AN EXPERIMENTATION STUDY TO INVESTIGATE THE EFFECT OF GREEN ROOF CONSTRUCTION ON INDOOR TEMPERATURE IN LOCAL CLIMATIC CONDITIONS

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ABSTRACT: *Pakistan has been suffering from acute energy crisis; energy outages and its high price are common problems of population around the country. The situation worsens when mechanical cooling turns in, to cool the buildings against scorching summer sun; whereas during winter, keeping the living places warmth is also an expensive business. Migration to big cities has also posed threats like land scarcity and high property prices leaving very little green spaces around. In such scenarios an effort has been made to investigate the impact of green roof construction on indoor temperature of the building in climatic conditions of Lahore city. Extensive green roof was laid using locally available materials, on existing experimental modules constructed on roof top of Department of Architectural Engineering & Design (AED), in University of Engineering & Technology (UET), Lahore. The temperature variations were monitored for 30 days during September and October, 2014. The results showed a significant reduction in indoor temperature peaks in comparison to ambient temperature. Similarly considerable reduction in green roof surface temperature was observed as compared to traditional roof surface.*

Key Words: Green Roof, Ambient Temperature, Indoor Temperature.

1. INTRODUCTION

Thermal performance of any building in summer and winter climates is of great concern to inhabitants. Mechanical cooling and heating of the building pose burden to overall living expenses, and in the country like Pakistan which is facing acute shortages and high prices of energy, the situation is exponentially worsens.

Lahore has a very rich architectural background, the Mughal and Colonial buildings have massive walls and roofs, which provide an excellent insulation against climate and keep indoor environment comfortable. However, modernization of architectural practices and increasing prices of real states has reduced the overall thickness of building envelop. Such buildings retain thermal energy more than normal diurnal cycle and do not allow enough time to dissipate it. The population influx has also posed additional burden to real estates [1], resultantly the green spaces within and around the cities are on continuous decline and given rise to urban heat island phenomenon [2].

Lahore is situated in semi arid climate. The summer is usually very long and hot and temperature exceeds 40 ^{o}C [3], whereas in winter temperature drops below 22 ^{o}C [4]. In Lahore both summer and winter conditions demand substantial amount of energy to create comfortable indoor environment. This situation necessitates implementation of passive cooling and heating techniques to reduce dependency on mechanical means and hence reduce the overall living expenditures.

Roofs are the most ubiquitous component of the building envelops which contribute significantly to the overall thermal gain of the building.

Green roofs are relatively new in Pakistan as compared to other parts of the world. There is no substantial technical data available regarding its performance in local climatic conditions. In this context an endeavor is made to study its impacts on indoor climate of building. Extensive green roofs were laid on two Experimentation Modules (EM) constructed on roof top of Department of Architectural Engineering & Design in University of Engineering and Technology, Lahore. A total eight Experimentation Modules on different orientations were constructed by Dr. Sabahat Arif in her doctorate Research titled "*Energy Efficient Design, Effect of Orientation on Indoor Temperature Profile"* [5].

In order to establish the thermal performance of green roof, ambient air temperature, surface temperature of traditional roof, surface temperature of green roof and inside temperature of Experimentation Modules 1 & 2 were observed and compared to determine the impact of green roof on indoor temperature of the building.

2. RESEARCH REVIEW

Jim C.Y. et al (2012) compared the thermal performance of an extensive green roof, bare roof and a controlled bare roof of a railway station building in humid-subtropical Hong Kong region. It was concluded that thermal performance of green roof was optimum on sunny summer day, declines on cloudy day and was negligible on rainy day. The extensive green roof constructed over 484 m^2 of area saved an overall 2.80 x 10^4 KWh of electricity for summer air conditioning [6].

Sonne J. K. studied the energy performance of a green roof constructed on roof of Central Florida University building, during summer and winter of year 2005. The green roof consisted of 6" to 8" of growing media containing plants native to Florida, was executed on 1650 square foot of area, whereas remaining equivalent half was conventional light colored membrane roof. It was concluded that the summer heat flux of a green roof was 18.3% less than the conventional roof heat flux. Similarly, during winter the weighted average heat flux of a green roof was 49.5% less than the conventional roofing system [7].

Ascione F. *et al* reviewed the economic feasibility of green roofs in different climatic conditions of European Countries using numerical procedure implemented in EnergyPlus through dynamic energy simulation. The investigated model was a typical traditional European building, insulated in accordance to recent international standards. Five different green roof typologies were modeled and compared their thermal performance with traditional roof system. It was concluded that in warm climates green roofs reduced the cooling energy demand from 0% to 11%. In cold climates green roofs reduce the cooling and heating energy demand by

1% to 7%. The variables like roof maintenance cost, water tariff and energy cost make green roofs scarcely feasible. However, additional benefits e.g. pollution reduction, aesthetic values etc. justify the adoption of green roofs [8].

