INFLUENCE OF GRASS COVER ON FLAT REINFORCED CONCRETE SLABS IN A TROPICAL CLIMATE

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Abstract: Reinforced concrete slab is a better alternative to regain the land due to the buildings because available land is insufficient for usage with respect to the rate of urbanization. However, the reinforced concrete roof slabs do not perform in acceptable level in tropical countries with warm humid climate condition and tend to act as heated bodies which emit long wave radiation to the occupants. As a solution, a green roof is proposed and its thermal performance was determined experimentally using small scale models. Using experimental results, large scale building models were developed to simulate the indoor thermal performance of green roofs and it is shown that the green roof provide satisfactory indoor thermal performance while providing many other benefits such as enhancing aesthetic and regaining lost land for the building.
Key words: Reinforced concrete slab, Green roofs, Indoor thermal performance, Warm humid climate

1. Introduction

The rapid increase in human population over the 20th century has raised concerns about whether Earth is experiencing overpopulation. The scientific consensus is that the current population expansion and accompanying increase in usage of resources is linked to threats to the ecosystem [1]. As a reason of rapid increase in this human population and industrialization, most of facilities such as money, services and wealth were centralized into the cities. Cities are where fortunes are made and where social mobility is possible. According to the UN State of the World Population 2007 report [2], in 2008, the majority of people worldwide migrated to towns or cities, for the first time in history; this is referred to as the arrival of the "Urban Millennium" or the 'tipping point' [3].

Therefore, available land per person is decreasing rapidly in most of developing cities and value of a land is also increasing unbearably. This leads to increase the usage of the available land in an effective manner and people tends mostly to construct high-rise buildings with flat reinforced concrete roofs to gain maximum usage from a minute area. Although this is a more desirable option than having a typical roof with a ceiling, it will create a few additional needs with respect to occupant thermal comfort [4].

However, the concrete roof slabs do not perform satisfactorily in warm humid tropical climate conditions [5] because they act as heated bodies and emit long wave radiation into the occupants in the day time. As a result, indoor thermal comfort of the buildings which having concrete roof slabs becomes fewer and passive features should be included as possible to enhance the indoor thermal comfort in these buildings as using robust roof slab insulation system and enhancing micro climate conditions. The green roof is also a superior alternative for augmenting the indoor thermal performance of a building. It was found that the rooftop temperature can be reduced by about 15^{0}C depending on the vegetation cover, which reduces the transmittance of solar radiation up to 50% [5]. In general, the green roof performs as a capacitive insulation and also short wave radiations are absorbed by the grasses. Hence, the heat flow into the concrete roof slab is insufficient and it enhances the indoor thermal performance in the building in addition to provide other benefits such as enhancing the aesthetic and regaining the land which is lost due to the building.

When introducing an alternative such as green roofs for the buildings as a substitute of reinforced concrete roof slabs, it is better to carry out a comparison between the green roof slabs and the reinforced concrete roof slabs to evaluate indoor thermal performance of each case. It may help to determine the real benefits of the green roofs rather than using artificial ventilations to achieve a better indoor thermal comfort condition in buildings.

2. Objectives and methodology

The main objective of this research is to determine the influence on the indoor thermal performance of a building by introducing a green roof in a warm humid climate condition. The following methodology was used to achieve the above objective:

a) The temperature measurements on actual models with green roof slab by having soil thicknesses of 25mm, 50mm and 75mm were used to find out the heat flow characteristics for computer simulations.
b) Computer simulations were carried out for a typical building with flat concrete roof and flat concrete roofs with green roof slabs.
c) A comparative study was carried out using the above simulation results for reinforced concrete roof slabs and green roof slabs with different soil thicknesses to determine the effect of the sensible heat component on the indoor thermal performance in a typical building.

3. Behavior of heat flow on a green roof

The initial investigation was to determine the indoor thermal comfort conditions in four small scale models. Each model consisted of 125mm thick concrete slab, two 125mm thick cement block walls in each side and the length and the height of walls are 1.25m and 0.5m respectively. A 10mm space was also provided at the top to represent the ventilation condition in a building. Buffalo grass (Bouteloua dactyloides) was used for those models. Buffalo grass is the very native turf grass type for a tropical country because Buffalo grass may reduce the cost for irrigation, maintenance and also it is less vulnerable to the grass diseases.

Four models were utilized to measure the heat flow through a green roof. One model was kept as concrete slab and other models were covered with soil layers of 25mm, 50mm, and 75mm respectively, which were rich with sand to provide a good drainage condition. Figure 1 shows the arrangement for obtaining the temperature measurements.

Figure1- Four models used for the data collection

The slab soffit temperature, slab top temperature, indoor temperature were obtained on a typical sunny day for following cases as without grass cover (case 1) and with a grass cover with soil thickness of 25 mm (Case 2), 50 mm (Case 3) and 75 mm (Case 4) respectively.

