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Determination of the Effect of Green Roofs on Indoor Temperature by the Use of Simulation in a Tropical Landscape

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Authors' contributions

This work was carried out in collaboration among all authors. Author DNT designed the study, performed the statistical analysis and wrote the first draft. Author LA managed the literature review. Author CK managed the analysis of the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To use a simulation base exploration to carry out 6 scenarios of green roof construction methods to determine the most efficient in improving indoor thermal comfort.
Study Design: Simulation Design was used as the study design.
Place and Duration of Study: The study was conducted at the Department of Horticulture – Kwame Nkrumah University of Science and Technology located at Kumasi-Ghana between 2016 and 2019.
Methodology: A simulation experimental setup was done to run for 1 year to cover the two seasons in Ghana. Version 5.0.2 Design Builder and Energy Plus 5.8 was used to work on 6 scenarios using leaf area indexes (LAI) of 2 and 5 as well as soil depth (thickness) of (70-150 mm), 200 mm, 300 mm and 500 mm. Also a real life experiment was done at the Department of Horticulture by constructing 9 test cells and using treatments such as *Portulaca grandiflora* and *Setcreasea purpurea* to validate the results for the simulation. The time setup for the simulation was from 12.00 am to 11.59 pm.
Results: A leaf area indexes (LAI) of 5 and soil depth of 70 mm-150 mm recorded the lowest

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simulated temperature ranging from 26.26°C to 29.30°C for scenario one. For scenario two, a leaf area indexes (LAI) of 5 and a soil depth of 200mm recorded the lowest significantly ($P \leq 0.05$) indoor temperature in August (26.20°C) and the highest (29.26°C) in March. In February, June and August, significant differences ($P \leq 0.05$) were achieved by leaf area indexes (LAI) 5 and soil thickness 500 mm for scenario three. January, March to July indicated significant differences ($P \leq 0.05$) between the treatments leaf area indexes (LAI) 2 and soil thickness 300 mm and leaf area indexes (LAI) 5 and soil depth of 300 mm recorded 26.32°C to 29.33°C for August and March respectively for scenario four. A soil depth of 500 mm and leaf area indexes (LAI) of 2 gave significantly ($P \leq 0.05$) low temperatures indoors all year (26.27 to 29.32°C) for scenario five and in August leaf area indexes (LAI) 5 and soil thickness of 500 mm recorded the least temperature all year for scenario six.

Conclusion: From the exploration, a soil depth of 70 mm – 150 mm and a LAI of 5, LAI of 5 and soil depth of 200 mm and LAI of 2 and soil depth of 500 mm achieved the lowest temperature and performed better in terms of temperature reduction which will lead to thermal comfort of occupants.

Keywords: Simulation; indoor temperature; tropical landscape; green roof; thermal comfort.

1. INTRODUCTION

Our natural landscape has been significantly modified as a result of man's activities on earth. Various developmental programmes in the bid to make human life more comfortable has led to diverse activities which are unlikely to come to an end once humans continue to live on earth. Infrastructural developments such as buildings, roads and others replace vegetation with impervious surfaces. The combined effect of the heat absorbing properties of such structures and that of the impervious surfaces results in higher temperatures indoors making it very uncomfortable [1]. According to Nyame-Tawiah [2], the city is becoming hotter and hotter at an alarming rate with maximum temperatures reaching 36°C and above in the hottest months (February and March). He further indicated that the temperature pattern from 1976 to 2015 shows a rise in temperature of 2.10°C. This is in line with the predictions by Environmental Protection Agency of Ghana that by 2050 there will be an increase in temperature by 2.00°C.

As at 2012, when the last national population and housing census was conducted in Ghana, the country had reached a point of rapid urbanization causing people to migrate from all over the country towards the major cities which are, Accra and Kumasi. Kumasi is thus at the threshold of rapid urbanization as the census showed that the City had reached a growth rate of 5.47% compared to the nation's at 2.5% and Accra, the national capital at 3.5% [3]. As people become increasingly committed to living in an urbanized high-tech style, the understanding of the importance of plants influence on the quality of life, human well-being, and social development cannot be over emphasized. Kumasi, the Ashanti Regional capital, which is the second largest city in Ghana had all the advantages offered by its natural landscape particularly urban trees but the landscape is being depleted at a fast rate making it lose almost all the advantages of a tropical rain forest ecology [4]. This trend of development results in the incidence of Urban Heat Island (UHI).

The phenomenon of urban heat islands (UHI) refers to the situation where urban air temperatures are higher than their corresponding rural values [5] and this has been widely studied in developed countries. Such studies are however relatively new in Ghana and most likely same with many developing countries. The UHI effects are likely to have caught up with the Kumasi Metropolis following its fast rate of development. Planting of vegetation has been shown to be one of the strategies in mitigating UHI effects [6].

Vegetation plays an important role in the reduction of heat in a space there by enhancing thermal comfort in the space. Green roofs are sources of vegetation cover in urban areas. Vegetative layer of a green roof is measured by several characteristics such as the plant height, leaf area index (LAI), fractional cover, albedo, and stomatal resistance [7]. Pre vegetated green roofs have been found to be more effective in impacting thermal comfort. Therefore, thermal performance of a building is fully optimised after full coverage is established [8]. The vegetation acts as a barrier to the sun rays and provide shade as well as undergoes other physiological functions such as transpiration which help reduce indoor temperature [9]. Niall [10] outlines the benefits of green roof to buildings and its surrounding environment as storm water management, improved water run-off quality, improved urban air quality, extension of roof life and a reduction of the urban heat island effects. Other benefits also include enhanced architectural interest and biodiversity. Green roofs reduced indoor temperature values by 3°C to 4°C when outdoor temperatures values were between 25°C and 30°C [11]. An identified added advantage of a green roof as indicated by Dunnett and Kingsbury [12], is for every decrease in internal building air temperature of 0.5°C, may reduce electricity use for air-conditioning up to 8%. In the building sector of Ghana, the increased use of air-conditioners, inefficient curtain walls and sliding windows, and the lack of sustainable design principles, especially in residential buildings have contributed to the present challenging energy situation in Ghana [13]. Energy is however, the bedrock for the success of every nation and leads to the improvement in the quality of life of people. Given that by 2020 almost 70% of the world population will be living in cities, 60% will be energy poor [14]. Developing countries may avoid spending $1.7 trillion on oil refineries, coal mines and new power plants by spending for the next 30 years $10 billion annually to improve energy efficiency and conservation [15]. The purpose of this study therefore is to use simulation based exploration to advance efforts towards the reduction of indoor temperature by the use of green roofs. Green roof has the potential as a viable option to reduce electricity consumption in the country.

2. LITERATURE REVIEW

Literature for this study includes areas such as Urbanisation, the incidence of UHI in Ghana and globally and Green Roof Technology.