Yang J. et al (2008) studied the level of air pollution removed by green roofs in Chicago, using a dry deposition model. It was concluded that 19.8 ha of green roofs removed 1675 kg of air pollutants in Chicago at an annual rate of 85 kg/ha/yr [9].

Bianchini F., *et al* analyzed the Net Present Value (NPV) per unit area of green roof by taking into account probabilistic social cost benefit over its lifecycle. It was concluded that green roofs are low risk, short term investments in terms of net returns. The probability of profits out of green roofs is considerably greater than the potential financial losses [10].

Speak A.F. *et al* investigated the effect of intensive green roof on air temperature 300mm above its surface in comparison to the conventional roof. The research was carried out in Manchester, UK. The results indicate that the temperature above green roof was 1.06 ^{o}C lower than the conventional roof. Similarly greatest cooling effect was observed at night with an average difference of 1.58 ^{o}C [11].

3. Experimentation

Experimentation was carried out on 2 No. Experimentation Modules (EM) constructed on roof AED Department in UET, Lahore. Layout plan of the modules is represented in Figure-1. After initial investigation of EM 1, 2, 3 & 4, Experimentation Modules 1 & 2 were selected for construction of green roof.

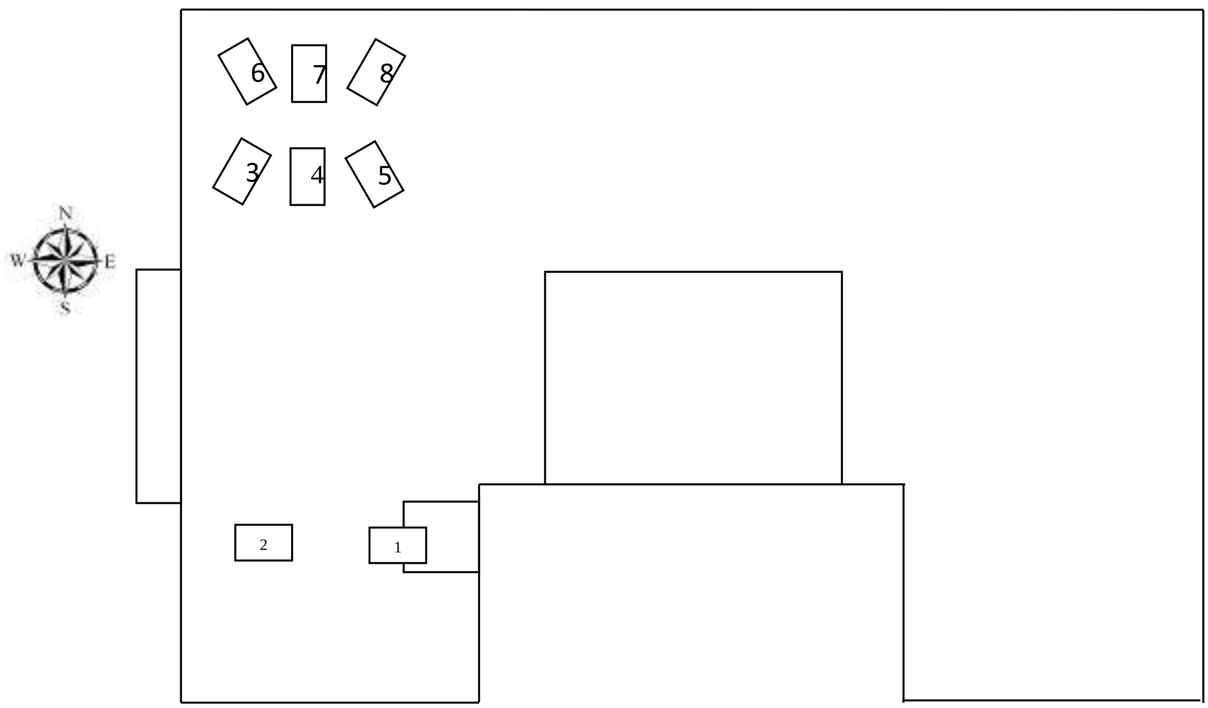


Figure – 1: Schematic Layout of Experimental Modules Constructed on Roof Top of AED Department

3.1. Description of Experimentation Modules

The dimensions of experimental module are 5.5 ft x 7.5 ft x 6.7 ft, each module is constructed in 9 inches thick brick masonry on west wing roof of AED Department at 22 ft above road level. 4 inches thick precast RCC slabs are used as roofing system. Galvanized iron door 6 ft x 2.5 ft and glass from outside with 4.5 inches thick brick work. panned window 4 ft x 5 ft are installed on shorter walls of each module. Figure-2 indicates plan and x-sectional views of a typical experimentation module.