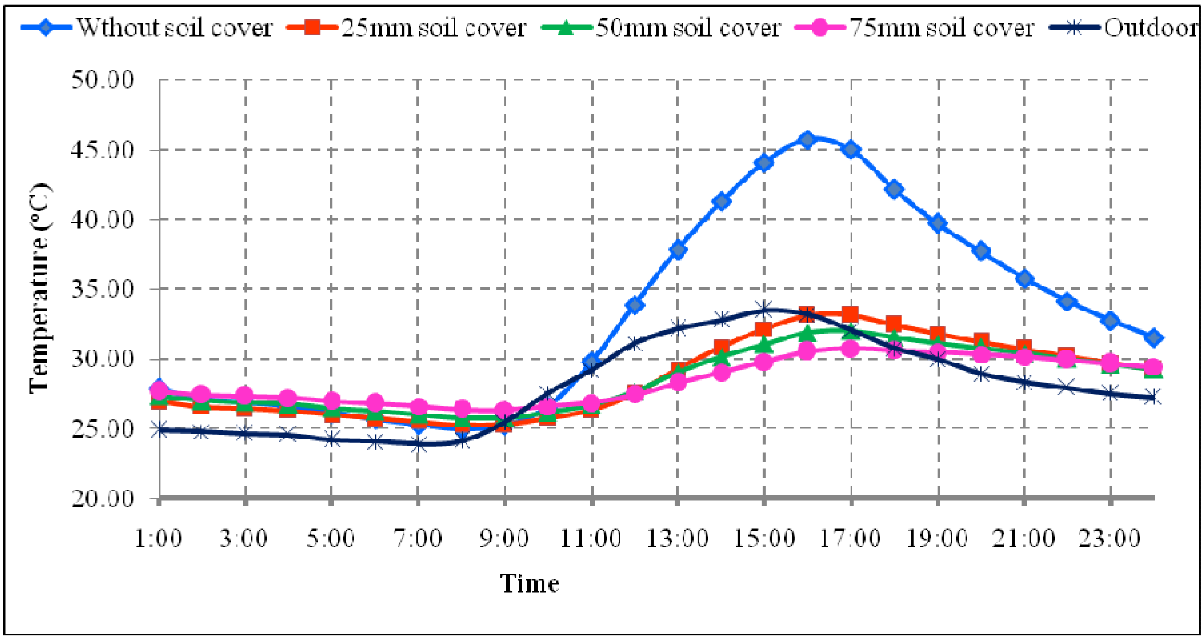

Figure 20- The temperature distribution at the Slab soffit for different soil thicknesses

Figure 2 shows that the slab soffit temperature variation in a typical sunny day for 24 hours. During day time, the maximum slab soffit temperatures of the models without soil cover, with 25mm, 50mm and 75mm soil cover are 45.7°C, 33.2°C, 32.0°C and 30.7°C respectively. According to the slab without soil cover emits considerable amount of long wave radiation and green roofs are not emitting much long wave radiation during day time because they are almost equal to the maximum outdoor temperature of 33.5°C. During night time, soffit temperatures of each model are approximately the same.

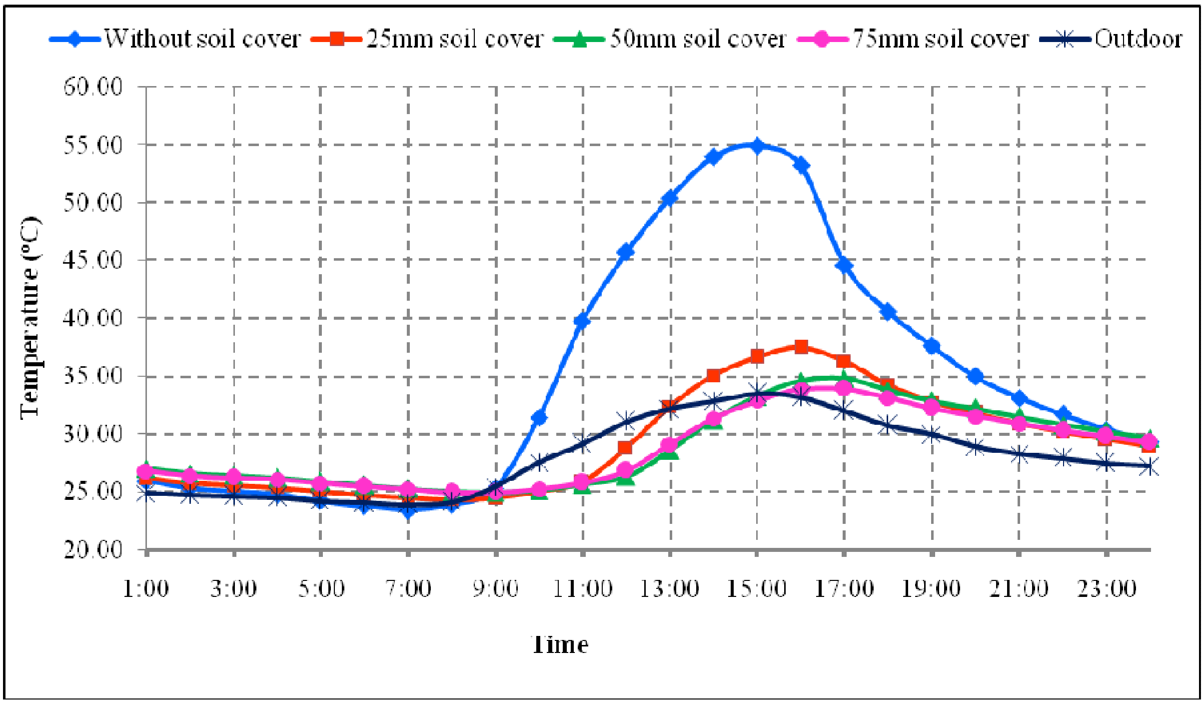

Figure 21-Surface (slab top) temperature distribution for different soil thicknesses

