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Rooftop gardening: A summer cooling technology in cities

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Abstract: *Dhaka, the capital of Bangladesh, is becoming exclusively urbanized day by day with an extreme environment. Rapid and unplanned urbanization is making the residential environment unsuitable for living. Application of greeneries in the prevailing infrastructures may be an effective option to minimize the problem. Therefore, the experiment was conducted in Dhaka, Bangladesh to observe the thermal performance of Rooftop Gardens in residential buildings. The data were recorded through two-way approach i.e., quantitatively and qualitatively. The quantitative data (Temperature and humidity) were measured both outdoor and indoor during the warmest week of the year (24^{th}-30^{th} April, 2016) in the roof garden over the four storied academic building of Sher-e-Bangla Agricultural University. Qualitative data were collected by questionnaire survey from the selected forty rooftop gardens of Mohammadpur and Dhanmondi metropolitan area of Dhaka city. The experimental analysis of thermal performance resulted that the average roof air temperature is reduced by 5.2°C with roof garden while average room temperature is reduced by 1.7°C with roof garden compared to bare roof in the diurnal period. Moreover, the temperature of the residence with roof garden stayed near the thermal comfort zone on maximum hour of the day. In the survey result, 60% of the respondents were found to stay within thermal comfort zone which was positively correlated to the vegetation coverage of that roof. Hence, green application on residential building is more appropriate into the contemporary building as a thermal comfort strategy for a climate smart urban planning of Dhaka city.*

Keywords: *Climate; Extreme environment; Green application; Thermal comfort zone; Urbanization.*

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I. Introduction

Cities are continuously in transition of urbanization process. Dhaka, the capital of Bangladesh and one of the fastest growing mega cities in the world is not an exception of this trend. Major environmental issues like GHE (green house effect), Global warming, climate change etc. resulted from human activities over the past 20 years are caused mainly due to land use change and deforestation and the effects of these issues are most prominent in urban areas. In the process of rapid urbanization of Dhaka city, it is found that about 20 percent vegetation coverage that was present in 1989 has gradually decreased to 15.5 percent and 7.3 percent in the year 2002 and 2010, respectively [4]. Vegetation was found in the Dhaka metropolitan area is only 1.87 percent [5].In this critical situation, the necessity of recovering vanishing green spaces is becoming increasingly critical to maintain environmental quality. In this situation, “Rooftop Gardens” and “Green Roofs” (roofs with a vegetated surface and substrate) can be a potential alternative remedy to reverse the problem through applying this green technology on contemporary buildings in Dhaka city [11]. Green roofs improve the energy efficiency of buildings through a combination of shading, evaporative cooling and insulation from both green roof plants and growing substrate and the thermal effects of the growing substrate [8]. This reduces the energy demand for space conditioning significantly in spring and summer. Roof top greeneries contributes thermal benefit to both micro climates of indoor environment and the surrounding outdoor ambient environment of the building.Basically rooftop gardens (RTG) are particular form of urban greening that uses the rooftops of buildings for growing plants. There are two main forms: green roofs and rooftop gardens, while both are of interest to urban areas. A green roof is the practice of growing vegetation directly on a roof over a waterproof membrane. A roof garden is a similar technique that places container gardens on a roof. Both techniques may partially or completely cover a roof. Green roof is less common in our country as it requires a high initial cost of production and maintenance compared to rooftop gardens. Hence, this research focuses on the latter. This research investigates the cooling effect of this green application technique for residential building in warm humid climate of Bangladesh.

II. Materials and Methods

A. Qualitative data collection: Regardless other thermal parameters, Air Temperature and Relative Humidity reading were taken as these two parameters are closely related to thermal behavior. The physical measurement was carried out by using the instrument "Thermo-hygrograph" which records air temperature and relative humidity on a continuous basis for every hour for seven days. The data were taken at the warmest week of summer season from 25th April to 30th April, 2016 in the roof garden (2500 sqft) over the four storied academic Building of Sher-e-Bangla Agricultural University. The garden was an extensive one, where plants were arranged densely in earthen pots. Outdoor temperature and RH were recorded 3 feet above the roof surface. Data were collected from both under plant shade area of roof garden and under the sun in bare roof simultaneously from the same building having a bare roof in one side and vegetation at the other. Indoor temperature and RH were taken in the top floor rooms both under the roof garden and under the bare roof. The collected temperature and RH reading were averaged to generate the final data. The result was analyzed by comparing the ambient air temperature and relative humidity.