The windows of each EM was closed from inside as well as from outside with 4.5 inches thick brick masonry, whereas doors were closed

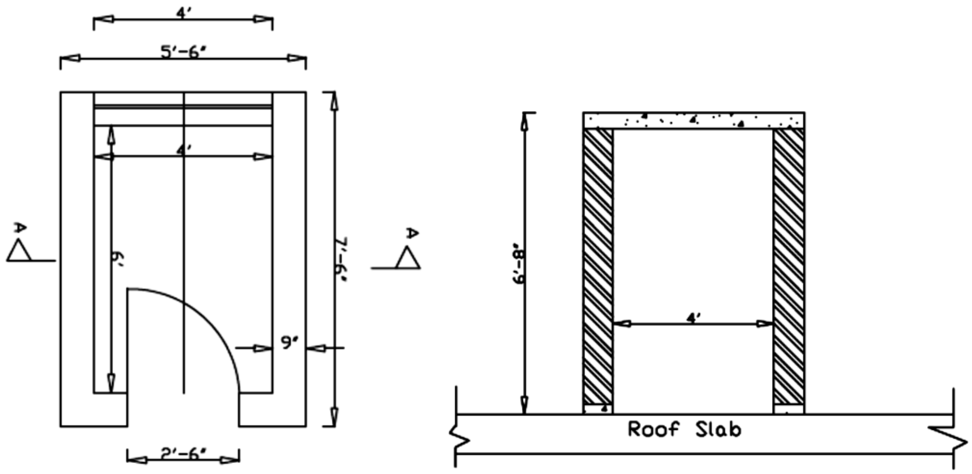


Figure – 2: Typical Construction of Experimental Modules.

3.2 Construction of Green Roof

The existing roofing system of Experimental Modules was modified by providing 1.3^o slope to roof slabs to facilitate drainage through substrate. The joints between precast RCC slabs were sealed with 1:3 cement sand mortar. 6 inches high parapet wall was constructed as retention to green roof substrate along periphery of each EM. Three drainage holes were provided along longitudinal retention wall of each EM. Each hole was fitted with plastic mesh and filtration cloth to retain fines of substrate. Two coats of Fospak Expanbrush were applied on roof and retention walls for water proofing. One inch thick layer of coconut husk was laid over the roof as water retention and filtration layer, over which 4 inches thick layer of growing media, prepared by mixing 2:1 soil and organic fertilizer, was laid. Figure – 3 indicates various green roof construction steps and Figure – 4 shows the x-sectional details of completed Experimentation Module. Plantation for the green roof were as selected which were resilient to micro and macro climatic conditions at roof top, have low irrigation requirements, thick foliage and locally available at low cost. Market survey of various nurseries in the city was carried out for the availability of such plants, and finally ornamental sweet potato vine was selected for plantation on the roof. Plantation was done in the last week of March, 2014. Figure – 5 shows the fully grown green roofs over Experimentation Module 1 & 2. Each green roof was irrigated every alternate day and 20 liters of water was applied each time to each roof.

Figure – 3: Various Steps Showing Construction of Green Roof.

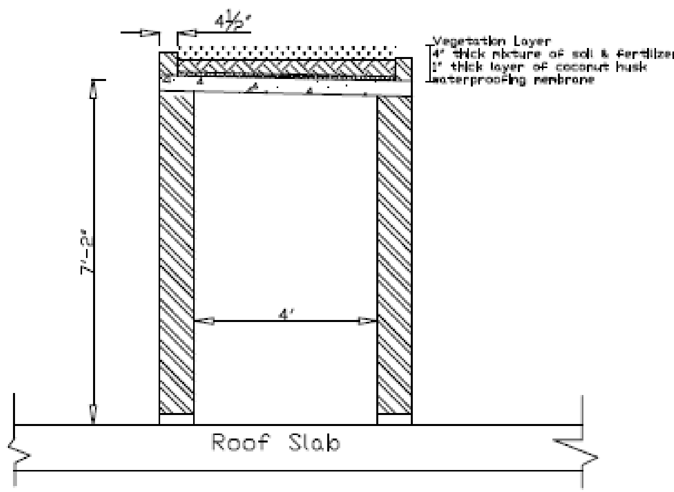


Figure – 4: X-sectional View of Completed Experimentation Module

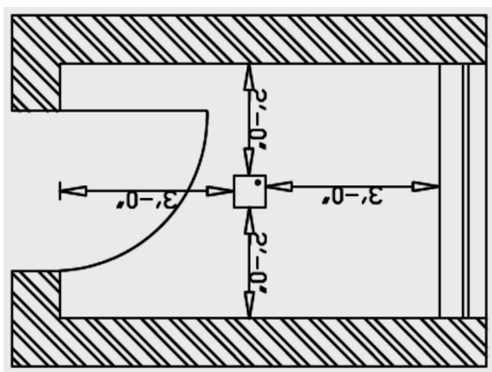
a) Experimentation Module # 1 b) Experimentation Module # 2