Figure 3 shows the slab surface temperature variations of four models for 24 hours and they also show a similar behavior as the slab soffit temperatures of the models. However they have higher temperature values than the slab soffit temperatures. The maximum slab top temperature reached up to 54.9^{o}C without soil cover slab because it directly exposed to the sun and absorbed a considerable amount of short wave radiation during day time. The maximum slab top temperatures of the models with 25mm, 50mm, and 75mm thick soil covers are 37.5 ^{0}C, 34.8 ^{0}C, and 33.9 ^{0}C respectively. Main reasons for having less slab top temperatures are the thickness of soil cover and the absorption of short wave radiation by grass for the photosynthesis.

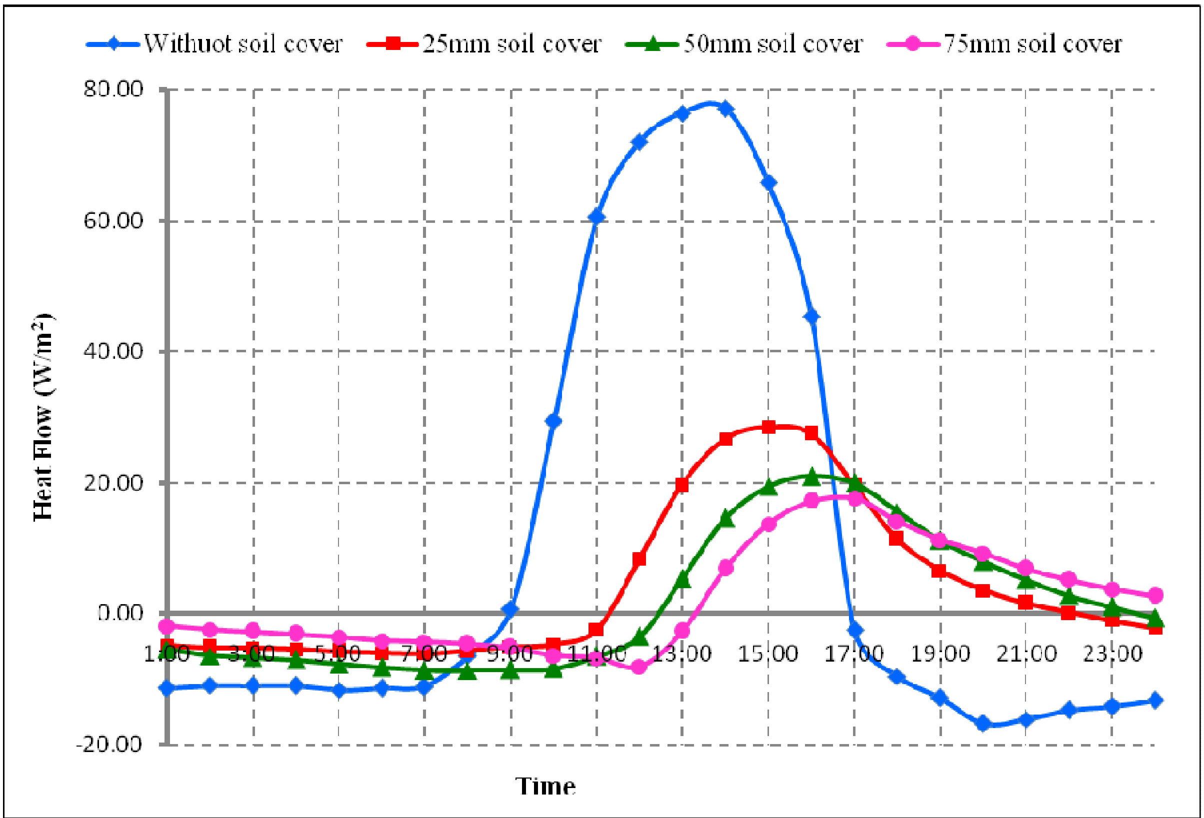

Figure 22-Heat flow values for different soil thicknesses

The heat flow values were calculated using "U" values, called the overall heat transfer coefficient of the materials. The detailed calculation of "U" values is presented in Appendix A. Figure 4 shows the heat flow variations for the models with soil covers and without soil cover. The maximum heat flow of the model without soil cover reached 77.1 W/m^{2} and there is a heat flow towards the occupants from 09.00 hours and 17.00 hours. Therefore, in the day time occupants in the buildings having only a flat concrete slab, feel more thermal discomfort due to this kind of heat flow. However, the maximum heat flow obtained was 28.5 W/m^{2} for 25mm, 20.9 W/m^{2} for 50mm and 17.6 W/m^{2} for 75mm thick soil cover models. This is a great amount of heat flow reduction, compared to the buildings having only roof slab. When referring this Figure 4, it can be easily proved that the green roofs performance better than unprotected slabs even in night times. Uncovered slab can reverse the heat flow from 17.00 to 9.00 while in green roofs remains approximately constant.

