FARU 2018 - PROCEEDINGS

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The peer reviewed and accepted research papers of the conference are included in this volume

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EFFECTIVENESS OF A DISCRETELY SUPPORTED SLAB INSULATION SYSTEM IN TERMS OF THERMAL PERFORMANCE

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Abstract
One of the main issues of the thermal discomfort inside buildings is heat gain from building envelope. As a remedy, active cooling solutions such as air conditioners are commonly used. But that can never be admired owing to the contribution of excessive energy usage and environmental pollution. Hence, passive cooling solutions such as building thermal insulation can be taken as a fruitful solution. Since about 70% of heat gain of buildings occur through roofs, thermal insulation of roofs takes a prominent place in the aforesaid matter. As a result of rapid urbanization and population growth, the amount of usable land for building constructions is very low and the constructions have to be done on a very limited space. There, flat concrete roofs provide additional working spaces and the possibility of future vertical developments with other benefits such as extra robustness and the cyclonic resistance to the structures. Anyhow, utilization of flat concrete roofs is unpopular due to the thermal discomfort in the immediate space beneath. Addressing this drawback of ordinary flat concrete roofs, a new roof slab insulation system introduced having the capability of achieving more than 75% of heat gain reduction. Thermal performance comparison between the novel system and existing roof slabs confirmed the effectiveness of the new system. Further, 50mm thick vegetation was added on top of the novel slab system and thermal performance was compared. Results showed 20% of peak cooling load reduction from new slab system and 21% of peak cooling load reduction in a summer day under tropical conditions when it was vegetated.

Keywords: *Roof slab insulation, Thermal Comfort, Cooling Load, Thermal Insulation, Vegetated slabs*

1. Introduction

The burning issue, global warmth has affected every nook and corner of the globe (Miezis, Zvaigznitis, Stancioff, & Soeftestad, 2016) and it has negatively affected the thermal comfort inside buildings. Hence, a number of researches are being carried out for finding long lasting solutions for the matter. Recent studies show that, if no necessary steps are taken to reduce the emission of CO_2 and other greenhouse gasses (GHG) to the atmosphere, the average surface temperature of the earth will rise about 1.1 ^oC- 6.4 ^oC by the end of 2100 (Aditya et al., 2017). On the other hand, due to the adverse climatic changes the severity and the intensity of natural disasters such as cyclones, snow melting, floods and droughts will be increased (Vázquez Rowe, Kahhat, & Lorenzo-Toja, 2017).

In many cases, active cooling solutions such as air conditioners are commonly used to maintain the internal thermal comfort of buildings. But that practice can never be encouraged owing to the contribution of excessive energy usage and environmental pollution. One of the best solutions to overcome this thermal comfort issue is admitting passive cooling techniques which focus on reducing heat gain/loss of buildings to enhance the indoor thermal comfort through a way of less energy consumption (Kamal, 2012). In there, building thermal insulation plays a major role. Though this consumes additional initial investment, it may be paid back within a reasonable time span (Dwaikat & Ali, 2018; Robati, McCarthy, & Kokogiannakis, 2018; Sterner, 2000). One of the main ways of increasing internal temperature of buildings is solar heat gain through the building envelope. Since about 70% of total heat gain of buildings occur through roofs (Vijaykumar, Srinivasan, & Dhandapani, 2007) thermal insulation of roofs takes a major part in thermal insulation of buildings.
When the aforesaid cyclonic effects are considered, having flat concrete roofs instead of ordinary roofs provide extra robustness to the structure due to its self-weight (Halwatura & Jayasinghe, 2009). Further, having flat concrete roofs will provide extra working space as well as the easy provision of

future vertical developments addressing the scarcity of usable lands for constructions (K Nandapala & Halwatura, 2017; Kasun Nandapala & Halwatura, 2016).

When the roof slab is heated due to the direct exposure of sunlight, the immediate space beneath becomes thermally uncomfortable. Thus, lower degree of thermal comfort of ordinary flat concrete roofs has affected the less popularity of them (Halwatura & Nandapala, 2014).