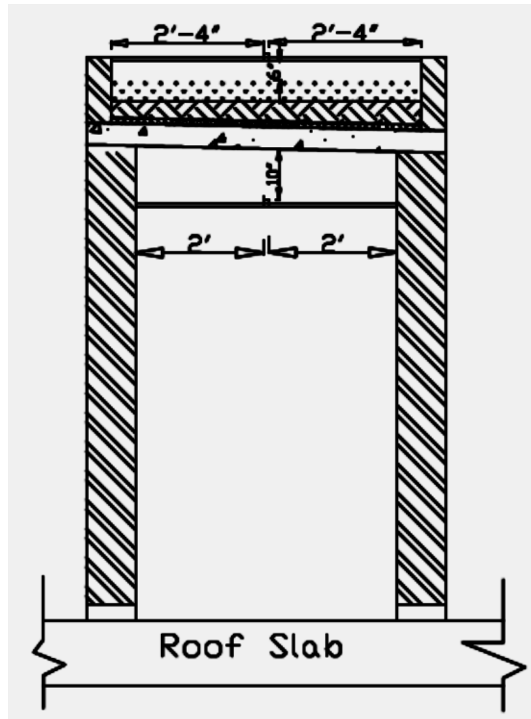
Figure – 5: Fully Grown Green Roof on Experimentation Modules.

.3

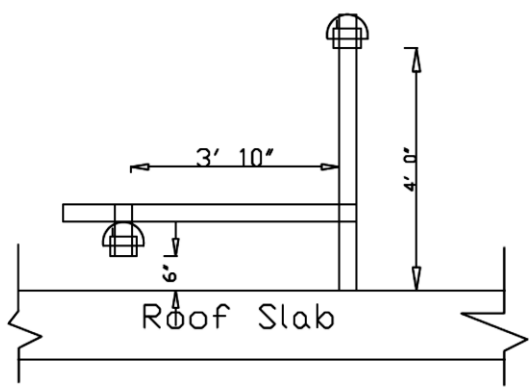
Temperature Monitoring

Temperature was monitored using Testo Saveris System, five temperature sensors were installed at various locations to monitor and record temperatures at half an hour time interval. Two temperature sensors were installed at 6 inches height to measure traditional roof surface and green roof surface temperatures respectively. Two temperature sensors were installed 10 inches below the inside roof surface in middle of each Experimentation Module and one sensor was installed at 4 feet height to measure ambient temperature [11]. Figure – 6 indicates location of different temperature sensors.





a) Location of Inside Temperature Sensor b) Location of Inside and Green Roof Surface Sensors



c) Location of Traditional Roof Surface and Ambient Temperature Sensors

Figure – 6: Location of Temperature Sensors

5. Experimentation Results

Temperature measurements were taken on half hourly basis from September 24th, 2014 to October 23rd, 2014. Table – 1 shows the 30 days average of half hourly temperature measurements at all five locations. Figure – 7 is the graphical representation of temperature variations indicated in different colors.