4. Computer simulation for the models

Computer simulations were used to predict the thermal performance of a building by varying its properties. DEROB-LTH software was utilized and it is a widely used software simulation package in creation of models of actual buildings. DEROB-LTH is capable of calculating thermal energy transmission across the building using of the building properties such as thickness of the layers of the wall and material types. The calibration detail of DEROB-LTH can be found in Halwatura and

Jayasinghe [5]. This has also been validated by many researchers [6, 7, and 8]. In this study computer simulations were used to predict the thermal performance of green roofs.

4.1 Model used

Physical models for computer simulation which described in section 3.0, were modelled using DEROB-LTH and analyzed to obtain the properties of the grass cover. After obtaining the properties of the grass cover, those results were used to analyze the large scale computer models. For large scale models, a two story scale building model was used for simulations because the upper floor of a two storey house is severely affected by the direct solar radiation than a single storey house. The plan area of the house models were 11.5m * 7m. The same house model was simulated with a flat slab and green roof as the roofing system. The aim of research was to investigate the performance of a green roof as a passive technique; therefore, the models were created including all possible passive techniques. The passive features that were included in the models are as follows:

- Windows were faced to Southern and Northern directions, so that the direct solar radiations can be minimized as much as possible
- Shading screens were used to protect the windows from the direct radiation
- 225 mm thick brick walls were selected to reduce the heat transfer through the exposed walls [9]

Such passive features generally have the potential to reduce the indoor air temperature by about 3^0C below the outdoor temperature [10]. The other possible passive features such as courtyards [8] were not considered because they may not be as common as the above mentioned passive features. For the two storey houses with a green roof, a 115mm thick reinforced concrete slab was used at the top floor and a soil layer was introduced over the top slab. This was taken as the case GR. For flat slabs, the top slab of the house models was taken as the roofing system. The thickness of the slab is 115mm and the bare flat slab was considered as the roof. This was taken as the case FS.

4.2 Different cases considered

In this paper two types of roofing systems related with roof slabs were discussed. They were flat slabs and green roofs. For the green roofs three different cases were considered while for the flat slab was considered along. For each case the indoor thermal performance was calculated using DEROB-LTH. The three different cases considered for simulations were as follows.

Case GR1: Green roof slab with 25mm thick soil layer
Case GR2: Green roof slab with 50mm thick soil layer
Case GR3: Green roof slab with 75mm thick soil layer
Case FS: Roof with a flat slab

Figure 5 and figure 6 show the DEROB models used for the simulation.