2.1 Trends of Urbanization in Ghana

Ghana's annual growth rate is about 2.5%, with this growth rate, the population of Ghana is constantly on the increase. This subsequently increases the population in the urban areas in the country (Table 1).

In 1921 less than 10% of the total population lived in towns and cities and the population increased to more than 51% barely in 2010 according to the 2010 census [16]. The population concentration is however dominated in the urban centers like Accra, Kumasi, Tamale and Sekondi-Takoradi of Ghana.

Comparing other population trends in Africa, Ghana's population is becoming urbanized. In recent times, more than 40% of Ghanaians live in the city or town with more than 5000 population. According to Naab et al. [17] more than half of Ghanaians would live in urban centers by the year 2020 if the trend does not change.

2.2 Urban Heat Island (UHI)

According to Getter and Rowe [18], before human activities on earth, vegetation was made up of a balanced ecosystem that managed water and solar energy more efficiently. These areas have been replaced with hard surfaces such as roads, concrete and so on. In the United States, about 10% of residential development and 71% to 95% of industrial areas and shopping centers are replaced with hard surfaces. Today, two-thirds of all hard surfaces are in the form of parking lots, driveways, roads, and highways [19]. The other one-third is made up of homes, buildings, and other non-vegetated or open areas. These materials making up the hard surfaces have the tendency to hold heat for a longer time before releasing it into the atmosphere in the cities than the surrounding rural areas.

The Urban Heat is as a result of the heating up of metropolitan areas that makes it warmer than its rural areas. The thermal mass of materials used in the urban areas such as asphalt, brick, concrete and glass differs from the ones in the rural areas such as trees, grass, water bodies, bare soil and so on. The canyon structure made by tall buildings creates heating by the sun. During the day heat energy is stored in the hard surfaces of the building and given out later [20]. In the urban areas, the stored heat energy is then radiated as long wave than in the rural areas during the night making the urban areas hotter than the rural areas [21].

Heat island is much felt under calm and clear weather conditions. The increasing winds mix the air and reduce the heat island effect and increasing cloud cover reduces radiative cooling at night thereby reducing the UHI [22].

Table 1. Total population and percentage urbanized, 1921-2010

Year	Total population	Percentage urbanized	Urban population	No. of urban settlements
1921	2,298,000	7.8	179,244	-
1931	3,163,000	9.4	297,322	-
1948	4,118,000	12.9	570,597	41
1960	6,727,000	23.1	1,551,174	98
1970	8,559,000	28.9	2,472,456	135
1984	12,296,000	32.0	3,938,614	203
2000	18,912,000	43.8	8,278,636	364
2007	23,000,000	49.0	11,270,000	492
2010	24,658,823	51.0	12,545,229	636

Source: [23]

2.3 Green Roof Technology

Green roof also called roof garden is made up of growing media and vegetation on roof tops. It replaces the vegetation that is destroyed during infrastructural development [24]. History tells us that roof gardens has existed many years ago. Example is the Hanging Gardens of Semiramis now called Syria is considered one of the seven wonders of the ancient world. Norwegians in the year 1600s to 1800s covered roofs with soil for the purpose of insulation and then planted vegetation for reinforcement of the soil. In the world today, Oberndorfer et al. [25] indicated that Germany is recognized as the place of origin for modern green roofs. Green roofs are developed to help in the protection against radiation on the roof and used as fire protection. As a result of growing environmental concerns especially in urban areas, Germany created opportunities to introduce progressive environmental thoughts, policy and technology [26]. These innovations and technologies were quickly embraced. The use and understanding of green roofs have allowed the formation of building laws that now require construction of green roofs in many urban centers. Green-roof coverage in Germany alone now increases by approximately 13.5 million square meters (m^2) per year [27]. Today, elaborate garden projects are designed for high-profile international hotels, business centers, and private homes [28].

Green roofs are grouped into two categories such as extensive and intensive green roofs. Intensive involves much maintenance and plants include shrubs, trees, and deeper planting medium. Extensive green roofs are of less maintenance and includes less and shallow soil media. Plants that are commonly used are drought tolerant succulents such as *Sedum oblanceolatum* [29]. No matter the type of green roof employed, either intensive or extensive type. Its effect on the UHI cannot be overlooked. There is a third type called natural green roof. It has spontaneous origin [30].

3. METHODOLOGY

3.1 The Study Area

Kumasi is the capital city of the Ashanti Region of Ghana. The city lies 270 km north of the national capital and between latitude 6.35°- 6.40° and longitude 1.30°-1.35° with an elevation of between 250 –300 m above sea level [31]. The city lies within an area of about 254 square kilometres. It is located in the transitional forest zone and characterized by heavy rainfall in the wet season (June and September). The roof types that are common in Ghana includes pitch (gable) roofs, hip roofs and flat roofs. These are relevant and prevalent in these areas because of the levels of high rains. There are however, other types of roofs depending on the function of the building and climatic conditions in the environment. They include lean-to roof, hip roof, mono pitch roof, flat roof and barrel roof [32].

3.2 Design and Construction of Test Cells

Nine test cells were constructed for a real life experiment and validation. Each treatment was replicated 3 times making up 9. This was oriented on the North South Azumith. Detail drawings are provided in Figs. 1 and 2. The walls for both the control and experimental cells are made of 20 mm thick cement mortar render for both external and internal wall of 150 mm sandcrete block with a mixture ratio of 1:2 (cement and sand). The floor of the cells are made of mass concrete (cement, sand and stone) aggregate with a ratio of 1:2:4. The roof of the control was constructed with 50 mm x 100 mm wooden rafter at 600 mm center to center interval with a wooden purlin size of 50 mm x 75 mm. It was then covered with colourlink premium aluzin 0.4 mm long span minor red roofing sheet (Fig. 2).

The test cells are made up of sandcrete walls and set up in a randomised complete block design at the Department of Horticulture - KNUST. The treatments were *Portulaca grandiflora* (Fig. 3) and *Setcreasea purpurea* (Fig. 4) with aluzinc roof being the control.

This experiment was set up in a grassed area boarded by a greenhouse to the west and other structures on the south and east 15 m away from the site.

A simulation experimental setup was then done to run the simulation for 1 year (12 months) to cover both wet and dry seasons in Ghana to try 6 scenarios of different leaf area indexes and soil depths. Version 5.0.2 Design Builder and Energy Plus version 5.8 was used to select 6 scenarios out of 30 scenarios created using leaf area indexes of 2 and 5 as well as soil depth of (70-150 mm), 200 mm, 300 mm and 500 mm. The time setup for the simulation was from 12.00 am to 11.59 pm.