III. **(b)**

Fig 1. Thermal data collection using thermo-hygrograph in (a) roof garden and (b) bare roof

B. Qualitative data collection: For collecting qualitative data, two metropolitan areas namely Dhanmondi and Mohammadpur were selected due to having successful, effective and higher number of roof gardens. Mohammadpur metropolitan includes adabor thana and Mohammadpur thana and Dhanmondi metropolitan includes Dhanmondi thana and Kalabagan thana. In order to achieve the sample size the purposive sampling method was used in order to select the first and known residents who have successful roof gardens in the study area collected from the DAE personnel. After the initial group was selected for the study about 900 roof gardeners. There are several methods for determining the sample size; here, the researcher used Yamane‟s (1967) formula for study group [16]:

$$n= \frac{z^2.p(1-p).N}{z^2.p(1-p).N + N.e^2}$$

where, n = Sample size;
N (Population size) = 900;
e (The level of precision) = 7%;
z = the value of the standard normal variable given the chosen confidence level (e.g., z = 1.96 with a confidence level of 95 %) and
P, The proportion or degree of variability = 50%;
The sample size (n) is = 40.

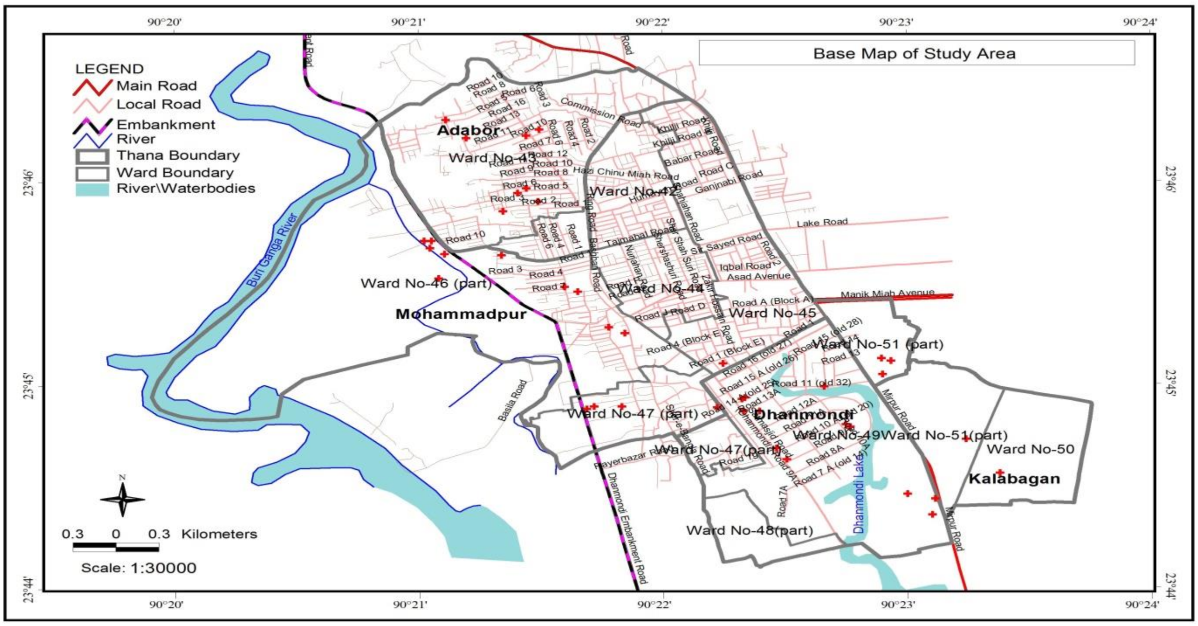

Fig2. Base map of the study area

Survey was conducted using a semi structured questionnaire from randomly selected total 40 households sample for this study. Data were collected by face to face[6] interviewing of the respondents from November 22, 2014 to March 23, 2016 and the questionnaire was analyzed in software "SPSS version 22". Pearson correlation test was also used to assess the level of thermal comfort according to amount of greeneries among different respondents.

