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# Thermal Benefits of Green Roof in the Tropical Region. Case Study of Malaysia

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***Abstract* - Climate change has led to a number of environmental issues such as; higher atmospheric temperatures and increased indoor discomfort. Green roofs; a form of transferring nature from the ground to rooftops holds a significant unfulfilled potential towards cooling the indoor environment and reducing cooling loads. In this study, the impact of soil cover and vegetation on roof tops were assessed. Three test cells covered with 150mm thick soil, 150mm thick soil /plants and the bare surface respectively were stationed and monitored for six consecutive days. During the experiment thermo sensors were used to measure the temperature profiles across the section of each roof from the ceiling inside the chamber and its ambient temperature. Results from the experiment showed thermal benefits. Comparisons of the roof covers demonstrate soil and plants cover were cooler over the whole period of the experiment than the bare roof. The daytime peak temperature periods were most prominent on the bare roof which had a temperature difference of 7.60$^0$C when compared with the soil cover and plants. Findings conclude the use of plants and soil on roofs displayed a great potential in reducing the indoor temperature of an enclosed space and reduces energy consumption in buildings.**

***Keywords: Green Roof, Soil, Plants, Indoor Temperature, Environment.***

## 1.0 INTRODUCTION

Trees, shrubs and green spaces contribute significantly in cooling cities and saves energy used in cooling loads [1]. Previous studies have shown that through shading from trees and shrubs planted close to the building, summer air-conditioning cost can be reduced typically by 15-35% [2]. However, natural vegetation is usually the first victims of urbanization [3]. In recent time the unstoppable force of urbanization globally has consumed vast quantities of natural vegetation; replacing with concrete structures and low albedo surfaces. These has resulted to changes in the thermal properties of surface materials and reduced evapotranspiration in urban areas, this has intensified the Urban Heat Island effect; a phenomenon characterized by higher temperatures in built up areas as compared to less densed areas. Studies reveal its effect has become a serious environmental issue traced in all parts of the world [4].

In the tropics of Malaysia, heated outdoor environment of the region has contributed a growing preference for a conducive emperature indoors. This has immersed pressure on the energy demand in cities due to heating and cooling loads. With the idea of introducing nature (vegetation) back into the urban landscape and improving the comfort index of inhabitants, A partnership is strengthening between nature and the cityscape with the aim of balancing their area of coverage in parts of the tropics [5]. Various studies have proposed the idea of deploying green vegetation to the top of roofs and buildings in urban cities. Planting on roofs known as the green roof technique has become one of the most innovative fields in the world of ecology, horticulture and the built environment. The green technique and its ability to reduce the heating and cooling load of the buildings has been the subject of various research studies by [6-8]. Further studies revealed that, the reduction of ambient temperature above the planted roof is much higher and close to 5$^0$C, however, the specific contribution of planted roofs varies with the substrate of the green roof and climatic characteristics [1, 5&9].

Previous studies have shown that examining the use of green roofs has been diverse [10-12]. Green roofs are seen to have limited benefits in their role as a cooling device for the building. Their contribution to the cooling of buildings was seen to be mainly due to the shading provided by the plants and not necessarily due to evaporation [13], this is because the process of transpiration takes place in the plants' leaves rather than in the soil, drawing energy from the environment and not directly from the soil-covered building. In addition, a thick layer of saturated air may form under the plant canopy, inhibiting evaporation from the soil substrate [7]. Further studies have shown that eliminating the exposed roof by placing the building underground or in some way sheltering it with a substantially thick layer of soil may be a possible means of mitigating solar heat gains on roofs. The analysis of earth-sheltered structures in the Negev has also shown that even wide daily temperature swings on the ground surface can be effectively stabilized by a modest layer of earth-cover [14], since over 90% of the daily sub-surface heat exchange occurs within the upper 20 cm of soil [15]. In the hot arid Negev regions, however, the average soil surface temperature in summer tends to be well above that of the ambient air, because absorbed solar radiation is greater than the combined long-wave radiant and convective losses over the daily cycle. Under such conditions, where the average daily air temperature is close to the upper limit of thermal comfort, the earth cover itself (unless it is thick enough to introduce a seasonal time lag) cannot provide a sufficient source of cooling to the building. Plants vegetation on bare roof tops will aid in mitigating the heat gains on roofs and improve the indoor air of buildings. In the hot humid climate of Malaysia which experiences intense rain storm,

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the nature of the roof substrate will need to be structured to withstand all the climatic factors within this region.

The present study aims to evaluate the effectiveness of separate roof components experimentally. The roof cover components which include 150mm thick soil cover, and vegetated plants are individually compared with the bare roof as the controlled experiment, to determine the thermal performance of each of the roof cover on the indoor air and surface temperature. The significance of this experimental study is to assess the impact of roof covers on the outdoor environment, and the heat transferred into the building towards achieving a comfortable indoor environment in the tropics.

## 2.0 RESEARCH DESIGN

### *2.1 SITE DESCRIPTION*

The field experiment was conducted in the Department of Electrical Engineering, Universiti Teknologi Malaysia located in the tropics. The site was selected based on minimal obstruction from human activities and surrounding structures. This was to enable test cells receive maximum exposure to climatic variables such as solar radiation and rainfall.