3.3 Location, Climate, Weather File Access and Schedule

The site location and exterior thermal environment is critical in determining the thermal performance of the test cells with regards to sun angles and air properties. The site location parameters such as latitude and longitude, time zone, site elevation above sea level and the average monthly ground temperatures of Kumasi were specified in the Input Data File. As a result of the test cells contact with the ground, the ground temperatures were specified by the use of the Design Builder program as the outside temperatures. The Latitude and Longitude for the test cell is 6.8° and -1.33° respectfully. The size of the test cell is 1000 mm by 1000 mm and a height of 1000 mm (Fig. 1). The time zone is 0 hours and the elevation above sea level is 258 m. The exposure of the site to wind was normal (not clouded). The texture of the ground was grass lawn with a surface solar and visible reflectance of 0.22. This means that the ground was not reflective. Annual average outdoor air temperature of 29.05°C and maximum difference in monthly outdoor temperature of 2°C was used for the simulation. The fact that Kumasi hourly temperature did not exist, the Accra Kotoka hourly temperature data file was edited using the Latitude and Longitude of Kumasi. The hourly temperature data file was then generated electronically for Kumasi which was used for the simulation. The simulation period used for the study was 1 year (12 months) from January to December 2016. Air temperatures and relative humidity was generated every 10 minutes.

The experimental cell (Green Roof) was the extensive type of green roof. Its roof construction is made up of 12 mm thick plywood fixed on 50 mm x 100 mm rafters and 50 mm x 75 mm purlin. 0.01 mm back polythene was then fixed on the plywood to act as a waterproof membrane. Also 12 mm size chippings are placed on the waterproof membrane to act as a drainage layer when there is excess water. A geo textiles material was then fixed on the drainage layer to act as root barrier. Top soil was obtained from the Department of Horticulture and sieved to remove any debris and stones. Each green roof test cell roof top was filled with 0.15 m^3 of sandy loamy soil (Fig. 2). The soil was characterised at the Department of Crop and Soil Science laboratory.

3.4 Simulation Parameters for the Scenarios

The site location parameters such as latitude and longitude, time zone, site elevation above sea level and the average monthly temperatures of Kumasi were specified in the input data file (3.0.1).

3.5 Surface Construction Elements

The Surface construction material used for the model (Fig. 5) was walls, roof, floor and plants. The specification of the various materials defining a zone was done by creating a database of the basic construction material types used in the Ghanaian construction industry. The Thermo-physical properties of the materials used in the model are presented (Table 2). The roughness of the material influences the convection coefficient and the exterior convection coefficient. The basic material used for the model has their thickness, conductivity, density and specific heat capacities specified.

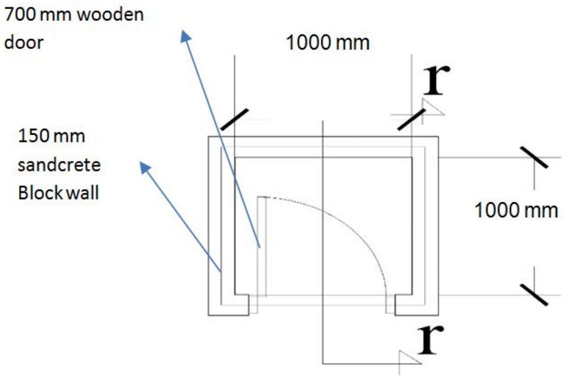


Fig. 1. Floor plan of test cell
r – r indicates the section line

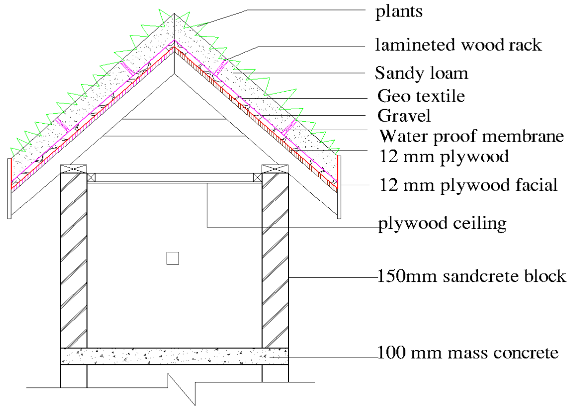


Fig. 2. Section through the test cell

Fig. 3. Fully covered *Portulaca grandiflora*

Fig. 4. Fully covered *Setcreasea purpurea*

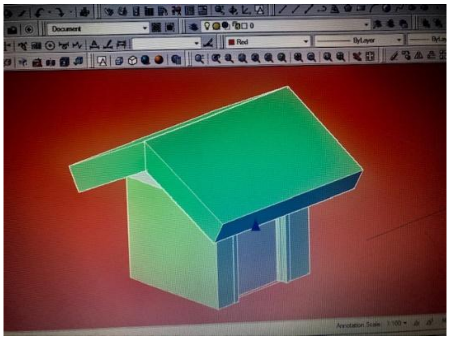


Fig. 5. 3D impression of the modelled test cell

Table 2. Thermo-physical properties of basic materials thermo-physical properties of basic material types [33]

Name	Thickness (m)	Conductivity (W/m K)	Density (kg/m^3)	Specific heat (J/kg K)	Thermal resist (m^2 K/W)
Mass concrete	0.150	1.95	2240	900	-
Sandcrete block	0.150	0.49	512	880	-
Timber-"Dawoma"	0.050	0.15	608	1630	-
Ceiling air Space	-	-	-	-	0.18
Render: 6m^2	0.020	-	-	-	0.026

Table 3. Simulated experiments involving six scenarios of leaf area index and substrate depth

Test	Scenarios
1	Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 70-150 mm (LAI 2/70-150 mm and LAI 5/70-150) on Mean Temperature (°C)
2	Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 200 mm (LAI 2/200 mm and LAI 5/200) on Mean Temperature (°C)
3	Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 500 mm (LAI 2/500 mm and LAI 5/500) on Mean Temperature (°C)
4	Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 300 mm (LAI 2/300 mm and LAI 5/300) on Mean Temperature (°C)
5	Effect of leaf Area index of 2 and 5 respectively, Soil depth of 70-150 mm and 500 mm (LAI 2/70-150 mm and LAI 5/500) on Mean Temperature (°C)
6	Effect of leaf Area index of 5 and 5 respectively, Soil depth of 70-150 mm and 500 mm (LAI 5/70-150 mm and LAI 5/500) on Mean Temperature (°C)

3.6 Assumption

For the purpose of the research, the following assumptions were made:

- It was assumed that apart from some level of infiltration into the test cells, there were no openings for ventilation.
- Heat transfers through the walls, doors and the floors was not considered except through the roof.

3.7 Leaf Area Determination of Ground Covers

Viticanopy, a computer software application for measuring grapevine canopy architecture designed and developed by the school of Agriculture, Food and Wine from the University of Adelaide was used to determine the Leaf Area Index of the selected plants. It uses digital photography and automated analysis by applying gap size assessment [34,35].