C. Comfort zone of Bangladesh:

Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. Hot and humid summer season prevails from March to June where April is the warmest month with temperatures from 33 to 36°C(91 to 96°F).The analytical method of evaluating the comfort zone for Bangladesh has been studied by several authors (Rajeh 1988; Jones 1993), using the concept of the "Neutrality Temperature". In various studies, neutrality temperature is defined as the temperature that gives a thermal experience that is neither warm nor cool, which is a state of "neutral" or "comfortable". Neutral temperature model was proposed by [1] as the best fit for Dhaka's Situation. This study used the neutrality temperature as a base to determine the thermal performance of the rooftop greenery system in the sub-tropical monsoon climate of Bangladesh. The concept of neutral temperature was introduced by Humphreys on the basis of a statistically established relationship between comfort and the outdoor temperatures [9].

For the free running Buildings where the outside temperature is not extreme, Humphreys suggested neutral temperature as: $T_n = 11.9 + 0.534\ To$ (°C)

Where T_n is the neutral temperature and To is the mean outdoor temperature. Later, Auliciems modified this for warmer climates where Ti is the mean indoor temperature and the neutral temperature is: $T_n = 0.73\ Ti + 5.41$

Moreover, [10] recommended the following model for occupants of natural ventilation buildings:

$T_n = 0.38\ Ti + 17$

According to [2], a band of ± 2.5 °C, centered on the neutral temperature T_n comprises the comfort zone. According to the comfort formula, the indoor and outdoor neutral temperature needed to maintain approximately at 30.5°C and 34°C respectively. In this research, the upper and lower limits of the temperature of the comfort zone would be then 33°C and 28°C for indoor and 31.5°C to 36.5°C for outdoor respectively.

Table 1. The neutral temperature of indoor and outdoor for Dhaka, Bangladesh(April,2016)

Adaptive models and equations for Neutral and Comfort temperature		Tn(ºC) Outdoor	Tn(ºC) Indoor
Humphreys (1976)	$T_n = 11.9 + 0.534\ To$ (°C)	34ºC	
Auliciems (1997)	$T_n = 0.73\ Ti + 5.41$		30.65ºC
Nicol and Roaf (1996)	$T_n = 0.38\ Ti + 17$		30.14ºC

T_n= neutral temperature, To = mean outdoor temperature and Ti = mean indoor temperature

A. Results and discussion

A. Quantitative findings of Thermal performance

i. Temperature:

The research concentrated on the comparative study of thermal performance of roof top greenery and bare roof to identify the ability of the green roof in reducing the indoor and outdoor air temperature of the building and the surrounding ambient environment.