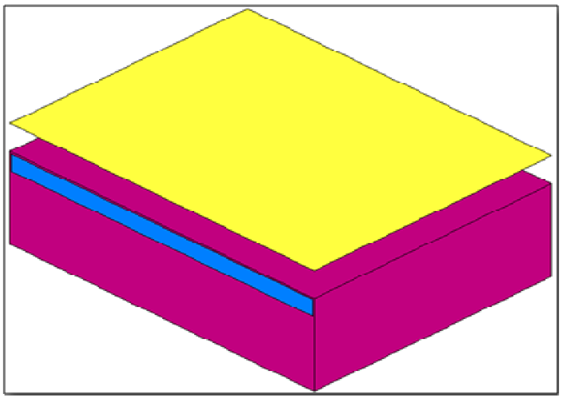

Figure 5- Field model used for the computer simulation

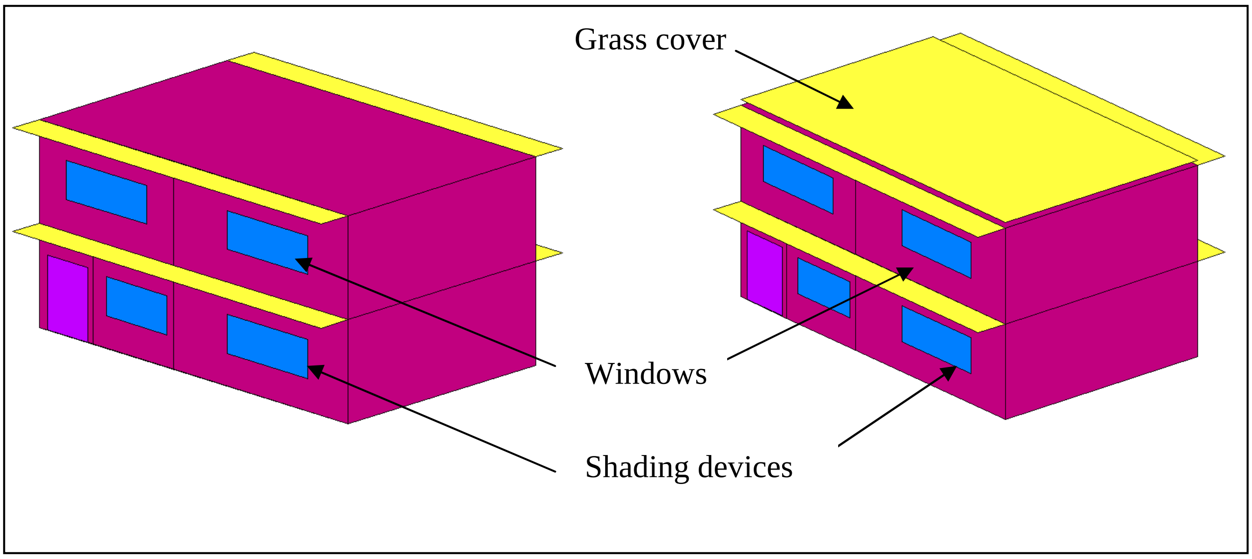

Figure 6- Large scale house models used for the computer simulation

5. Results and Discussion

5.1 Performance of field model

Figure 7 shows the indoor temperatures variation of the field model with a 50mm soil cover. The data was taken in three bright sunny days for a period of 12 hours. In all three days the maximum indoor temperature of the field model was about 32^{0}C. Also the maximum temperature was observed around 14-16 hrs in each day.

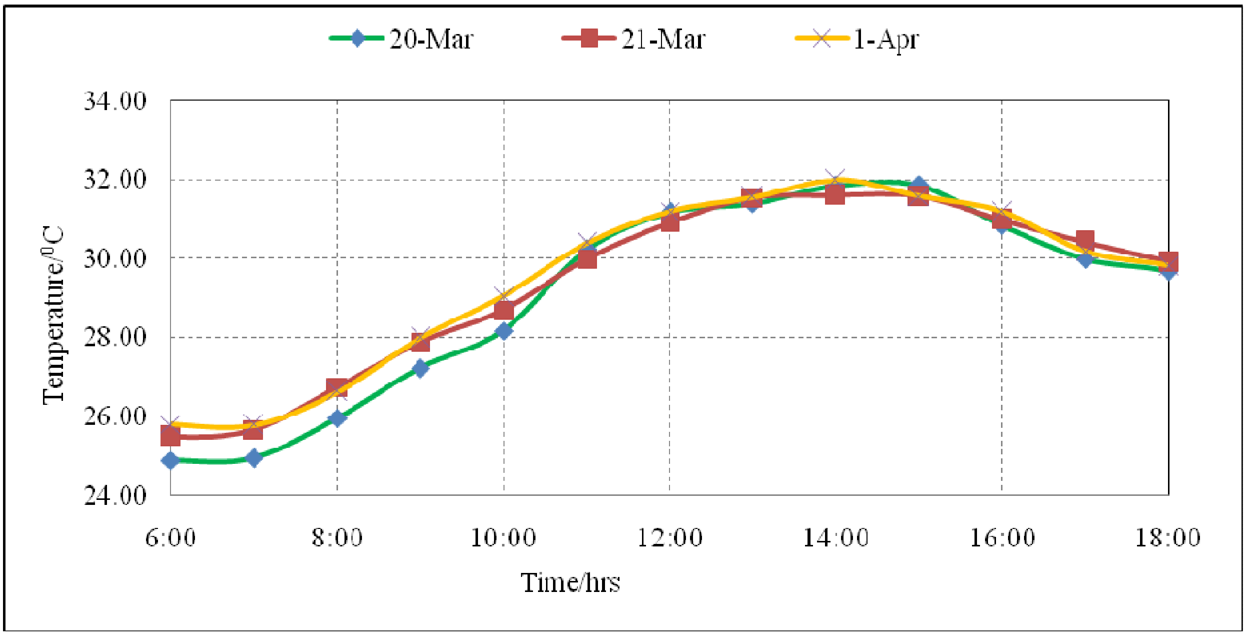

Figure 7- Indoor temperature of the field model for bright sunny days

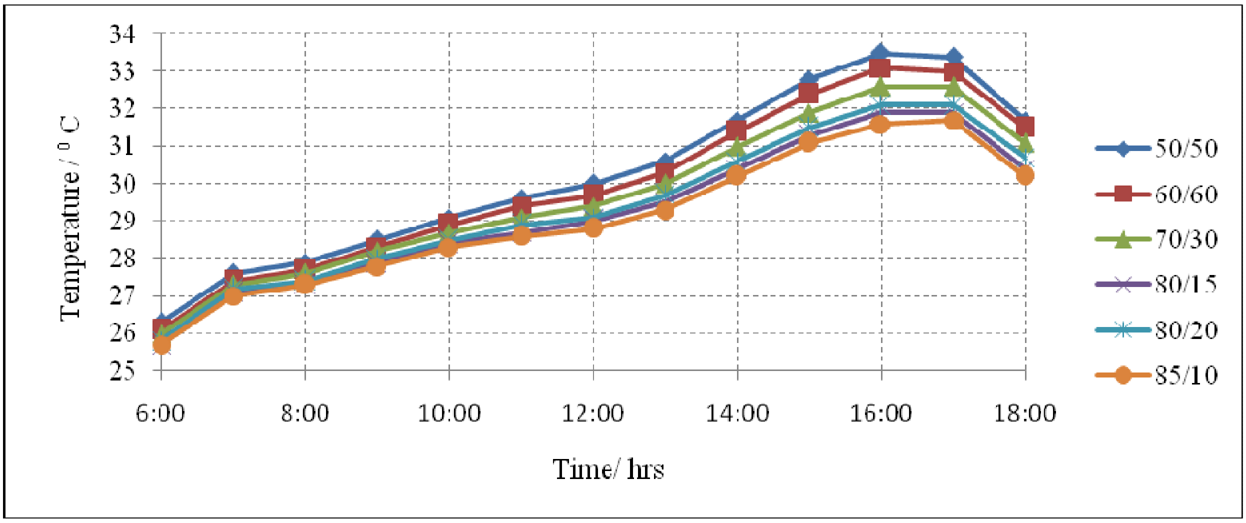

Figure 8- Indoor temperature variation of the DEROB model with different absorptivity/transmisivity

Figure 8 shows the results of the computer simulation that was carried out for the field model.