Leaf Area Index is a measurement of development of canopy at a given time. It can be quantified by the formula LAI= [Leaf area (m^2)/Ground cover (m^2)]. Therefore the leave area index of 2 and 5 was achieved by dividing the area of the leaf by the ground area. Both are measured in meter square hence the cancellation of the meter square.

3.8 The Scenarios in Summary

The below are the six (6) tests conducted in the simulated experiments.

Soil depth is a measure of the thickness of the soil in millimeters.

4. RESULTS

This section presents the simulation results of the various scenarios with the treatments which access the effect of leaf area index (LAI) and Soil depth of a green roof on indoor temperature. The results provide the basis for the best options in selecting plants and deciding on the depth of soil in the construction of Green Roof in the tropics.

4.1 Scenario One: A Soil Depth Range of 70-150 mm with a Vegetation Cover of LAI 2 and 5 from January to December 2016

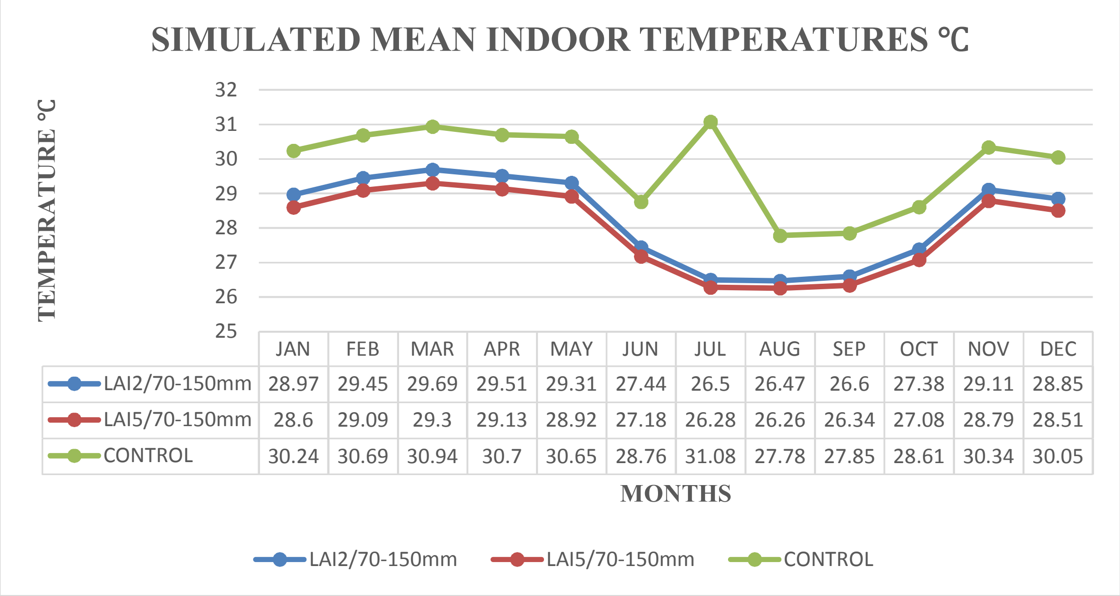
At a soil depth between 70-150 mm, a vegetation cover with a LAI of 5 gave significantly (P≤0.05) low temperatures indoors for all the month (January to December). The control's indoor temperature ranges from 30.24°C to 31.08°C in the months of January, May and November to December. This indicates the inception of the dry season through to the start of wet season in May. There was however a peak temperature of 1.08 in the month of July. The vegetative roofs also recorded a temperature range 26.50°C to 29.69°C from January to December for a plant with LAI of 2.

In addition, a vegetation cover with a LAI of 5 gave a simulated temperature ranging from 26.26°C to 29.30°C. The temperature recording in the ranges of 29°C occurred in the month of February, May and April and the lowest temperature in the ranges of 26°C in the months of July, August and September (Fig. 6).

4.2 Scenario Two: A Vegetative Cover with a Leaf Area Index of 2 and 5 Respectively, and Soil Depth of 200 mm on Mean Indoor Temperature (°C) from January to December 2016

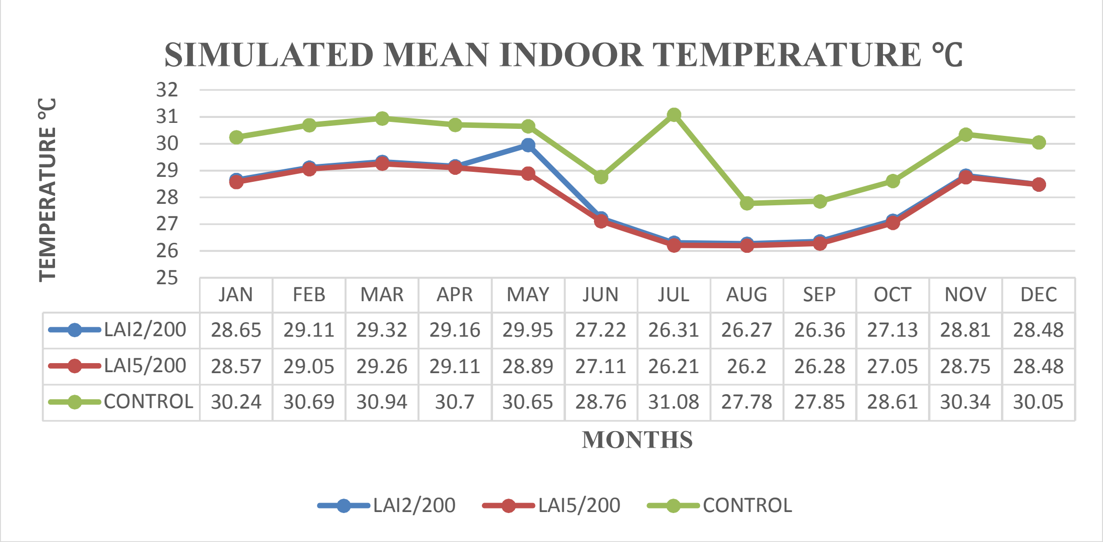
A vegetative cover with a leaf area index of 2 with a soil depth of 200 mm recorded indoor temperature within the range of 26.47°C to 29.69°C in the month of August and March. In addition, a vegetative cover with a leaf area index of 5 and a soil depth of 200 mm recorded the lowest significantly (P≤0.05) indoor temperature in the month of August during the wet season (26.20°C) and the highest (29.26°C) in March during the dry season.

Also, the control recorded temperature ranges from 30.24°C to 30.94°C in the month of January, May and November to December. It recorded the highest indoor temperature of all the three treatments (Fig. 7).