There are several techniques used in terms of roof thermal insulation, such as applying cool paints (C. Romeo and M. Zinzi, 2013), using a variety of insulation materials in roofing (K. Manohar, 2012) and using rooftop vegetation (S. W. Tsang and C. Y. Jim, 2011). As a fruitful substitution for those systems, a novel roof slab insulation system was introduced addressing both issues, thermal discomfort inside buildings and cyclonic effect. In this study, the thermal performance of the newly introduced roof slab insulation system will be compared with existing flat concrete roofs. Further, the thermal performance of the novel slab insulation system under a 50mm thick vegetation layer on top of the slab will be investigated and the fruitfulness of the innovation will be proved.

2. Objectives

The ultimate objective of the study is to check the effective thermal performance of novel roof slab insulation system. The specific objectives are;

1. To compare the thermal performance of new roof slab insulation system with existing flat concrete roofs.
2. To check the thermal performance of novel system with and without a vegetation layer
3. To find the peak cooling load reduction which can be achieved by the newly designed system with and without a vegetation layer

3. Thermal performance comparison between new roof slab insulation system, existing flat concrete roof and vegetated roof slab

3.1. METHODOLOGY ADAPTED

Small-scale physical model testing was used to fulfil the objective. The used models are as shown in Figure 15. In there, one model was with an ordinary flat concrete slab of 125mm thick and other models were with the new roof slab insulation system with and without 50mm vegetation on top of the slab. The details of the new roof slab insulation system are as shown in Figure 16.

Figure 15, Physical models constructed for thermal performance comparison

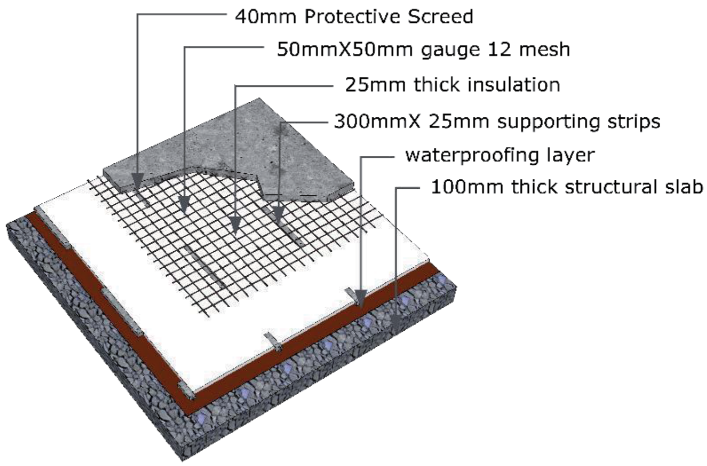

Figure 16, Newly designed roof slab insulation system (Kasun Nandapala & Halwatura, 2016)

Uninterrupted set of temperature readings were taken during continuous five days at ten-minute intervals until a constant ambient temperature was obtained using GL820 Midi Data Logger. The average temperature of each hour was calculated removing outliers and adjusted temperature readings of slab top and slab soffit were used in the comparison.

3.2. RESULTS

The experiment was conducted over a period of 24 hours during continuous five separate days. One graph representing whole five-day results was prepared considering the temperature values with minimum standard deviations. Figure 3 shows the graphical representation of slab soffit and slab top temperature readings of the model with an ordinary flat concrete roof over a time period of 24 hours, Figure 4 shows the graphical representation of slab soffit and slab top temperature readings of the model with the newly designed roof slab insulation system over a time period of 24 hours. In there, as shown in Figure 16, 25mm thick Expanded Polystyrene (EPS) layer with the thermal conductivity of 32 mW/mK was used as the thermal insulation barrier. Figure 5 shows the variation of slab top and soffit temperature readings of the new roof slab insulation system when there is a 50mm vegetation layer contained with an ordinary grass layer with a height about 60mm.

All the results were taken in 2nd week of September 2018 in Sri Lanka under tropical climatic conditions.