The indoor temperature variation of the small model with 50mm soil cover was obtained by varying the properties (absorptivity and transmitivity) of grass cover. As shown in Figure 8, the indoor temperature of the computer model also increases with the increase of transmisivity. As mentioned in the previous paragraph, the maximum temperature obtained in the field model was about 32^{0}C. In the computer model, for absorptivity 80% and transmitivity 15%, the same behaviour can be observed as in the field model. For the simulation with large scale models, this data has been used in this paper.

5.2 Performance of the large models

Figure 9 shows the indoor thermal behaviour of a ground floor of the large scale model. The figure shows the indoor temperature of the ground floor is at a low value than the outdoor temperature in the daytime. The variation of the indoor temperature with the variation of the soil cover does not show any significant difference. For all three different soil covers the indoor temperature remains the same. Another important observation in this graph is the variation in indoor temperature is very low. The daily indoor temperature of the ground floor is in the range of 27.6^{0}C and 29.4^{0}C. This will facilitate for more comfort indoor thermal conditions for the occupants.

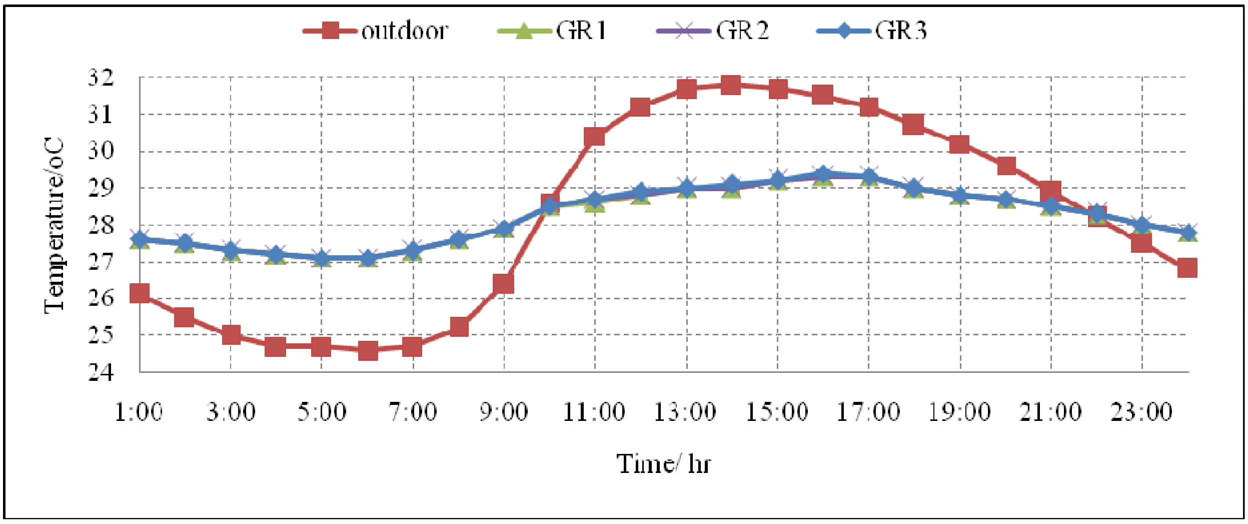

Figure 9- indoor temperature variation in the ground floor for different cases

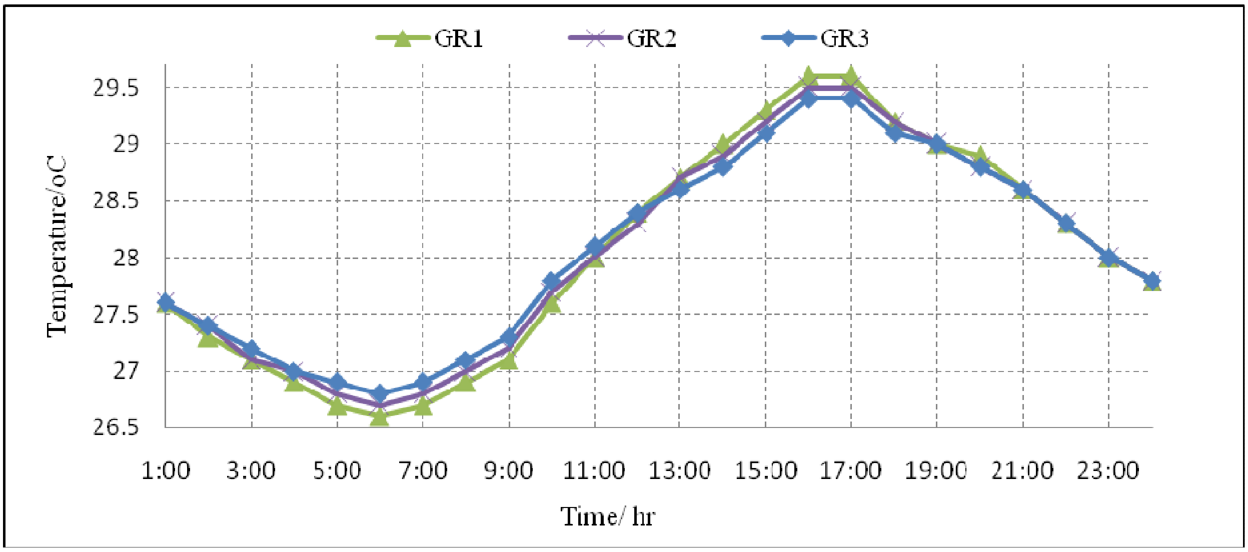

Figure 10- Indoor temperature variation in the upper floor for different cases

Figure 10 shows the indoor thermal behaviour of green roof for the upper floor of the computer model. As Figure 9 indicates, the outdoor temperature reaches a maximum of 32^0C in the daytime. In Figure 10, it shows lower temperatures in indoor than the outdoor. With the increase of the soil thickness, the indoor temperature also decreases. This is because of the capacitive insulation behaviour of the soil cover. Sri Lanka is a country which experiences tropical climatic conditions and in low altitude the neutral temperature can be taken as 26 ^{0}C [9]. The indoor temperature of the upper floor ranges from 27-29.6^0C in the above green roofs. This is close to the basic comfort temperature of the Sri Lankan low altitudes.