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LAI2/70-150mm	28.97	29.45	29.69	29.51	29.31	27.44	26.5	26.47	26.6	27.38	29.11	28.85
LAI5/70-150mm	28.6	29.09	29.3	29.13	28.92	27.18	26.28	26.26	26.34	27.08	28.79	28.51
CONTROL	30.24	30.69	30.94	30.7	30.65	28.76	31.08	27.78	27.85	28.61	30.34	30.05

Fig. 6. Effect of LAI 2/70-150 mm and LAI 5/70-150 on mean indoor temperature



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LAI2/200	28.65	29.11	29.32	29.16	29.95	27.22	26.31	26.27	26.36	27.13	28.81	28.48
LAI5/200	28.57	29.05	29.26	29.11	28.89	27.11	26.21	26.2	26.28	27.05	28.75	28.48
CONTROL	30.24	30.69	30.94	30.7	30.65	28.76	31.08	27.78	27.85	28.61	30.34	30.05

Fig. 7. Effect of LAI 2/200 mm and LAI 5/200 on mean indoor temperature

4.3 Scenario Three: At a Soil Depth Range of 500 mm with a Vegetation Cover of LAI 2 and 5 from January to December 2016

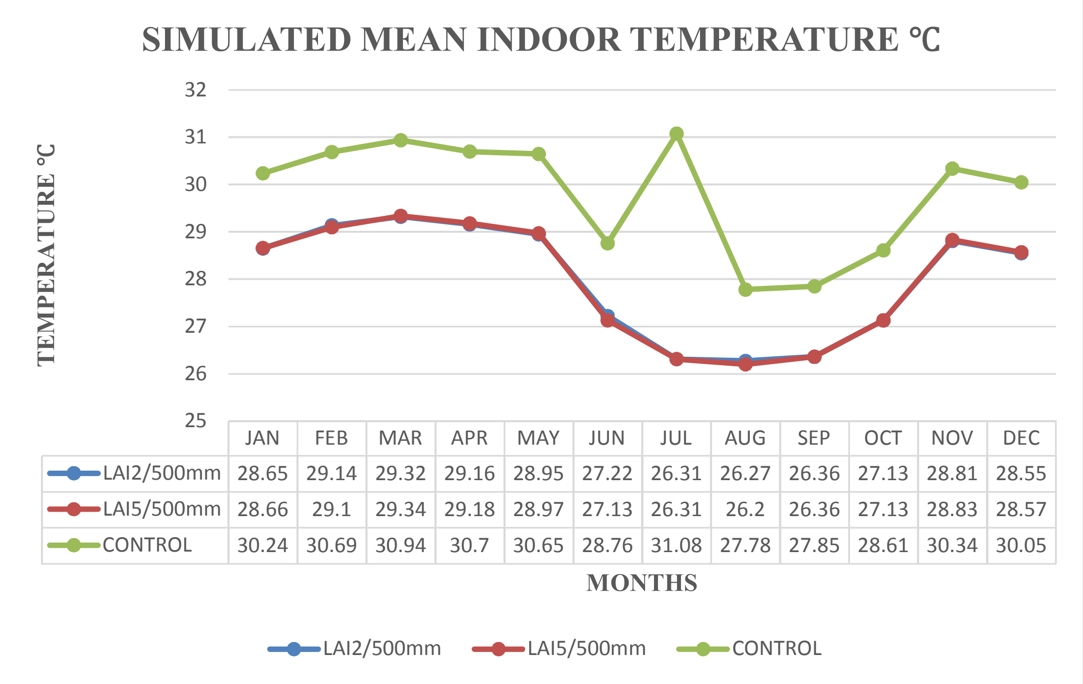
A soil depth of 500 mm and a vegetative cover with a leaf area index of 2 recorded the range of temperature (29.32°C) in May and in August (26.27°C). March, April and May depicted significant differences (P≤0.05) between the treatments where the control had the highest temperature and the least was recorded by LAI 2/500 mm. This observation followed a similar trend to the month of November and December. Also a vegetative cover with a leaf area index of 5 and a soil depth 500 mm recorded temperature range between 29.34°C in March and 26.20°C in August. In the month of February, June and August, significant differences (P≤0.05) were achieved by the treatments where the lowest temperature was recorded by LAI 5/500 mm and the highest by the control but for the month of January, July, September and October, significant differences were not showed by the treatments. In both treatments, the control recorded a temperature range of 30.94°C to 27.78°C which were the highest in all the months (P ≥0.05) (Fig. 8).

4.4 Scenario Four: At a Soil Depth Range of 300 mm with a Vegetation Cover of LAI 2 and 5

A vegetative cover with a leaf area index of 2 with a soil depth of 300 mm recorded temperatures ranging from 26.28°C in August during the wet season to 29.30°C in March during the dry season. January, March to July indicated significant differences (P≤0.05) between the treatments where the least temperature was recorded by LAI 2/300 mm and the control had the highest temperature (Fig. 9). A similar trend was shown in the month of September, November and December. The treatment with the soil depth of 300 mm and leaf area index of 5 recorded temperatures in the range of 26.32°C to 29.33°C for the months of August and March respectively. February, March and April recorded higher temperature values by LAI 5/300 mm and the highest by the control in all the month. Significant low temperatures were recorded in February, August and October (P≤0.05) (Fig. 4).

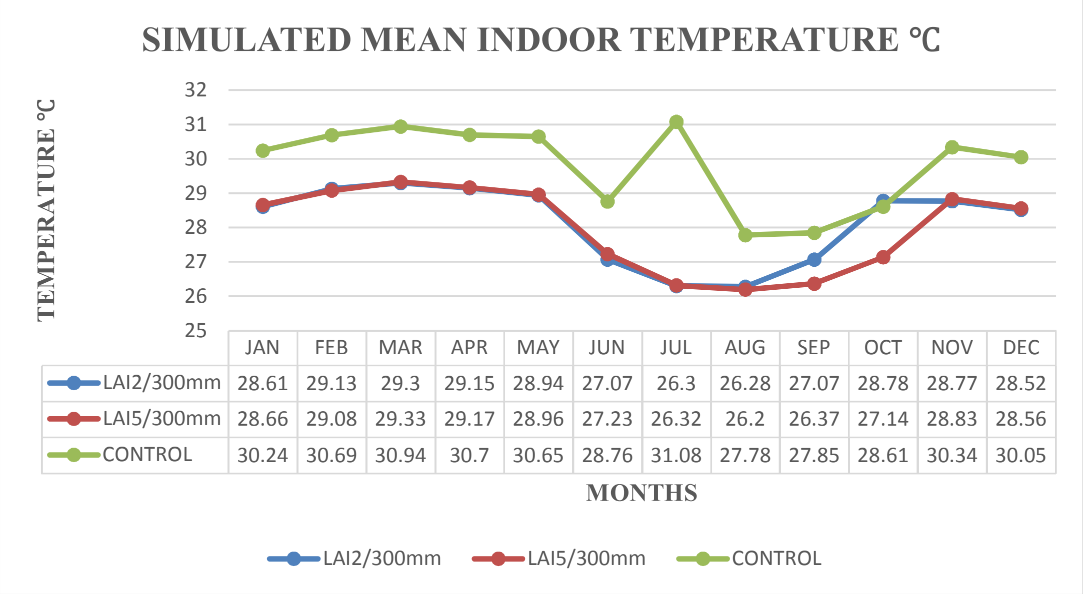
4.5 Scenario Five: At a Soil Depth Range of 70-150 mm and 500 mm with a Vegetation Cover of LAI 2 and 5

At a soil depth of 500 mm, a vegetation cover with a LAI of 2 gave significantly (P≤0.05) low temperatures indoors for all the month (January to December) at a range of 26.27 to 29.32°C for the month of August and March. The control's indoor temperature ranges from 30.24°C to 31.08°C in the months of January, May and November to December. However, the temperatures recorded by the control were higher than the temperatures recorded by the two treatments. A vegetative cover with a leaf area index of 2 and a soil depth range of 70-150 mm recorded temperature range of 26.48°C in August and 29.69°C in March (Fig. 10).