### *2.2 MATERIALS USED FOR EXPERIMENT*

### *2.2.1 Test Cells*

Three identical test cells were used. The test cells used were 1m in height, 1m width and 1m length, and supported structurally by timber /wood with the top of the cell covering 1m x 1m x 5mm thick plywood were used for the experiment. The tests cells were sealed with double sided aluminum insulators to minimize heat transfer from the sides of cell and the bottom surface. The top plywood slab was covered with a plastic material which severed as a water proof layer as shown in Figure 2.1. and 2.2. To give a stable support the test cells were placed on concrete bricks as shown below. The edges were properly masked and sealed to avoid any errors during the experiment.

Figure 2.1: Typical unit of Test Cells

Figure 2.2 Interior view of test cell

### *2.2.2. Plant Selection*

The plants were selected based on the climatic features of the region, the soil medium, the design type to be adopted, the specie to be used, maintenance planned during and beyond the establishment phase. Generally, it is ideal to have a mix of plant species in order to mimic a somewhat natural system that will function independently filling in any missing pieces. Plant selection were based on research by (16; 17) on potential of vegetation plants in reducing the indoor temperature of a room. A hard succulent beach morning glory was chosen as plant sample to be placed on the planter box. It was selected due to its capability of up taking higher carbon dioxide as compared to other plants and the ability to withstand higher outdoor temperature.

Figure 2.3: *Ipomoea pes capre* / Beach morning glory

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### *2.2.3 Instruments and Equipments*

Instruments used for the experiment include; Thermo Recorder TR-72U, Thermo Recorder TR-52, Environ data and Weather Station. Thermo Recorder TR-72U (Figure 2.4a & 2.4b) was used to record temperature and relative humidity outdoor and indoor of the cell. Thermo Recorder TR-52 was used to record indoor surface temperature. Each thermo recorder was connected to sensor which offers high accuracy, internal memory and low power consumption. Environ data Weather Station was put in place near the experimental site for monitoring and recording continuous weather data.

Figure 2.4a: Thermo Recorder TR-72U

Figure 2.4b: Thermo Recorder TR 52 (below)

Figure 2.5a: Weather Station

Figure 2.5b: Environ data

### 2.2.4 *Method of Experiment*

The objective of this experiment was to investigate the effects of different top cell treatments which include Cell A (bare roof ), Cell B (150mm soil + plants) and Cell C (150mm soil cover) with respect to the indoor air temperature (*Ti*) and indoor surface temperature (*Ts*) of the cells. Cell A was used as the reference cell with no roof cover on its top. Each cell was equipped with thermo recorders and sensors to measure; (i) indoor air temperature ($T_i$) 500mm below the surface, (ii) indoor surface temperature ($T_s$) directly below the internal surface simultaneously, as illustrated in Figure 2.6. The thermo recorders were set to record data at hourly intervals. The data loggers recorded data from 17th - 22nd June and the climatic data was monitored and recorded concurrently by the weather station installed on the site.

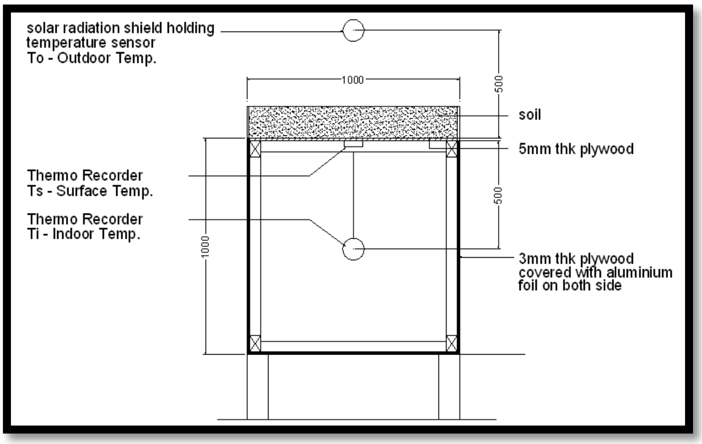

Figure2.7: Cell C (150mm soil without plant )

Figure 2.8: Cell B (150mm soil with plant)

## 3.0 RESULTS AND DISCUSSIONS

Results obtained for the indoor temperature of the three test cells with different roof treatments (Bare roof, 150mm soil, 150mm+plants cover). The evaluation on indoor space was based on the Indoor Surface temperature (*Ts*) and Indoor air temperature (*Ti*) at 500mm below the ceiling. In an aim to find the difference in response of the variables for the three test cells, they three results were presented in the same graph as a function of the Indoor air temperature (*Ti*), indoor Surface temperature (*Ts*). The sequence of the analysis is as follows;

Where Cell A – Bare roof (Controlled cell)
Cell B –150mm soil cover + plant cover
Cell C –150mm soil cover without plant

Table 3. 1: Sequence of analysis

| Variability/Parameters | ComparativeAnalysis | | | |
|---|---|---|---|---|
| Indoor air temperature (Ti) | Cell A,<br>Cell B<br>Cell C | Cell A<br>Cell C | Cell A<br>Cell B | Cell B<br>Cell C |
| Indoor surface temperature (Tsi) | Cell A<br>Cell B<br>Cell C | Cell A<br>Cell C | Cell A<br>Cell B | Cell B<br>Cell C |

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### *3.1 Indoor Air Temperature*

The daily cycles of temperature presented in Figs. 3.1 – 3.4, show averaged values based on results continuously recorded on hourly intervals for six consecutive days. Temperature measured below the thick ply wood ceiling of each cell were taken to be a primary indication of the thermal behaviour of that roof configuration, while temperatures on the upper soil surface and throughout the depth of the soil layer provided additional explanatory data. It should be stressed that internal air temperatures, while useful for comparative purposes, are somewhat limited in their ability to represent the indoor conditions of a realistic building due to the size of the experimental cell, the constricted roof area relative to that of the exterior walls and the lack of window openings.