Case GR1 has the highest indoor temperature among all three cases while GR3 shows the best indoor thermal performance. For GR1, the growing performance of the grass cover should be low due to lower thickness of soil cover. GR3 gives good healthy grass cover while having a high construction costs due to a thicker soil layer.

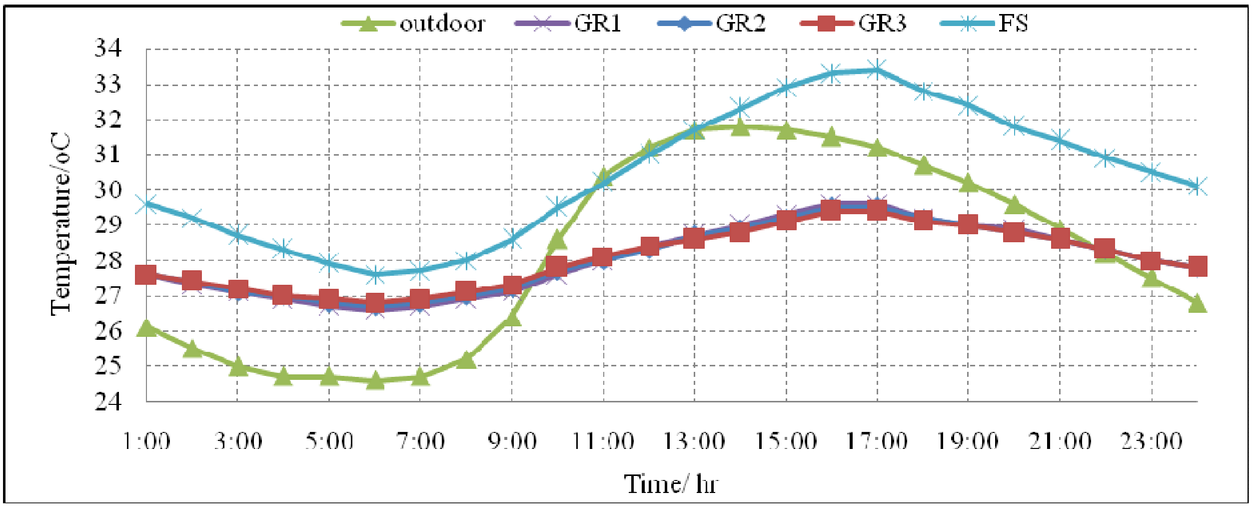

Figure 11- Indoor temperature variation in the upper floor for different cases in green roofs and flat slabs

Figure 11 indicates a comparison of houses with green roofs and flat slabs. It can be seen that the green roofs are much better in thermal performance than bare flat slabs. The indoor temperatures of the flat slab remain higher than in the green roofs almost all the day.

It is important to study the indoor thermal behaviour of flat slabs and green roofs when they get older. In flat slabs, the absorptivity and transmitivity increases with aging. Hence, the indoor temperature of the house with flat reinforced slab will increase significantly. In the case of green roof, the grass cover grows continuously and as a reason, it does not show behaviour like in the flat slab. The worst case in the green roof is the stage that where it has no grass. The analysis of these two situations is also very important in studying the indoor thermal performance of green roofs.

Figure 12 indicates a comparison between green roofs and flat slabs for present and future stages. It clearly shows that the flat slabs increase indoor temperature when they get older. It shows that it can reach up to temperature values close to 35^0C. And also the indoor temperature remains higher than the outdoor, every time for older flat slabs. In the case of green roofs, an increase in the indoor temperature can be visualized. However, it remains lower than the outdoor temperature most of the times in the daytime. The aging of flat slabs were an unavailable phenomenon while the green roofs behave as a fresh green roof always if it is maintained properly.