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LAI2/500mm	28.65	29.14	29.32	29.16	28.95	27.22	26.31	26.27	26.36	27.13	28.81	28.55
LAI5/500mm	28.66	29.1	29.34	29.18	28.97	27.13	26.31	26.2	26.36	27.13	28.83	28.57
CONTROL	30.24	30.69	30.94	30.7	30.65	28.76	31.08	27.78	27.85	28.61	30.34	30.05

Fig. 8. Effect of LAI 2/500 mm and LAI 5/500 on mean indoor temperature



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LAI2/300mm	28.61	29.13	29.3	29.15	28.94	27.07	26.3	26.28	27.07	28.78	28.77	28.52
LAI5/300mm	28.66	29.08	29.33	29.17	28.96	27.23	26.32	26.2	26.37	27.14	28.83	28.56
CONTROL	30.24	30.69	30.94	30.7	30.65	28.76	31.08	27.78	27.85	28.61	30.34	30.05

Fig. 9. Effect of LAI 2/300mm and LAI 5/300 on mean indoor temperature

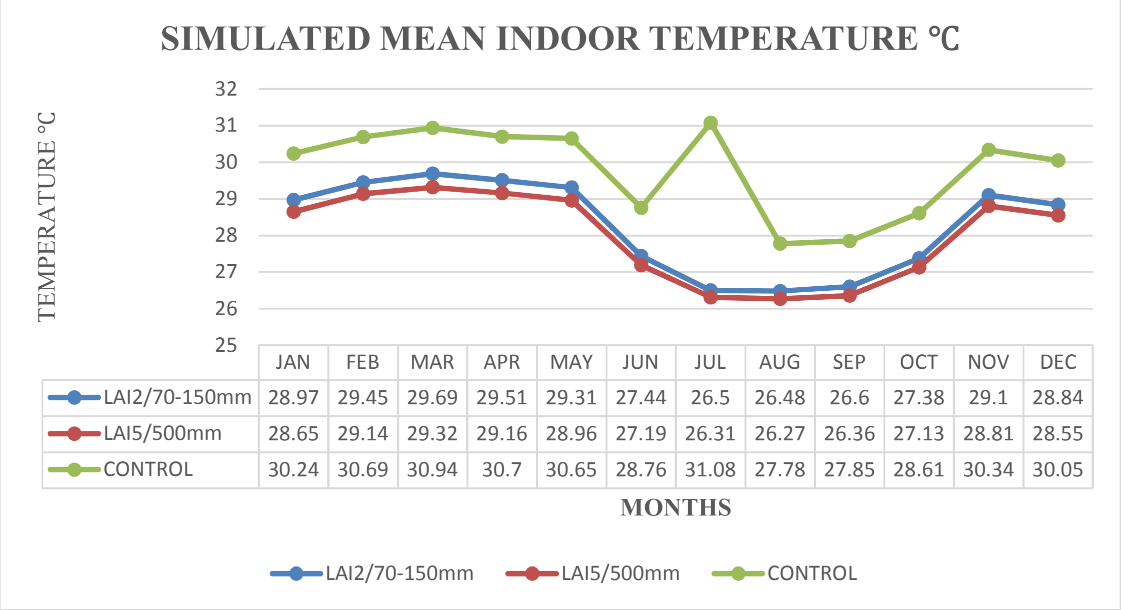
4.6 Scenario Six: A Vegetative Cover with a Leaf Area Index of 5 and 5 respectively, and Soil Depth of 150 mm and 500 on Mean Indoor Temperature (°C)

A soil depth of range 70-150 mm and a vegetative cover of leaf area index of 5 recorded temperature in the range of 29.30°C in March to 26.26°C in August. January, March, April, May, July depicted significant differences ($P \le 0.05$) between the treatments where the control had the highest temperature and the least was recorded by LAI 5/70-150 mm. This observation followed a similar trend in the month of September to December. A vegetative cover with a leaf area index of 5 and a soil depth of 500 mm recorded temperature in the range of 26.2°C to 29.3°C. However, in the month of August LAI 5/500 mm recorded the least temperature among all the months (Fig. 11).

4.7 Green Roof Dynamics

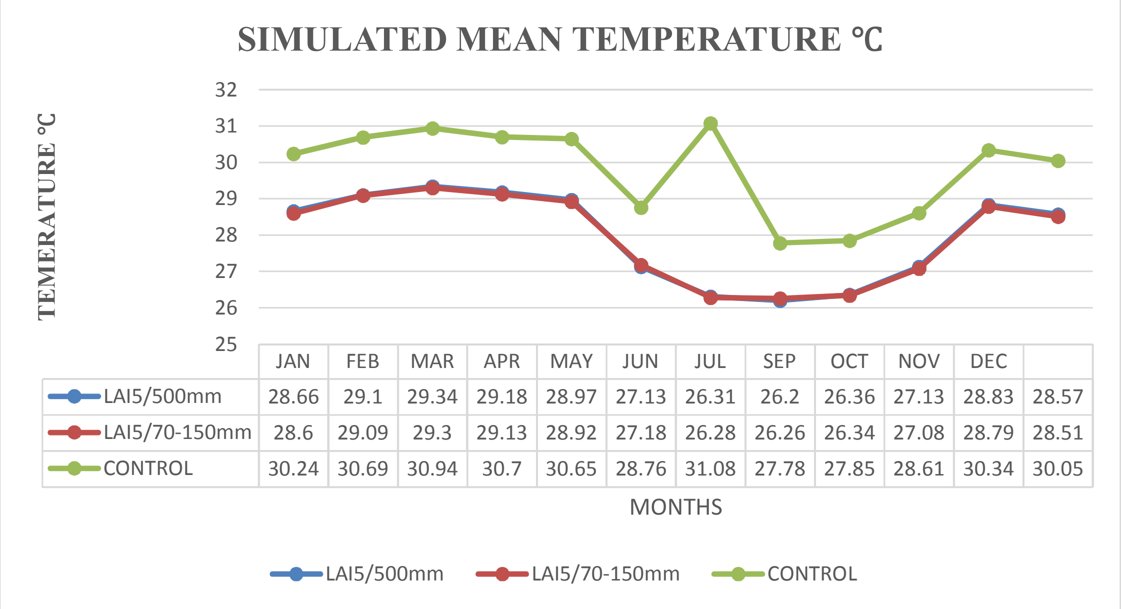
One day was selected in the month of February and one day in the month of August to represent dry and wet seasons. The graphs below indicates how temperature behaves for a day (00.00- 23.59).