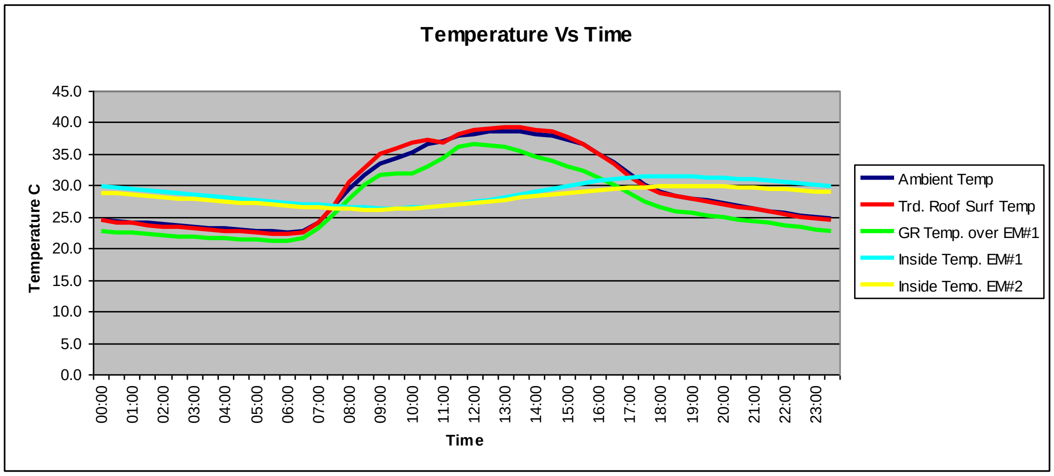


Figure – 7: Average Half Hourly Monitored Temperature Profile

Table – 1: 30-Days Average of Half Hourly Monitored Temperature

Average Half Hourly Temperature °C													
Sr	**Time**	**Ambient**	**Trad. Roof Surface**	**Green Roof Surface**	**Inside EM#1**	**Inside EM#2**	**Sr**	**Time**	**Ambient**	**Trad. Roof Surface**	**Green Roof Surface**	**Inside EM#1**	**Inside EM#2**
1	00:00	24.6	24.4	22.8	29.7	28.8	25	12:00	38.1	38.8	36.6	27.4	27.2
2	00:30	24.4	24.2	22.6	29.5	28.6	26	12:30	38.6	38.9	36.4	27.7	27.4
3	01:00	24.2	24.0	22.6	29.3	28.5	27	13:00	38.5	39.2	36.1	28.1	27.7
4	01:30	24.0	23.7	22.3	29.1	28.3	28	13:30	38.5	39.2	35.5	28.5	28.0
5	02:00	23.7	23.4	22.0	28.9	28.1	29	14:00	38.2	38.9	34.5	29.0	28.2
6	02:30	23.6	23.3	21.9	28.7	27.9	30	14:30	37.9	38.6	33.8	29.5	28.5
7	03:00	23.4	23.1	21.9	28.5	27.8	31	15:00	37.1	37.7	33.1	29.9	28.8
8	03:30	23.2	22.9	21.7	28.2	27.6	32	15:30	36.6	36.6	32.3	30.3	29.0
9	04:00	23.1	22.8	21.6	28.0	27.4	33	16:00	35.1	35.0	31.3	30.7	29.2
10	04:30	22.9	22.6	21.4	27.8	27.3	34	16:30	33.6	33.5	30.1	31.0	29.4
11	05:00	22.7	22.4	21.3	27.6	27.1	35	17:00	31.9	31.4	28.7	31.2	29.6
12	05:30	22.7	22.3	21.3	27.4	26.9	36	17:30	30.0	29.8	27.5	31.3	29.7
13	06:00	22.5	22.2	21.2	27.2	26.8	37	18:00	28.9	28.8	26.4	31.4	29.8
14	06:30	22.7	22.6	21.6	27.0	26.6	38	18:30	28.3	28.2	25.9	31.4	29.9
15	07:00	24.0	24.2	23.2	26.9	26.4	39	19:00	27.9	27.8	25.6	31.4	29.9
16	07:30	26.8	26.7	25.5	26.7	26.3	40	19:30	27.6	27.4	25.2	31.3	29.9
17	08:00	29.4	30.5	27.8	26.6	26.2	41	20:00	27.2	27.0	24.9	31.2	29.8
18	08:30	31.7	32.8	30.1	26.5	26.1	42	20:30	26.7	26.6	24.5	31.0	29.7
19	09:00	33.4	35.0	31.7	26.4	26.1	43	21:00	26.3	26.2	24.3	30.9	29.6
20	09:30	34.3	36.0	31.9	26.4	26.2	44	21:30	25.9	25.8	24.0	30.7	29.5
21	10:00	35.3	36.7	31.9	26.5	26.4	45	22:00	25.6	25.4	23.6	30.5	29.3
22	10:30	36.6	37.2	33.0	26.6	26.5	46	22:30	25.2	25.1	23.3	30.3	29.2
23	11:00	37.0	36.8	34.2	26.8	26.8	47	23:00	24.9	24.7	23.0	30.1	29.0
24	11:30	37.9	38.1	36.1	27.1	26.9	48	23:30	24.7	24.5	22.8	29.9	28.9

6. Data Analysis

5.1 Comparison between Ambient and Traditional Roof Surface Temperature

Figure – 8 indicates the 30 days average half hourly ambient and traditional roof surface temperatures. The data shows a general cyclic trend. The roof surface remained warmer than than the ambient temperature during 0700 hrs till 1500 hrs. whereas ambient temperature was greater than roof surface temperature .

Maximum difference between traditional roof surface temperature and ambient temperature was 1.7 ^{o}C, which can be interpreted as; traditional roof surface was 4.7% warmer than the ambient temperature.