### *3.2 Indoor air temperature at 500mm below ceiling surface for Cell A, B and C*

A typical diurnal variation of the mean indoor air temperature of the three test cells and data from the weather station for six days is illustrated in Figure 3.1. It was observed that the indoor temperatures of the test cells with roof treatments were higher than that recorded by the weather station.

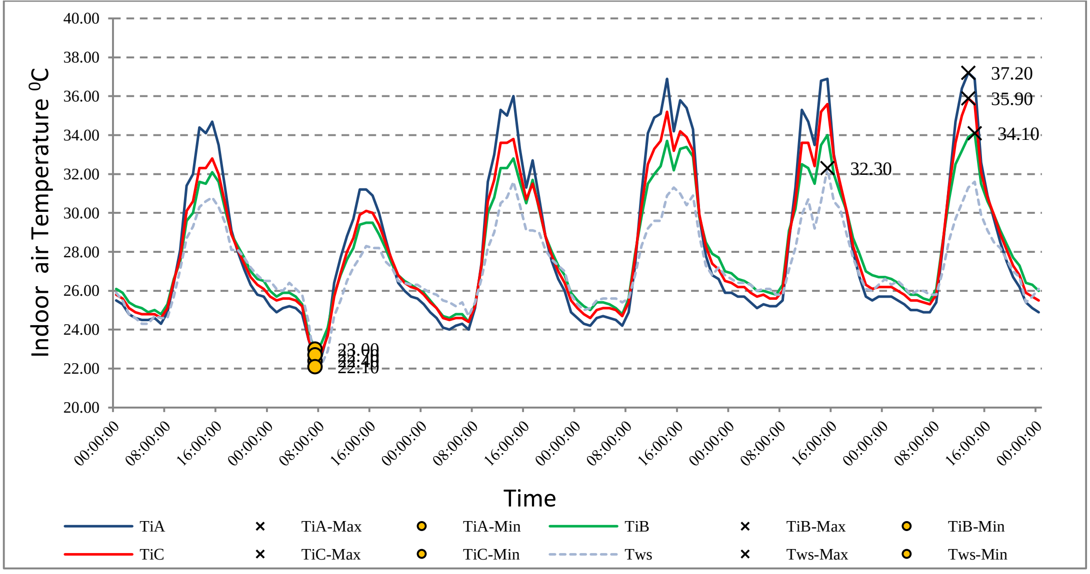

Figure 3.1 Comparison of Indoor air temperature in Cell A, Cell B and Cell C from 17$^{th}$ to 22$^{nd}$ July.

The temperature below the bare roof Cell A was significantly above Cell B (150mm soil + plants cover) and Cell C (150mm soil thickness). During the period of experiment. Figure 3.1 shows the peak indoor air temperature at about 1500hrs of the day and the lowest temperatures at 900hrs of the day. The three test cells however show the peak ambient temperature at 37.20°C was observed below Cell A at 1500hrs on the 22$^{nd}$ and the lowest ambient temperature of 22.20$^0$C was also observed below Cell A at 900hrs on the 18$^{th}$. The Figure further illustrates the indoor temperature below Cell C was higher than Cell B during the whole period of experiment. This shows the substantial effect of Cell B on Cell A, expressed in terms of its temperature stabilization as compared to Cell A and Cell C.

### *3.3 Indoor Air Temperature below Cell A and Cell C*

The experimental configuration compared the indoor air temperature of 150mm soil covered test roof (Cell C) with a bare roof (Cell A) at 500mm below the ceiling surface. Figure 3.2 illustrates the comparison of indoor temperature for two days; it shows the effect of Cell C expressed in terms of its temperature variation. The daily maximum temperature of the test cell's was just over 32.80$^0$C was reached with a temperature attenuation of 2–3$^0$C relative to the ceiling of the controlled bare roof. The diurnal temperature of the soil cover was shown to reduce below the bare roof temperature during the hottest afternoon hours 1500hrs at 32.10$^0$C on the 17$^{th}$, the lowest indoor temperature recorded in Cell A and Cell C was on 18$^{th}$ at 07.00 hrs was given as 22.40°C and 22.70°C respectively. It further showed indoor temperature increased by 1.32% during the night time in

Cell C compared to Cell A and during the day time the 150mm thick soil prevented the top of the cell from direct heat from the sun as compared to Cell A. It absorbed heat and released at night which resulted in higher indoor temperature at night compared to Cell A. Thus, while the large heat capacity of the soil layer lowers the heat burden on the roof considerably, it was observed that this simple addition of thermal mass does not provide a sufficient means of cooling for the building without a method for removing heat from the mass.