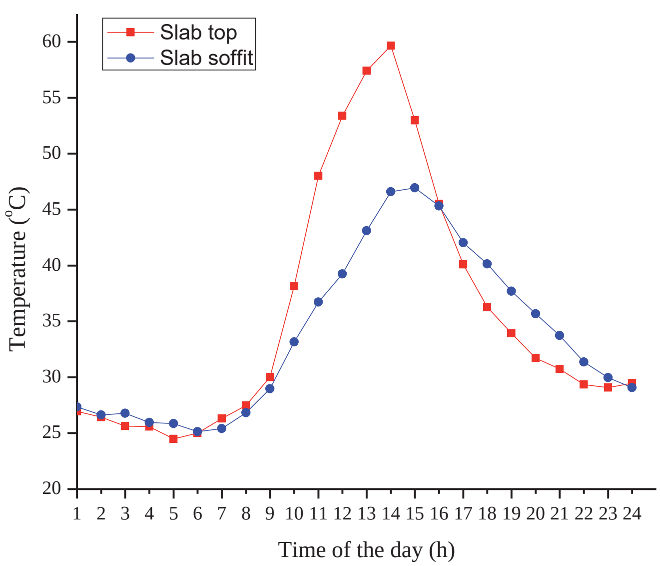

Figure 17, Slab top and slab soffit temperature readings of the model with an ordinary flat concrete roof over a period of 24 hours

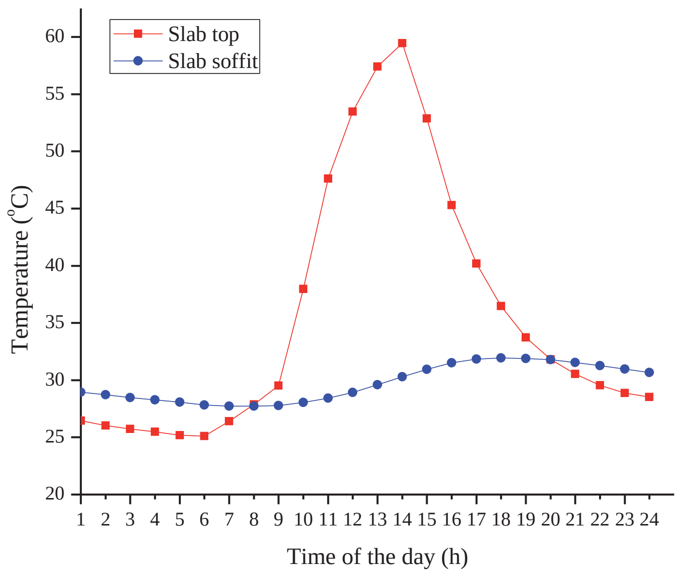

Figure 18, Slab top and slab soffit temperature readings of the model with new roof slab insulation system over a period of 24 hours

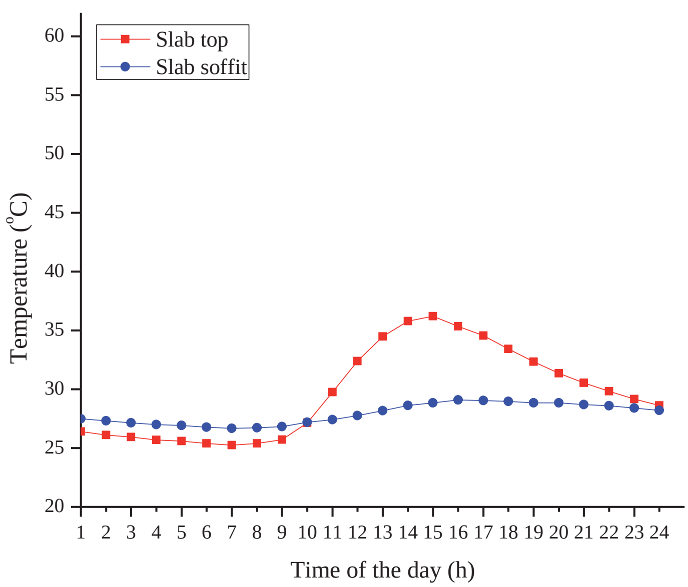

Figure 19, Slab top and slab soffit temperature readings of the model with a vegetated roof slab insulation system over a period of 24 hours

Self-insulation characteristics of the flat concrete roof due to the effect of thermal mass can be seen through Figure 17. However, in the case of the ordinary flat concrete roof, the slab soffit temperature has reached 45.5 °C which can be considered as a higher value which definitely results in thermal discomfort. When the novel slab insulation system was treated with a 50mm thick vegetation layer, the slab top temperature values show an outstanding reduction.