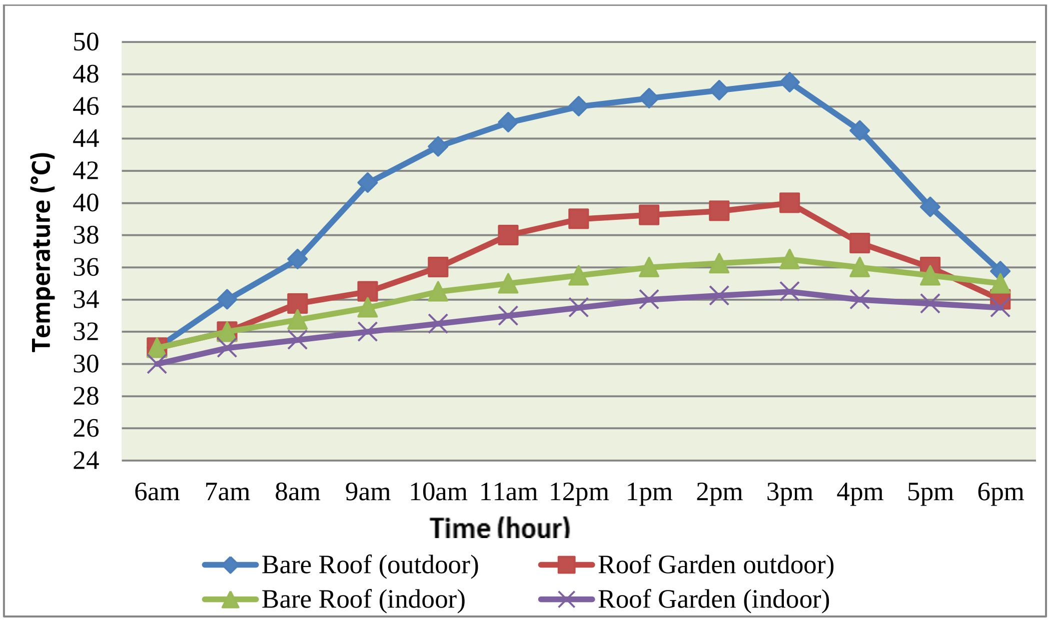

Figure 3. Diurnal temperature variation in rooftop gardens with bare roof

The study showed that daily average outdoor and indoor air temperature with bare roof was 41.40°C and 34.5°C respectively which was reduced by 5.2°C and 1.7°C respectively with roof garden. A maximum reduction of temperature was observed during peak heating period of 2pm to 3:30pm and minimum reduction was observed during 6am to 8:30am.Rashid R. *et.al*., (2009) reported that roof garden can reduce the indoor air temperature 4°C to 5°C during day time. The temperature fluctuation was also found higher in bare roof than the roof garden. Daily temperature fluctuations cause thermal stresses in materials and decrease their durability. Green roofs minimize temperature fluctuations by creating a barrier between solar radiation and structural layer [8].

According to the graph profile the temperature (with roof garden) of the residence showed that maximum hour of the day was staying near the thermal comfort zone both indoor (28°C and 33°C) and outdoor (31.5°C to 36.5°C) which is a desirable condition for the resident. [12] reported that rooftop greeneries reduce roof surface temperature and air temperature of both indoor and outdoor. This finding is also in contrast with the past studies of [15] and [3].

ii. Relative Humidity:

The study found that the average indoor RH in bare roof is lower than the RH reading in roof garden for most of the time in a day. The average reduction of RH was 4.4% while the RH reading was more or less similar from 2pm to 4pm.

According to the study (Fig. 3.1.2) the average outdoor RH was more or less similar in both roof garden and bare roof until 11 am but started to fall from 11 am to 3pm from 60% to 45%. This was due to the rise of temperature outside. Moreover, both indoor and outdoor, the RH (%) was comparatively higher in roof garden than the bare roof but the RH fluctuation was found higher in the bare roof. According to the comfort zone analysis for Bangladesh by [14] during the summer season, the comfort temperature range is between 28 ºC to 32 ºC while relative humidity range lies in 50% (lower limit) to 90% (upper limit). In the study, the RH of roof garden (both indoor and outdoor) did not drop below the comfort limit (50%).

