Therefore, green roofs can be a useful tool for reducing urban rainfall runoff [3].

Throughout the roof building, the heat of external air (which is high in summer) moves into the building, what necessitates the use of a large amount of energy to adapt the internal atmosphere of the building [4]. The interior heat of the building is also lost in winter, and moves into the cold outside air surrounding the building (according to thermodynamic laws) [5,6]. Therefore the bill of energy consumption will be high in summer and winter [7,8].

In Saudi Arabia, the temperature of the external atmosphere may reach more than 50 °C, and the main construction material in roofs is reinforced concrete, which is classified as a construction material with high thermal conductivity coefficient. Therefore, the cost of air conditioning may reach 70% of the total consumption of electricity for buildings [9,10]. Accordingly, it is necessary to review the construction and design requirements related to the roofs of buildings in Saudi Arabia in terms of thermal conductivity, and to determine the necessary constructional adjustments and specifications [11] to improve its efficiency, especially concrete ones, whether the concrete is reinforced depending on the known traditional methods using steel rebar, or reinforced depending on the modern methods, such as non-metallic fiber reinforced concrete [12] or steel fiber reinforced concrete [13–15]. One of the environmentally preferable options is to convert the conventional roofs designs to green roofs compatible with the thermal conductivity standards adopted in Saudi Arabia, with attention to the impact of that on the mechanical properties of the plain concrete or the reinforced concrete, whether the reinforcement is conducted by steel rebar or fibers [16–18].

In literature, there are complex methods and simplified methods for evaluating the thermal transfer coefficient (U) for green roofs. These methods are also used to evaluate the efficiency of green roofs in terms of their ability to reduce the amount of heat transferred from the external atmosphere to the air inside the building (Q-Value). The complex methods are based on the study of detailed computational models of the types of used vegetation, the expected shading areas and the density of this vegetation, as well as the identification of the soil types, which support the plant (Canopy and Substrate). Therefore, computer programs should be used for the necessary analysis, such as (TRNSYS, EnergyPlus, … etc.). The simplified methods are carried out through thermal models aim to reduce the total value of the thermal transfer coefficient (U-Value) of the studied roof. This is done using experimental values of the thermal properties of the used vegetation cap, whether this cap in the form of Turfing or Shrubs or Trees.

Sailor developed an energy balance model for green roofs [19]. This model depends on equilibrium equations of energy balance, which are developed by Frankenstein, and Koenig [20], this model has been used to evaluate the consumption of energy in offices buildings in Chicago and Houston.

Del Barrio developed a thermal model for the impact of green roofs on the performance of buildings in terms of energy consumption [21]. In this model, the researcher divided the green roof into three parts: (Canopy, Soil and Roof Slab), and then conducted the heat balance calculations between each part and the other with boundary conditions at the (Canopy-Soil, Soil-Roof Slab, and Roof Slab-Indoor Air Interfaces).

Takakura et al investigated the cooling effect of vegetation layers on roof models in summer [22]. Where four models were prepared of concrete roofs covered with different types of green layers, and a reduction in indoor room temperature was obtained by 15 °C because of the use of the vegetation cover.

Alexandri and Jones have developed a two-dimensional model to study the effect of green roofs and walls on the microclimate in a typical canyon [23]. An analytical study was conducted on nine types of typical climates. The results of this study showed that the temperatures can be reduced by 12.5 °C in Riyadh, and that the largest reduction possible in Mumbai up to 26 °C.

Generally, literatures have shown that the green roofs reduce (cooling demand) and improve (summer thermal comfort) [19,21,23,24–26]. Few studies take into account the effect of green roofs on (heating demand), where in the Mediterranean climate, such as Athens, this effect depends on the month in which the effect study is conducted and on the usage type of the building [24,27], or on constitutes a decrease in the demand [26]. In winter also, the energy consumption can be reduced depending on the green roofs like the winter climate in Houston and Chicago [19].

Several factors can be considered when assessing the performance of green roofs, such as the total Thermal Transfer Coefficient of the constituent layers of the green roof (U), and the amount of heat transferred through this roof, which usually called as Conductivity Heat Transfer (Q), which can be calculated using Fourier's law. Based on the evaluation of the performance of thermal models of green roofs and their comparison with thermal models of conventional roofs, appropriate adjustments can be considered as requirements in the design and construction stages of buildings. The aim of this research is to extract some of these adjustments in accordance with the adopted standards in Saudi Arabia in the field of thermal conductivity of the different structural elements in buildings.

2. Materials and methods

2.1. Determination of thermal modeling method

Green roofs can be analyzed by complex methods or simplified methods. In all cases, it is necessary to use an appropriate thermal model, in addition to specific functions, to conduct all necessary calculations. Complex methods are preferred to use to conduct an assessment studies to determine the performance of a specific type of vegetation, compared to other types classified in same vegetation class. For example, these complex methods can be used to compare different types of turfing, or different types of shrubs. In case of shrubs, the area of shade, which is obtained from its leaves, may change from type to type of shrubs, what will affect the performance of this type compared to the other types, all are classified as shrubs, despite of this variation in its performance.

In this research, the goal is to verify, in general, the feasibility of using the green roofs in Saudi Arabia, through the main classifications of plant coverings (turfing, shrubs and trees) without going into details of each of these items. Therefore, simplified methods can be used to achieve this goal. This is done through the development of simplified thermal models for green roofs, and doing the necessary calculation and analysis to evaluate the performance in terms of thermal conductivity and the amount of heat transferred through these models.

The thermal performance of the proposed green roofs is then compared to each other using different types of vegetation (turfing, shrubs and trees), to determine the best of them compared to the conventional roofs, which are currently used in Saudi Arabia buildings.

In order, to determine the feasibility of the use of green roofs in Saudi Arabia, it would be necessary to take measured temperatures of indoor and outdoor temperatures of several samples of buildings in different geographical zones (see Table 1). All measured temperatures in Table 1 were taken for the last floor of residential buildings, which have conventional reinforced concrete roofs. The temperature