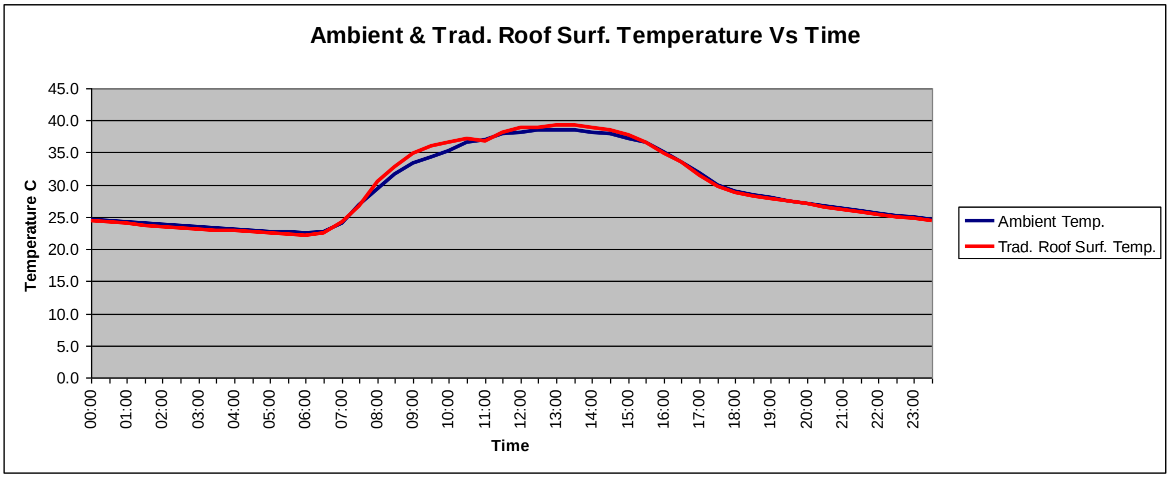


Figure – 8: Ambient and Traditional Roof Surface Temperature Profile

5.2 Comparison between Ambient and Green Roof Surface Temperatures

Figure - 9 shows 30 days average half hourly temperature data of ambient and green roof surface temperatures. Maximum difference between ambient and green roof surface temperature was 4.3 ^{o}C, which means ambient temperature was 13.2% greater than the green roof surface temperature. The data reveals that the ambient temperature remained warmer than the green roof surface temperature round the clock.

5.3 Comparison between Green Roof Surface and Traditional Roof Surface Temperatures

Figure - 10 represents the 30 days average half hourly temperature observation of traditional roof surface and green roof surface temperatures. Maximum difference between traditional roof surface and green roof surface temperature was 4.8 ^{o}C, which means traditional roof surface was 15.1% warmer than the green roof surface. The data further reveals that the traditional roof surface remained hotter than the green roof surface round the clock.