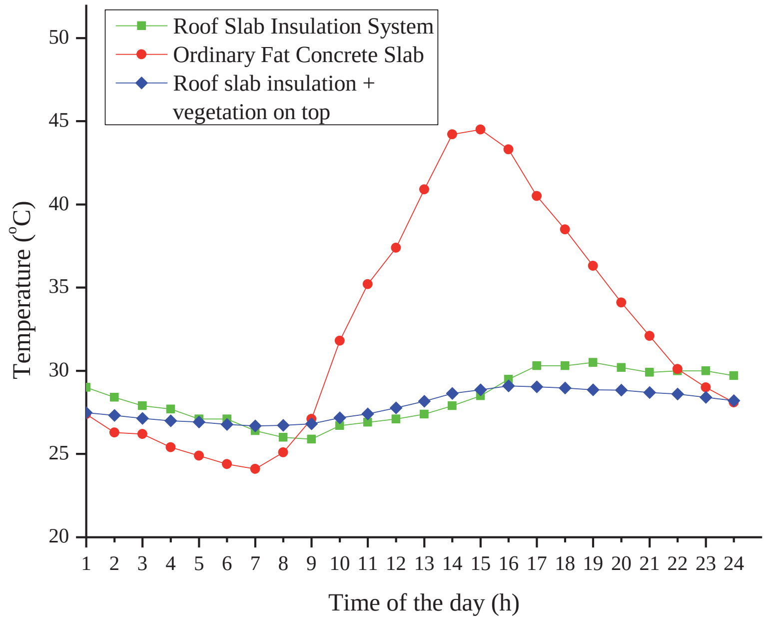

Figure 20, Slab soffit temperature readings of the considered three models over a period of 24 hours

Figure 20 clearly elaborates that the maximum slab soffit temperature at the presence of new roof slab insulation system has limited to 30.5 °C which can be considered as a satisfactory value. That value shows a further reduction to 29.1 °C at the presence of 50mm thick vegetation layer.

At the presence of the new roof slab insulation system, the slab soffit temperature lies between 25.9 °C and 30.5 °C. It is a very satisfactory condition comparing with the situation of the ordinary flat concrete roof. Since the temperature further goes down when it comes to the human occupation height, utilization as well as the capacity of air conditioners can be effectively mitigated. Anyhow, the vegetation layer has limited the slab soffit temperature in between 27 °C and 29.1 °C. But it is a slight difference from the performance of novel slab without vegetation and will be clearly discussed with respect to cooling load reduction under section 4.

It has been proven in a previously done study by one of the authors that, this kind of systems are having a heat gain reduction about 75% (Halwatura & Jayasinghe, 2008). According to the above results and since the new system was developed considering drawbacks of existing slab insulation systems, it can be predicted that the new roof slab insulation system is having a heat gain reduction more than 75%.

4. Peak cooling load reduction of the system

4.1. METHODOLOGY ADAPTED

A computer simulation was performed using the software package "Design Builder V5" to find out the cooling load reduction of a selected office building. A typical 15m x 15m office building was used since previous literature is available for such a building. Other housing elements ware included with less influence since the main objective was to study the heat gain effect through the roof. In there, external walls were selected to be 225mm thick ordinary brick walls, no windows were placed in East and West walls, and windows in North and South directions were shaded with 1m overhangs by means of preventing direct solar radiation penetration. The model used in the simulation is as shown in Figure 21.