Observations from Fig. 12 in the month of February and Fig. 13 in the month of August. Temperature begins to fall from 16.30 up to 22:30 when sun shine reduces its intensity till is off. Temperature increases steadily from 27.5°C to 29.1°C from 10.00 to 16.30 when the sun has



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LAI2/70-150mm	28.97	29.45	29.69	29.51	29.31	27.44	26.5	26.48	26.6	27.38	29.1	28.84
LAI5/500mm	28.65	29.14	29.32	29.16	28.96	27.19	26.31	26.27	26.36	27.13	28.81	28.55
CONTROL	30.24	30.69	30.94	30.7	30.65	28.76	31.08	27.78	27.85	28.61	30.34	30.05

Fig. 10. Effect of LAI 2/70-150 mm and LAI 5/500 on mean indoor temperature



	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEP	OCT	NOV	DEC	
LAI5/500mm	28.66	29.1	29.34	29.18	28.97	27.13	26.31	26.2	26.36	27.13	28.83	28.57
LAI5/70-150mm	28.6	29.09	29.3	29.13	28.92	27.18	26.28	26.26	26.34	27.08	28.79	28.51
CONTROL	30.24	30.69	30.94	30.7	30.65	28.76	31.08	27.78	27.85	28.61	30.34	30.05

Fig. 11. Effect of LAI 5/70-150 mm and LAI 5/500 on mean indoor temperature

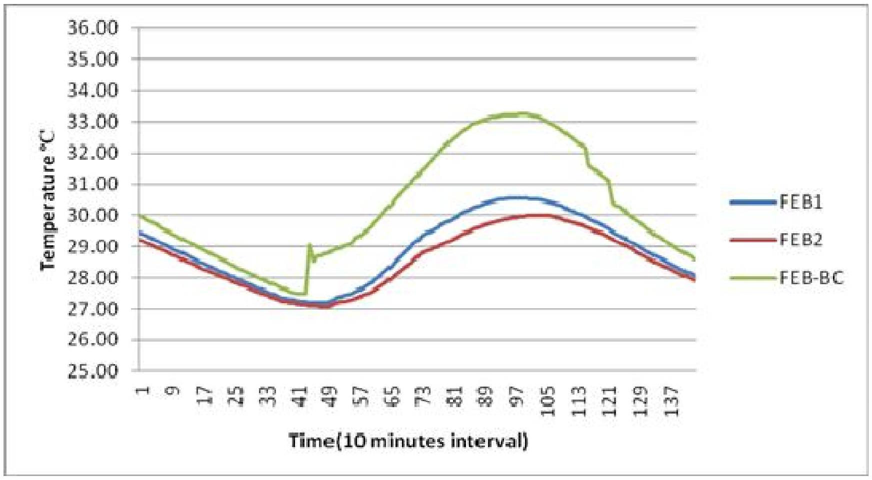


Fig. 12. Indoor temperature pattern (1st February, 2016)
FEB1= Leave area index 2 and Soil depth of 70-150 mm
FEB2= Leave area index 5 and Soil depth of 70-150 mm
FEB-BC= Control

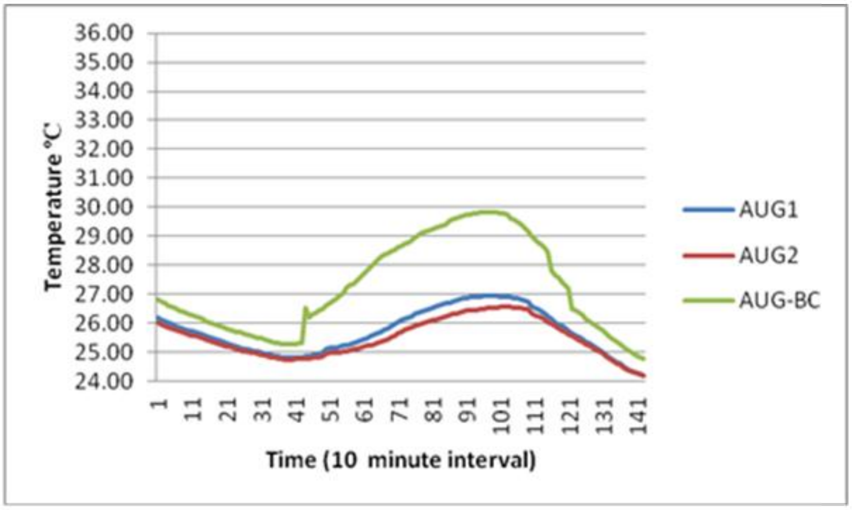


Fig. 13. Indoor temperature pattern (7th August, 2016)
AUG1= Leave area index 2 and Soil depth of 70-150mm
AUG2= Leave area index 5 and Soil depth of 70-150mm
AUG-BC= Control

started shining. Temperature then begin to rise to a maximum of 33.21°C at 16.30. At this point the temperature has reached its maximum and then begin to fall gradually.

5. DISCUSSION

This section presents the discussion of the simulated results of the six scenarios drawn for the study. They included effect of leaf Area index of 2 and 5 respectively, and Soil depth of 70-150 mm, Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 200 mm, Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 500 mm, Effect of leaf Area index of 2 and 5 respectively, and Soil depth of 300 mm, Effect of leaf Area index of 2 and 5 respectively, Soil depth of 70-150 mm and 500 mm on and Effect of leaf Area index of 5 and 5 respectively, Soil depth of 70-150 mm and 500 mm on Mean Temperature (°C).

5.1 Scenarios One, Two, Five and Six: Effect of Leaf Area Index of 2 and 5 Respectively, and Soil Depth of 70-150 mm, Effect of Leaf Area Index of 2 and 5 Respectively, and Soil Depth of 200 mm, Effect of Leaf Area Index of 2 and 5 Respectively, Soil Depth of 70-150 mm and 500 mm and Effect of Leaf Area Index of 5 and 5 respectively, Soil Depth of 70-150 mm and 500 mm on Mean Temperature (°C)

The main issues arising from this study is that green roofs thermal performance and behavior depends on a number of factors such as canopy architecture, leaf properties and substrate characteristics [36,37].