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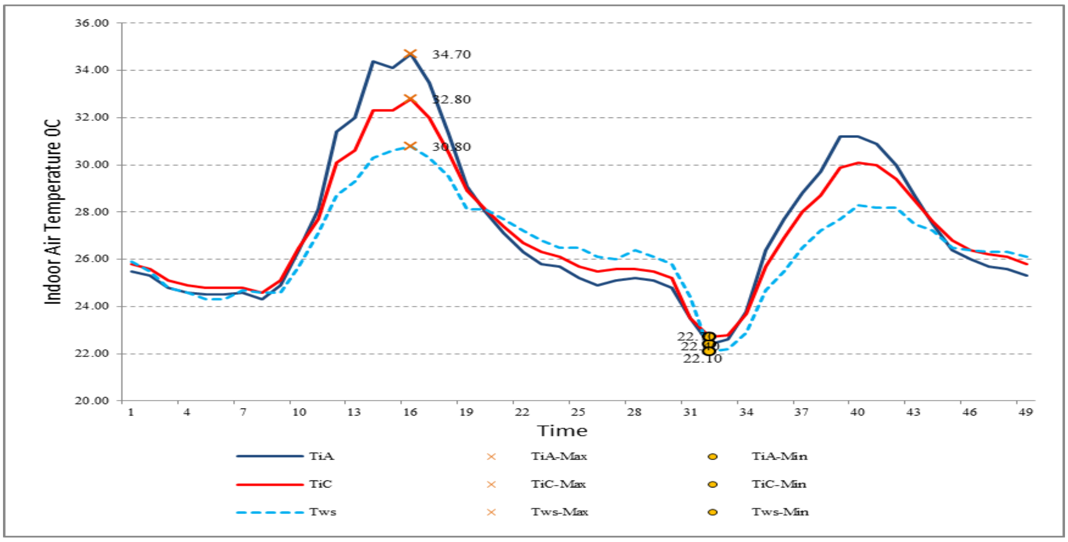

Figure 3.2 Comparison of Indoor air temperature below Cell A (Bare roof) and Cell C (150mm Soil) from 17th to 18th June.

*3.4 Indoor Air Temperature below Cell A and Cell B*

Figure 3.3 illustrates the temperature variation for Cell A and Cell B. The figure illustrates the experimental result for two days. Cell A recorded the highest temperature at 34.70°C and the lowest temperature at 22.40°C. When compare Cell A to Cell B with 150mm soil thickness and plants treatment, a difference of 2.60°C was observed, this resulted in a 7.5% heat reduction as a result of the plants. Plants provide sunshade to the soil cover and cool the air surrounding due to a process known as evapotranspiration.

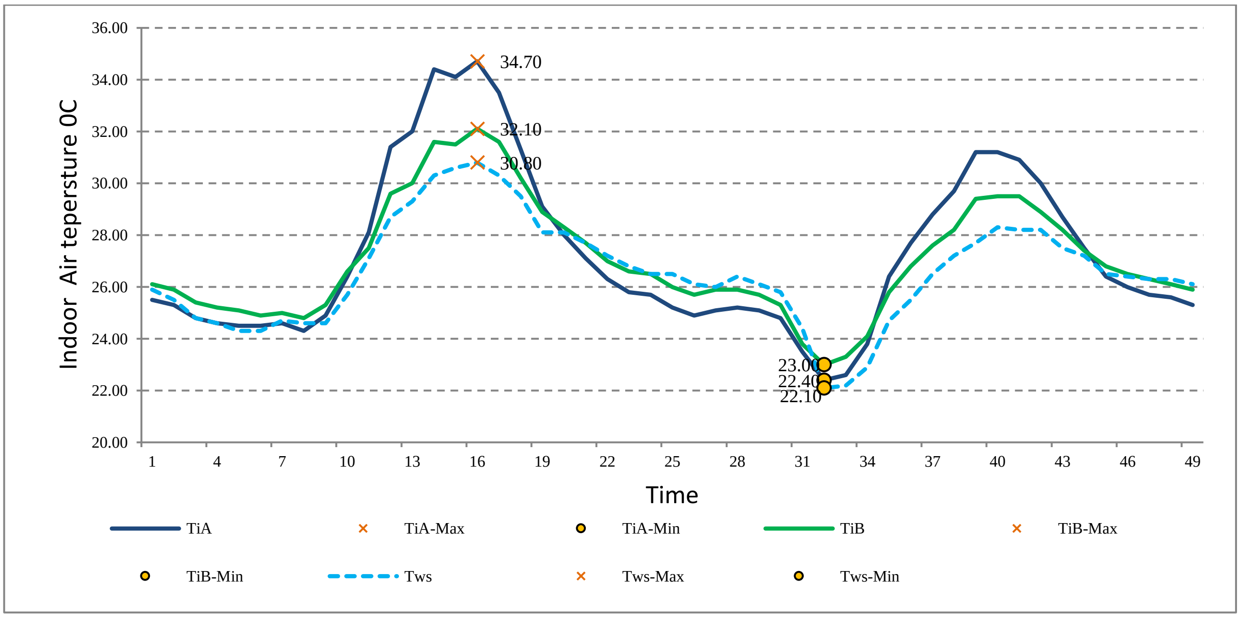

Figure 3.3 Comparison of Indoor temperature in Cell A (Bare roof) and Cell B (150mm Soil +plant cover) from 17th to 18th July.