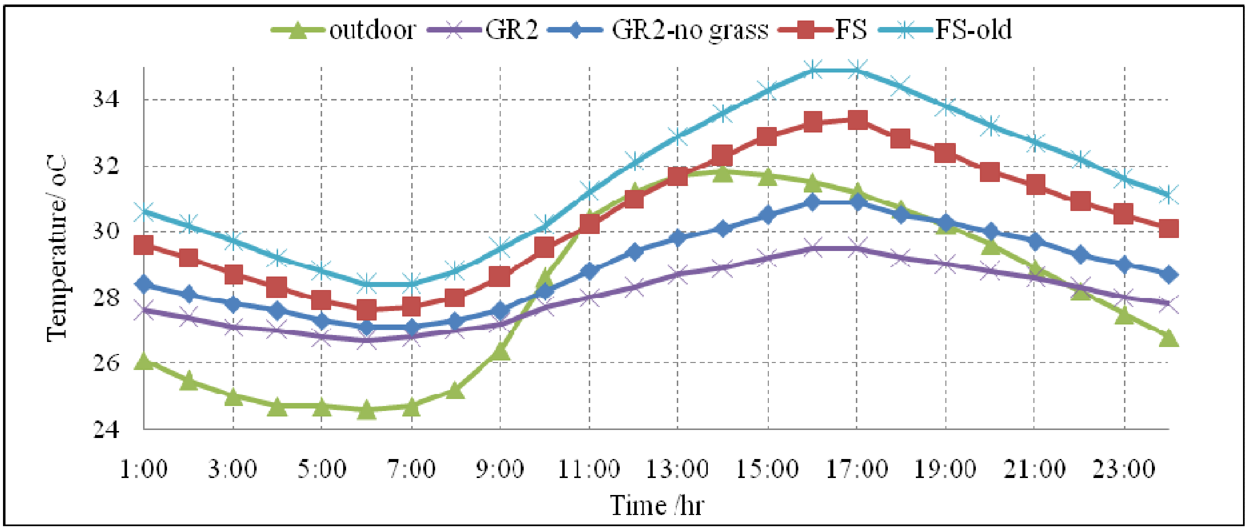

Figure 12- Comparison of indoor temperature for present and future stages in green roofs and flat slabs

5. Conclusions

The turf roof slabs are one of the most attractive trends in house designs in the modern days. It provides number of benefits than a house with conventional roofs. It has the potential to protect occupants from the high temperature conditions prevail in tropical countries by acting in harmony with the natural environment.

Absorptivity and transmitivity are the governing properties of a grass cover when dealing with indoor thermal performance. For buffalo grass, the absorptivity and transmisivity were obtained from the computer simulation as 80 and 15 respectively. The indoor temperature decreases mainly in green roofs due to the low transmissivity of grass.

With the increase of soil thickness, the rate of decreasing in indoor temperature increases. In ground floors of green roof houses, thickness of soil cover does not affect the variation of the indoor temperature. The upper floor of a green roof is much affected by the thickness of the soil cover. The average indoor temperature of an upper floor of a green roof in the day time is close to the basic comfort zone of low altitudes in Sri Lanka

In the case of a good healthy grass cover, low soil thicknesses are not preferred. But in terms of economy and structural stability of the roof slab, thicker soil covers are also not preferred. A moderate soil thickness of 50mm can be considered as the best fit for a green roof.

When considering green roofs and flat slabs, green roofs behave more efficiently on the indoor thermal performance. The buildings with green roofs have considerably low indoor temperatures than flat slabs. With time, the absorptivity of the flat slab increases and the increasing in heat transmission through the slab result in increased indoor temperatures. Well maintained green roofs don not have such effect to the indoor temperature because the properties of the grass cover remains same. The worst condition of a green roof is time where there is no grass on the green roof. However this behaves better than flat slabs.

Green roofs are more effective than flat slabs in terms of indoor thermal performance. In real green roof construction some other materials are also used such as for filtering and drainage purposes. These layers are also helpful to enhance the thermal performance of green roof houses which is not accounted in the simulation. On the hand, a house with a green roof has a regained land on the rooftop which can be use for various purposes. With the upcoming global warming issue, green roofs can be a great alternative to flat slabs.

Acknowledgements

The authors extend kind appreciation to all the staff of the Department of Civil Engineering, all the non-academic staff of the Department of Civil Engineering and all individuals who helped and encouraged to complete this research successfully.

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Appendix A

Table 1- Conductivity of

Materials	Conductivity (W/m k)
Concrete	1.7

Table 2- Surface Resistances

Ceiling downwards	R_{si}	0.14
Roofs	R_{so}	0.04

Calculation of "U" values.

- For Case1- Without soil cover

125mm thick slab, R_{body} = 0.125/1.7
=0.07 m^2 K/W

Total resistance R_{total} = $R_{si} + R_{body} + R_{so}$
=0.140 +0.07 +0.040
=0.254 m^2 K/W

U value = 3.94 W/ m^2K

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