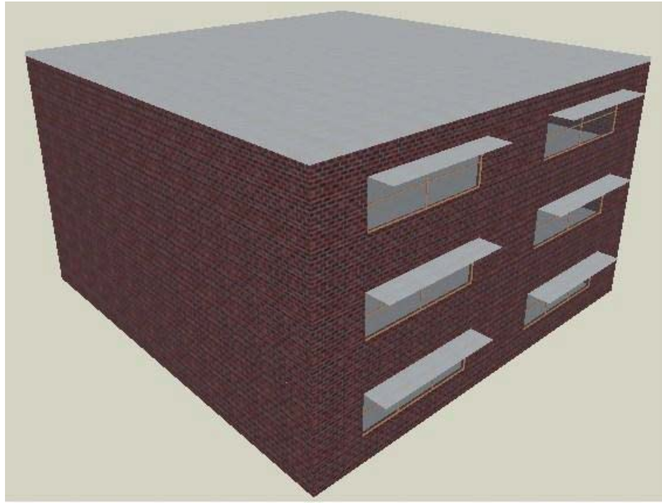

Figure 21, Virtual model used in computer simulation

4.1. RESULTS

Figure 21 office building shown in Figure 21 was analyzed in “Design Builder V5” to figure out the cooling load requirement to obtain neutral human comfort conditions on a typical summer day. Here, neutrality temperature was used as 26^{o}C which has been mentioned as a reasonable value for tropical conditions (Jayasinghe, Attalage, & Jayawardena, 2002).

Table 7, Cooling load demand over a period of 24 hours

Cooling required (kW)			
Time of the day (h)	Uninsulated slab	Roof slab insulation system	Roof slab insulation system +50mm vegetation on top
1	51.0030	55.2007	56.153
2	50.5711	55.0891	56.2200
3	48.4080	52.9293	54.1391
4	46.0967	50.6569	51.9040
5	44.2352	48.8192	50.0772
6	42.4248	46.9857	48.2246
7	41.4340	45.8303	47.0408
8	40.2569	43.3924	44.5793
9	52.1464	52.4538	53.4592
10	53.4525	49.2790	50.1252
11	59.9516	51.1731	51.6680
12	66.0990	53.1785	53.2508
13	70.0835	57.4962	54.5302
14	75.7483	60.7652	56.7003
15	81.1211	60.7652	59.6103
16	**83.8256**	64.0852	62.7123
17	83.6048	67.1330	65.7241
18	74.0339	62.0511	60.7000
19	73.0867	**67.3199**	**66.3531**
20	68.8214	66.1350	65.5401
21	65.9136	64.0991	63.8983
22	61.6634	61.5979	61.7556
23	56.9902	58.7270	59.1940
24	52.4503	55.6461	56.3776

The cooling energy requirement of aforesaid building at the presence of thermally insulated slabs and thermally uninsulated slab are as listed in
Table 7. The cooling load reduction calculation is as mentioned below;

Cooling load reduction with respect to novel slab system without vegetation and ordinary uninsulated roof slab

Cooling load reduction = [1- (67.3199/83.8256)] x 100% = 19.69% ≈ 20%

Cooling load reduction with respect to novel slab system with vegetation and ordinary uninsulated roof slab

Cooling load reduction = [1- (66.3531/83.8256)] x 100% = 20.84% ≈ 21%

Calculations show a 20% cooling load reduction due to novel roof slab insulation system over ordinary flat concrete roof slabs. The value gets a positive advancement about 1% due to the vegetation layer. But such a vegetation requires additional investment as well as proper maintenance. Since the cooling load difference is about 1%, roof slab insulation system without any vegetation can be chosen as the most fruitful solution.

3. Conclusion

The newly designed roof slab insulation system can be used to fulfil both requirements; indoor thermal comfort of buildings and cyclonic resistance addressing the key drawbacks of ordinary flat concrete roofs.

Since the comparison with literature data deviated that novel system can achieve more than 75% heat gain reduction under tropical climatic conditions and it was proven through performance analysis that new system provides about 20% cooling load reduction on a typical summer day it can be concluded that newly designed roof slab insulation system is suitable for addressing existing indoor thermal comfort issues of countries under tropical climatic conditions in an energy efficient manner providing extra cyclonic resistance to the structure too. At the presence of new roof slab insulation system, requirement of air conditioning equipment will be reduced and expected human comfort condition can be fulfilled with low capacity air conditioning equipment.

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