Evapotranspiration according to USEPA (2008), is the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the plants by transpiration thereby cooling its environs. The figure further illustrated the lowest temperature recorded at night was 22.40°C in Cell A compared to 23.0°C in Cell B which is higher by 0.60°C. During the day time Cell B absorbs heat and slowly releases at night. However on Cell A, in the absence of any top medium, the bare roof directly absorbs heat and releases it easily to the indoor temperature during day time and decreases at night faster than Cell B.

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### *3.5 Indoor Air Temperature below Cell B and Cell C.*

Figure 3.4 illustrates the temperature variation for Cell B and Cell C. both test cells had 150mm thick soil top treatment but Cell B was covered with plants. The maximum indoor temperature was observed on 17th June at 1500 hrs with values given as 32.80°C in Cell B and 32.10°C in Cell C, giving a difference of 0.60°C. The difference in temperature recorded in Cell C compared to Cell B was as a result the plants which preventing the bare roof top from receiving direct heat through sunshade and evapotranspiration process. The thermal performance of Cell C and Cell B show that effect of both roof toppings in reducing the indoor air temperature more than each will perform in isolation.

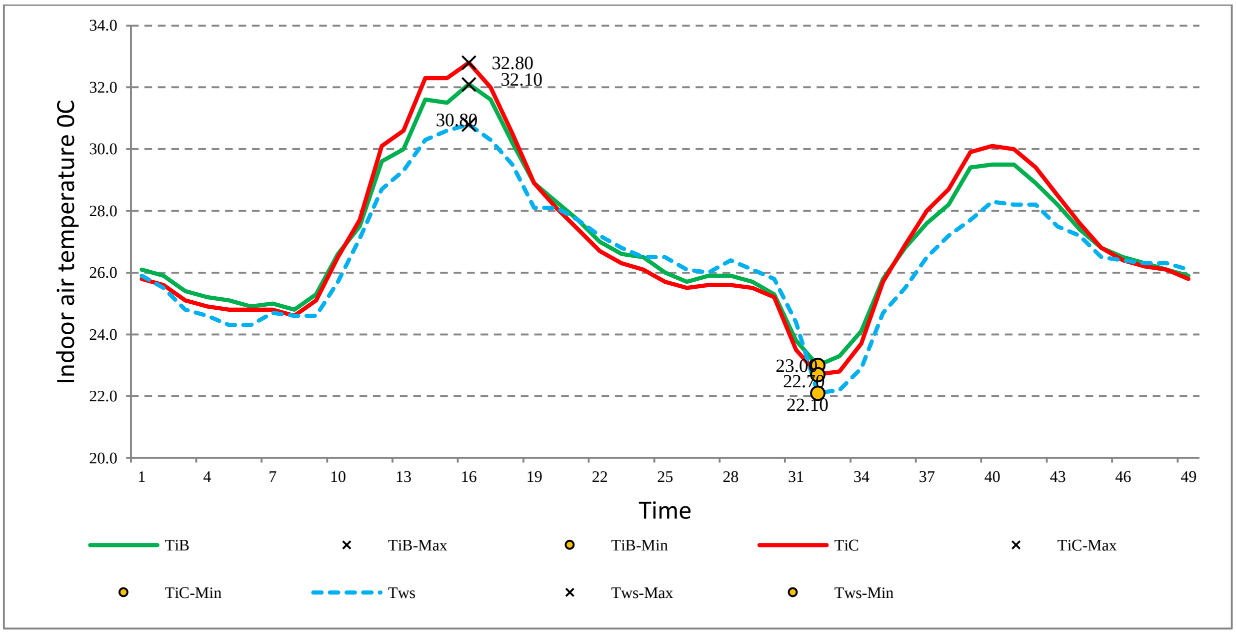

Figure 3.4 Comparison of Indoor temperature in Cell B (150mm Soil + Plants) and Cell C (150mm Soil) from 17th to 18th July.

### *3.6 Summary of Indoor Air Temperature of Test cells*

The results obtained from the experiment on the indoor air temperature of the three test cells shows that roofs with treatments (Cell B and Cell C) maintained indoor temperatures consistently below the bare roof during the whole period of the day. The results do however illustrate the desired effectiveness of soil cover and plants. The maximum indoor temperature measured during the experiment was observed at 15:00h. Cell B treated with 150mm thickness of soil and plant was appreciably lower during the day time by 2.60$^{0}$C as compared to Cell A and Cell C. This means optimum indoor temperature can be achieved by maximizing roof top treatments by plants.

### *3.7 Indoor Surface Temperature for Cell A, Cell B and Cell C*

The introduction of shading by means of either soil cover or plants had a pronounced effect on indoor air temperatures below the surface of the ceiling. Results from the surface temperature showed a similar trend as in the indoor air temperature. Figure 3.5 illustrates the highest indoor surface temperature recorded was in Cell A at 43.20°C on the 20th June at 1400 hrs, it also had the lowest temperature at 21.90°C on 18th which was cooler than the surrounding temperature by 0.3°C. Thus, the experimental results reinforce the conclusion drawn by [18] that shading on roof systems is indispensable since on balance, evaporation from shaded soil results in a lower temperature than a higher evaporation rate from exposed soil.