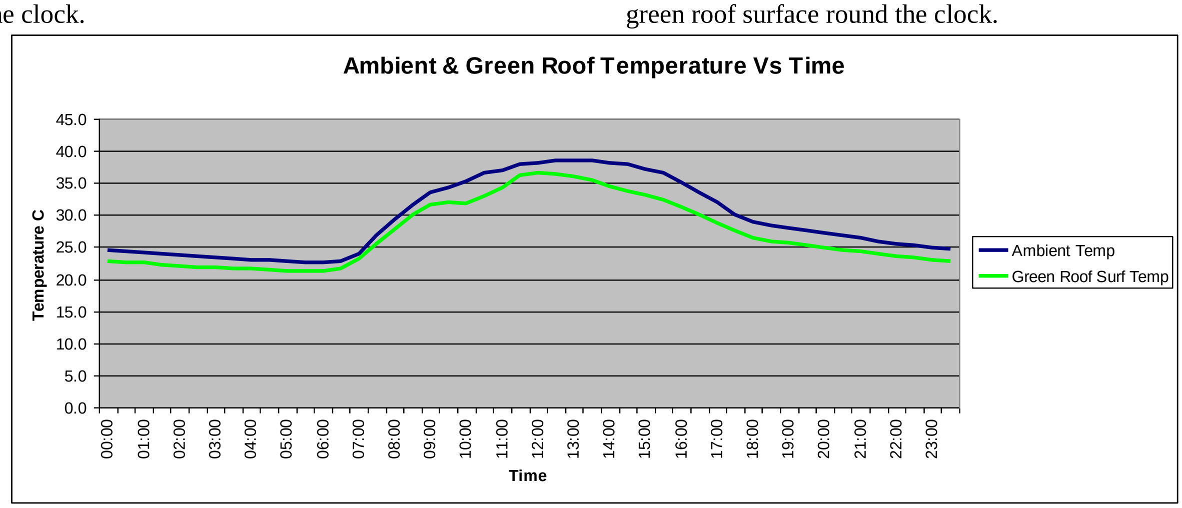


Figure – 9: Ambient and Green Roof Surface Temperature Profile

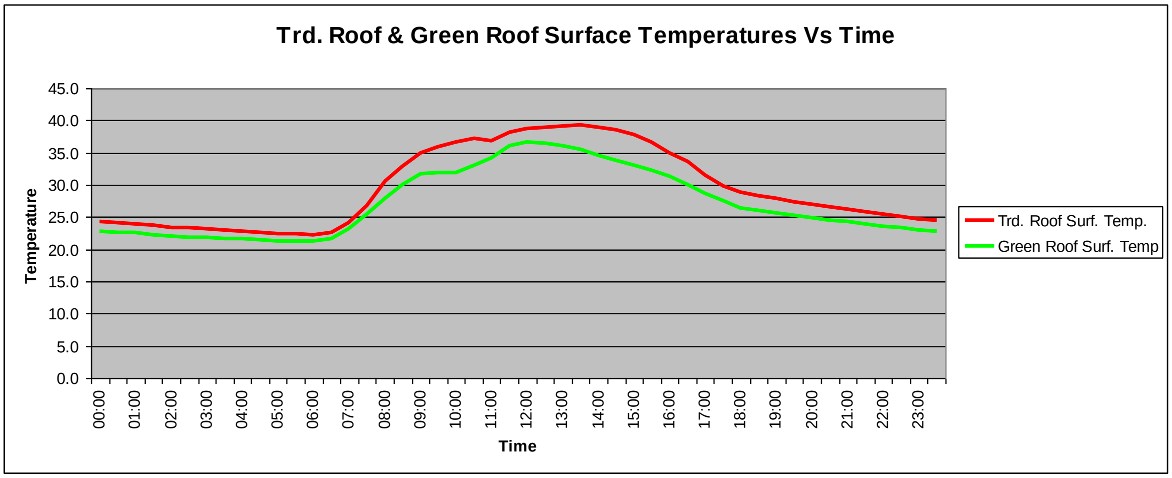


Figure – 10: Traditional Roof Surface and Green Roof Surface Temperature Profile

5.4 Comparison between Ambient and Inside Temperature of Experimentation Module # *1*

Figure - 11 shows 30 days average half hourly records of ambient temperature and inside temperature of experimentation module#1. Maximum difference between ambient and green roof surface temperature was 10.9 ^{o}C, which means ambient temperature was 39.2% greater than the inside temperature of EM#1. 24 hrs inside average temperature of EM#1 was 28.9 ^{o}C. The data revels that inside temperature of EM#1 remained lower than the ambient temperature from 0730 hrs till 1700 hrs, whereas inside temperature of EM#1 remained warmer than ambient temperature from 1730 hrs till 0700 hrs in next morning.

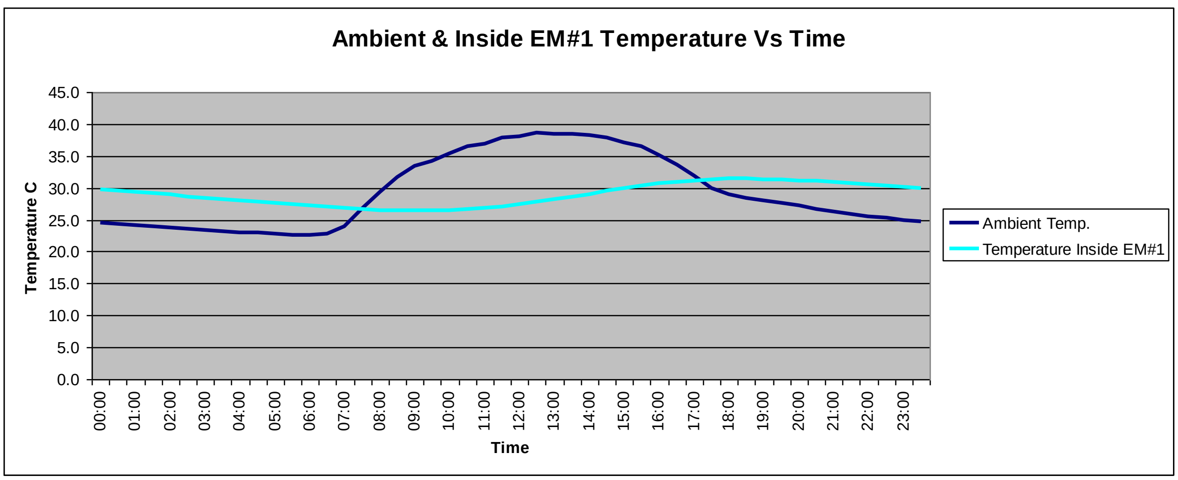


Figure – 11: Ambient and Inside of Experimentation module # 1 Temperature Profile.