Observation from Fig. 6, 7, 10 and 11, a soil depth of 70-150 mm and a leaf area index of 5, LAI 5/200 mm, LAI 2/500 mm and LAI 5/70-150 mm recorded the lowest temperature and performed better in terms of temperature control than a leaf area index 2 and 70-150 mm soil depth, LAI 2/200 mm, LAI 2/70-150 mm and LAI 5/500 mm through out year. Though the soil depth and the leave area index are the determining factor in these scenarios. Plant type such as succulents have special characteristics [38] which help them tolerate high temperatures and stores water for a longer time as compared to herbaceous plants. *Setcreasea purpurea* whose leave area index is 5 is considered as a succulent plant. According to Lee and Kim [39], succulents develop multiple structural mechanism called CAM (crassulacean acid metabolism) that prevent water lost as compared to herbaceous plants. When there is water, they absorb it through their roots and binds it in interior water storage cells. This makes the roots always moist and cools the soil around.

The canopy architecture of the leaves of succulents (*Setcreasea purpurea)* is thicker, large and provides shading effect [40] by cutting away the solar radiation from the surface of the soil [41]. This conforms to studies by Neda et al. [42]. They indicated that due to plant shading effects, the received total radiation at bare-soil surface is 32% (6.2 kWh. m^{-2}) higher than that at fully- covered green roof media surface. This phenomena makes the vegetative substrate surface cooler than bare soil.

Another reason for the reduction in temperature is the coated and waxy leaves of most succulents (*Setcreasea purprea)* which help prevent water loss. This slows water movement out of the surface of the leave there by conserving water. The above assertion is confirmed by Minke [43] by indicating that of the total light energy that falls on a leaf, 2% is used for photosynthesis, 48% goes through the leaf and stored in the plant water system, 30% is translated into heat by transpiration and 20% is reflected away. Weng et al. [30] studies also suggest that of the total solar radiation, green roofs reflect 20% to 30% and absorb 60% for photosynthesis. The remaining 20% is transmitted to the growing media as heat energy. Fang [44] focuses on the thickness and fractional coverage of the leaves as a contribution factor in thermal reduction of green roofs. This assertion is true as *Setcreasea purpurea* with thicker leaves than *portulaca gradiflora* performs better in temperature reduction (6, 7, 10 and 11).

Also, the physiological mechanism of succulents has a specialised form of photosynthesis called crassulacean acid metabolism which help prevent water loss. The stomata [45,46] of these plants opens only at night and stores the carbon dioxide they absorb and use it for photosynthesis during the day. This helps the plant reduce its metabolism rate, keeping and maintaining moist internal tissues.

5.2 Scenarios Three and Four: Effect of Leaf Area Index of 2 and 5 Respectively, and Soil Depth of 300 mm and 500 mm on Mean Temperature (°C)

As observed in Figs. 8 and 9, the test three (LAI 2/500) recorded the lowest temperature for 5 months which is statistically significant as compared to LAI 5/500 mm which obtained the lowest temperature for only 3 months. For test four, LAI 2/300 mm recorded the lowest temperature for 9 months of the year whislt LAI 5/300 mm recorded the lowest temperature for 3 months. Looking at a Leaf Area Index of 5 for both Soil depth of 300 mm and 500 mm. It would have been assumed that the shadding provided by *Setcresea purpurea* would have recorded the lowest indoor temperature throughout the year. From these scenarios, a Soil depth of 500 mm and a bigger leaf area should have performed better in terms of temperature reduction than 300 mm soil and small leaf area of 2. The above asersion was determined by the soil depths not the leave areas.

A critical look at the soil profile, it is observed that a soil depth of 300 mm and 500 mm is warm from midday to late evening [47,48] which is gradually transmitted to the indoor space as it cools. Such indoor spaces are warmer than the thinner depths of 70-150 mm as only 20% [49] of the solar radiation is transmitted to the soil. As the depth is small, the heat is not stored for a longer time but is transfered gradually into the atmosphere and the indoor space. Investigations done by Berardi et al. [50] suggested that, Soil works as inertial mass with high thermal capacity and low thermal transmittance.

Wong et al. [51], Emilsson et al. [52], and Sun et al. [53] argue that deeper vegetative roofs produce lower temperatures (heat gain and loss) and that they have a better thermal performance. They suggested that 10 cm (100 mm) increase in soil depth increases the thermal resistance of dry clay soil by 0.4 m^2 KW. Berardi et al. [54], suggested that the presence and quantity of water affects the thermal properties of the media. However, results from this study suggest that thinner depth of 70 mm-150 mm performs better in terms of temperature reduction than 300 mm-500 mm in the tropical environment. This occurance is so because the deeper soil warms up from midday and because of the depth (300 mm-500 mm) heat flux is stored for a longer time which is discharged into the indoor space.

Also, a wet media provides additional evapotranspiration which prevents heat energy into the indoor space. This phenomena acts as a passive cooler by cooling the building [55,56].

5.3 Green Roof Dynamics

Green Roof behaves this way (Figs. 12 and 13) because of the characteristics of the components such as the plant and the soil [57]. From evening to morning, temperatures begin to fall gradually because of the physiological mechanisms of succulents plants such as *Setcreasea.* These mechanisms helps them conserve water in their tissues for a longer time by regulating the opening of the stomata [58,59]. This makes the soil moist and increasing relative humidity through the process of transpiration.

In the early mornings to noon to evening, temperature increases steadily in Green Roofs and the control because there is the presence of sun light. Comparing both temperatures in green roofs and the "control", green roofs has lower temperature with a temperature difference of 3.2°C. This happens because of the canopy architecture of the plant which enables it to cut solar radiation from the soil by shading [60] and portion of the sunlight for photosynthesis [61]. The soil component of the Green Roof also plays a role by acting as an insulative material to slow the transfer of heat by radiation, conduction and convection [62].

6. CONCLUSION AND RECOMMENDATION

The study presented a simulation base exploration to advance efforts towards the reduction of peak temperature by the use of Green roofs. To accomplish this, a methodology was developed by employing experimentation and simulation. Design builder simulation program was used to develop a base mode of roofing commonly constructed in Ghana. A series of scenarios were made to achieve 6 models that were used to investigate the effects of leaf area index and soil depth on peak indoor air temperature. From the studies, due to plant shading effects provided by larger leaf area index of 5, the received total radiation at bare-soil surface is 32% (6.2 kWh m^{-2}) higher than that at fully - covered green roof media surface. This phenomena makes the vegetative substrate surface cooler than bare soil.

The results from the studies indicates that thinner depth of 70 mm-150 mm and larger leaf area index performs better in terms of temperature reduction than 300 mm-500 mm in the tropical environment. This occurance is so because the deeper soil warms up from midday and because of the depth (300 mm-500 mm) heat flux is stored for a longer time which is discharged into the indoor space. This an indication that soil works as inertial mass with high thermal capacity and low thermal transmittance. Future studies should also consider Green wall envelops and green roofs combined and their impact on indoor temperature.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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