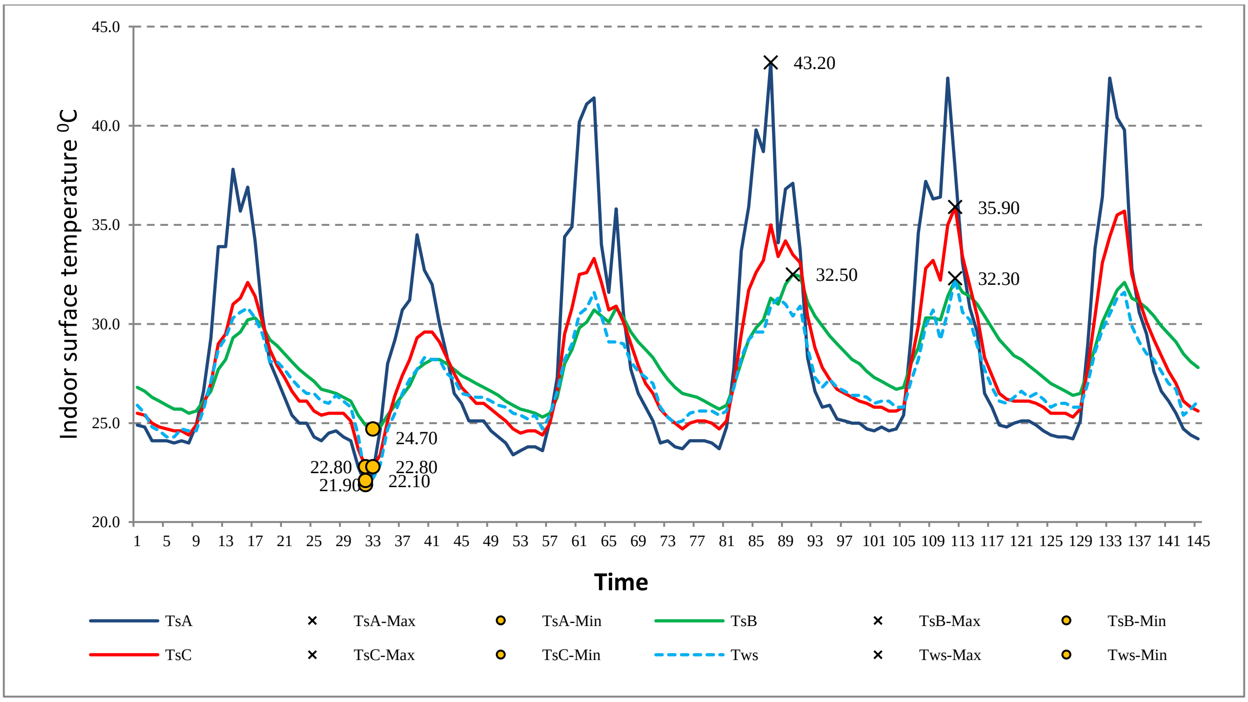

Figure 3.5 Comparison of indoor surface temperature in Cell A (Bare roof), Cell B (150mm Soil + Plants) and Cell C (150mm Soil) from 17th to 22nd June.

*3.8 Indoor Surface temperature for Cell A and Cell B*

During the peak heat periods of the day at 1500hrs, Figure 4.6 illustrates a significant difference of 7.50°C on indoor surface temperature between Cell A (37.80°C) and Cell B (30.30°C). Heat reduction of 19% was evaluated on indoor surface temperature as a result of soil and plants. The soil and plants contributed in preventing the heat transmitted directly from the sun and outer source into the cell. The ability of soil to retain amount of water after a rainy day also contributed in keeping the surface cool. The lowest indoor surface temperature of 21.90°C was recorded on 18th June at 0700 hrs in Cell A, Cell B recorded its lowest temperature of 24.70°C at 0800hrs on the same day.