5.4 Comparison between Ambient and Inside Temperature of Experimentation Module # 2

Figure -12 shows 30 days average half hourly data of ambient temperature and inside temperature of experimentation module#2. Maximum difference between ambient and green roof surface temperature was 11.2 ^{o}C, which means ambient temperature was 40.7% greater than the inside temperature of EM#2. 24 hrs inside average temperature of EM#1 was 28.1 ^{o}C. The data revels that inside temperature of EM#2 remained lower than the ambient temperature from 0730 hrs till 1730 hrs, whereas inside temperature of EM#2 remained warmer than ambient temperature from 1800 hrs till 0700 hrs in next morning.

7. Discussion on Results & Analysis

The research was carried out to determine the impact of green roof system on indoor air temperature. It involves measurement of ambient, surface temperature of traditional roof and green roof and inside temperature of experimentation modules. The measurements were taken for 30-days and average half hourly temperature was analyzed. The observations revealed that green roof has significantly impacted the inside temperature of experimentation modules. Maximum difference of 11.2 ^{o}C has been observed between ambient and inside EM temperature. Green roof has imparted significant insulation effect to the modules, which kept the maximum inside temperature peak to 31.4 ^{o}C in EM#1 and 29.9 ^{o}C in EM#2. Temperature of inside experimentation modules remained higher than ambient temperature from 1730-1800 hrs till 0700 hrs, whereas ambient temperature remained higher than inside EM temperature from 0730 hrs till 1700-1730 hrs of EM#1 & EM#2 respectively. The green roof has also impacted the surface temperature, a difference of 4.8 ^{o}C has been observed between traditional and green roof surfaces.

8. Conclusions

This research work clearly demonstrates the significance of green roof system in prevailing energy crisis. Green roof system has kept the overall inside temperature peak well below the ambient temperature also green roof has reduced the surface temperature, from where it can be concluded that by constructing green roof system, cooling and heating loads of the building can be reduced significantly. Furthermore, green roof was also helpful in reducing overall surface temperature. The reduced surface temperature will ultimately be helpful in reducing the urban heat island effect if executed at vast scale. Further research should also be carried out to study the effect of intensive and semi-extensive/intensive green roofs on indoor and surface temperatures in local environmental conditions.

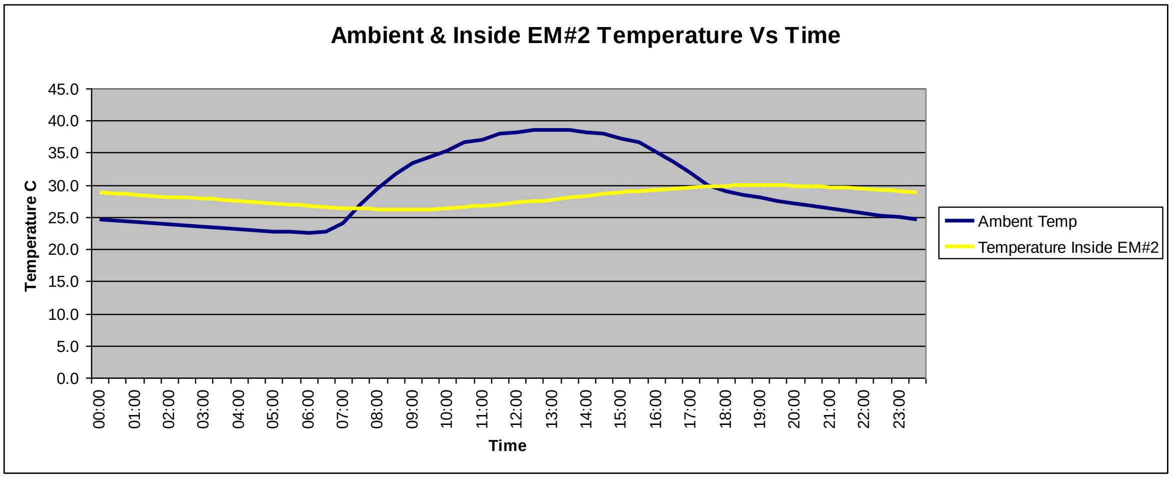


Figure – 12: Ambient and Inside of Experimentation module # 2 Temperature Profile.

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