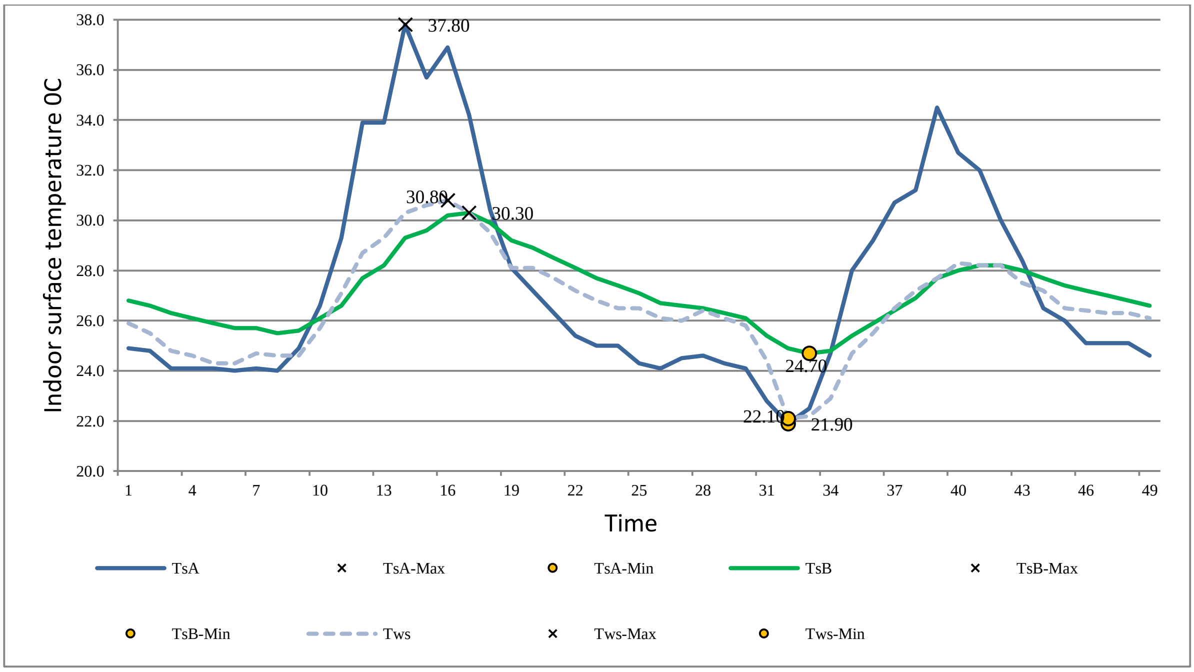

Figure 3.6 Comparison of Indoor surface temperature in Cell A (Bare roof) and Cell B (150mm Soil + Plants) from 17th to 18th July

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### *3.9 Indoor Surface temperature of Cell A and Cell C*

The 150mm soil on Cell C helped in preventing heat increase on the surface temperature of the ceiling compared to Cell A as illustrated in figure 4.7 Observations made on two days were plotted and a difference of 5.70°C was observed during the peak hours 1500hrs on Cell A (37.80°C) and Cell C (32.10°C) which contributed almost 15% of heat reduction on the surface temperature of the ceiling.

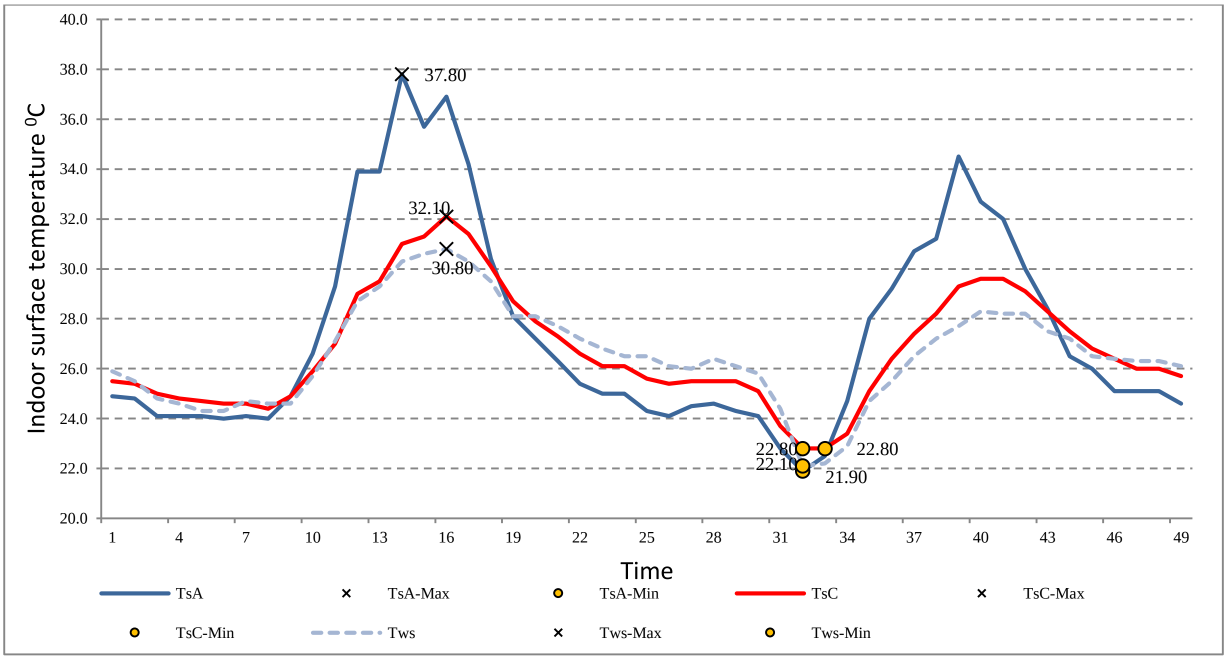

Figure 3.7 Comparison of indoor surface temperature in Cell A (Bare roof) and Cell C (150mm Soil) from 17th to 18th July.

### *3.10 Indoor surface temperature of Cell B and Cell C*

The Figure 4.8 shows the shading and evapotranspiration from plants on Cell B contributed to the reduction of indoor surface temperature. It evaluated a difference of 1.80°C between the highest temperature recorded in Cell B 30.30°C and Cell C 32.10°C which contributed almost 5% of heat reduction. The temperature recorded on the weather station was slightly higher than the surface temperature below Cell B during the day 30.80$^0$C and Cell B 30.30$^0$C, however during the morning hours the temperature in Cell B was higher than that of the weather tracker. It was also observed that the bare roof experienced the highest temperature during the day at 32.10$^0$C.

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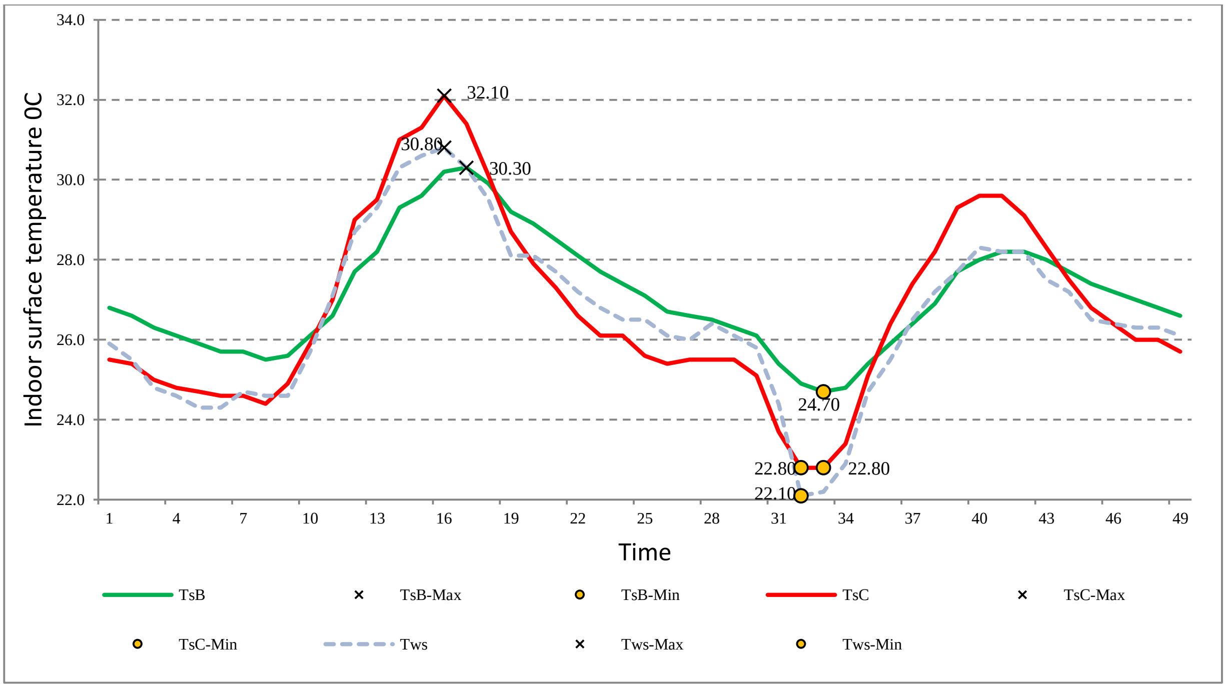

Figure 3.8 Comparison of surface temperature in , Cell B (150mm Soil + Plants) and Cell C (150mm Soil) from 17th to 18th July.

### *3.11 Summary on Indoor Surface Temperature*

The findings conclude that Cell B experienced the lowest temperature as compared to the bare roof Cell A and the 150mm soil cover Cell C during the afternoon hours 1500hrs when the heat released from the solar radiation was at its peak. During the morning and evening hours the temperatures of all test cells were relatively low between $24.0^0$C -$28.0^0$C higher than the bare roof as illustrated in Figure 4.8. This showed that at peak hours the bare roof absorbed temperatures higher than the roofs with treatment and there by transmitting more heat to the ceiling surface and its ambient temperature.

## 4.0 CONCLUSION

A green roof was seen to have many benefits over a conventional bare roof, this include environmental, economic, and aesthetic benefits. This study examined the environmental benefits of green roofs, particularly thermal benefits The original hypothesis that covering a building's roof with soil, and shading soil surface with plants (green roofs) may provide a simple and efficient means of low-energy cooling in hot and dry climates was explored.

The experimental findings showed clearly that soil mass provide thermal stabilization, it cannot however be solely relied on, Therefore, shading of the soil layer by plants on a roof is also an effective means of evaporative cooling and has the particular benefit of cooling during the hottest hours of the day. Substantial contributions for cooling were achieved when the soil was shaded by plants. Regardless of shading method, this step allows a more efficient utilization of soil mass and evaporation increasing cooling potential. The comparison of two roof treatment's, the 150mm soil cover and the soil + plant cover, demonstrated that the soil produced a slightly but systematically greater daily cooling output. During the daytime hours when cooling loads were highest, though, output was higher with soil and plants cover which was especially significant given the potential for augmenting cooling performance through evapotranspiration, as additional findings showed. During the cool hours (Morning and Evening) experiments demonstrated that when covered with soil and plants the heat was retained significantly better than with bare soil only. All the covers used in the experimental configurations were distinguished by their feasibility, making them practical for a wide range of applications including low-cost construction and retrofits.

The evaporative cooling effect of plants illustrated most dramatically in the marked depression of daytime temperatures on the Cell B, which was up to $7.60^0$C lower than the bare roof and 150mm soil cover. This cooling effect was also transferred into the building, but on a more moderate scale: while ceiling temperatures below the soil cover were stabilized around $32.10^0$ C, the introduction of evaporative cooling through plants brought these temperatures down to the range of 30– $31^0$C. Despite its slightly larger daily fluctuation, this temperature curve represents a significant improvement. This is due both to the absolute value of the temperatures relative to the limits of thermal comfort and to the timing of the maximum temperature, which occurs after sunset (when night ventilation may contribute to comfort cooling). Nevertheless, it is clear that installing plants on roof tops

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leaves a considerable potential for improvement. When unshaded, the evaporating topsoil surface reaches temperatures in excess of 0 .60$^0$C during the daytime and although the dry soil surface reached over 32.8$^0$C. It has hereby been largely confirmed under the conditions of the experiment that by using these strategies in combination, cooling could be significantly improved beyond what any of them provide in isolation.

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