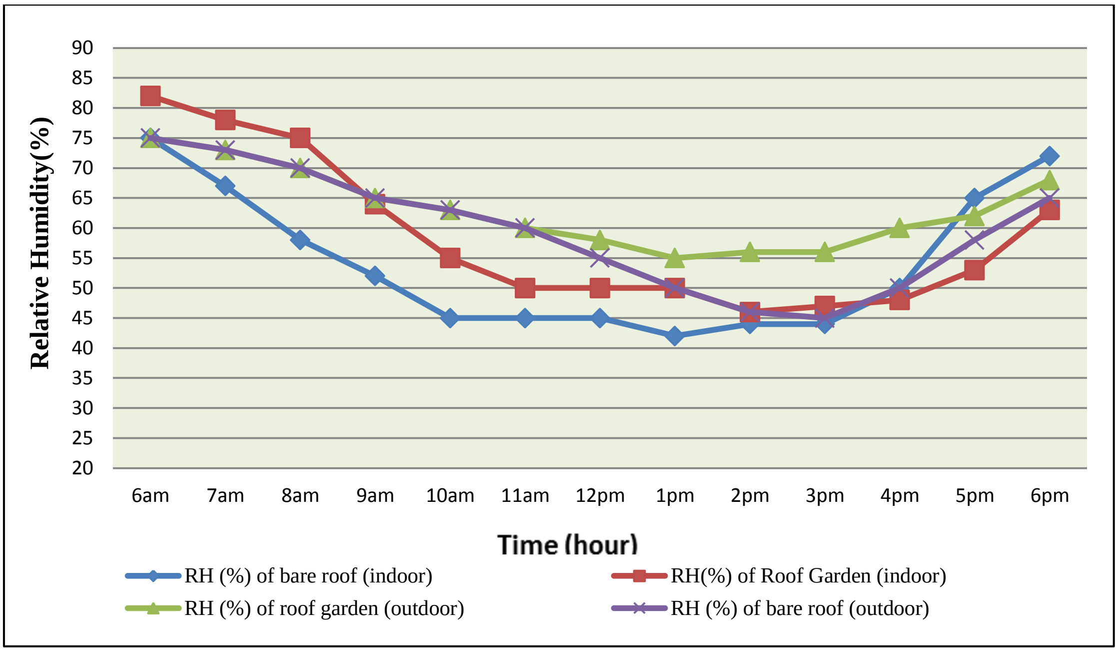

Figure 4. Diurnal relative humidity variation in rooftop gardens with bare roof

This comparative study revealed that the temperature of bare roof was higher than roof gardens with average 62.5% RH.A study of [7] revealed that high relative humidity, together with high air temperatures, increases heat stress because the body cannot be cooled by evaporation.

B. Qualitative analysis of thermal regulation

Survey was conducted using a semi structured questionnaire from selected 40 roof gardeners for this study, where the number of male and female respondents were almost same. In case of age, education, occupation, majority of them were middle aged (46 years), graduate and retired persons occupying higher middle class in the society (Table 3.2.1)

Table 2. Distribution of garden owners according to general information

Sl. No.	Variable	N	Minimum	Maximum	Mean	Std. Deviation
1.	Gender	40	1	2	1.45	0.51
2.	Age		26	67	46.05	11.60
3.	Marital status		1	3	1.15	0.48
4.	Education		3	20	14.05	3.88
5.	Occupation		1	3	2.17	0.91
6.	Family size		2	12	5.50	2.61
7.	Annual income (BDT)		200000	1200000	589250	220470.22
8.	House ownership		1	3	1.23	0.57
9.	Roof surface area (sq. ft.)		950	3500	2070	539.92
10.	Frequency of visit		1	3	1.23	0.48
11.	Spending time		1	3	2.07	0.73

All the three types of roof gardens (extensive, semi-intensive and intensive) were surveyed in this study where the roof gardens were categorized into high, medium and low according to the percentage of plant vegetation covering the roof surface area. 50% roof gardens was found to have medium (25-50%) vegetation coverage.

Table 3. Distribution of garden owners according to vegetation coverage

Category	Range		Respondents		Mean	SD
	score	observed	N	P (%)		
Low	3 (upto 25%)	18-75%	4	10	49.18	17.242
Medium	2 (25-50%)		20	50		
High	3 (>50%)		16	40		
Total			40	100		

Although the direction of the respective building, partial shade by neighboring buildings, climate of the area etc. have direct or indirect effect on thermal environment of the roof. However, each respondent was asked about their personal overall (outdoor) thermal comfort perception with given choices in the questionnaire survey.

Table 4. Distribution of garden owners according to thermal comfort

Category	Range		Respondents		Mean	SD
	Score	Observed	N	P (%)		
High	3 (<32°C)	30-43°C	9	22.5	35.6	3.934
Medium	2 (33-36°C)		15	37.5		
Low	1 (37-40°C)		13	32.5		
Not at all	0 (>40°C)		3	7.5		
Total			40	100		

The study found that (Table 3.3) maximum respondents (37.5%) said their roof garden provide medium thermal comfort while 32.5% roof garden provide low thermal comfort followed by 22.5% high thermal comfort and only 7.5% provide no thermal comfort at all. The result revealed that thermal perception of 60% respondents was within neutrality temperature range 31.5°C to 36.5°C which is a desirable condition.

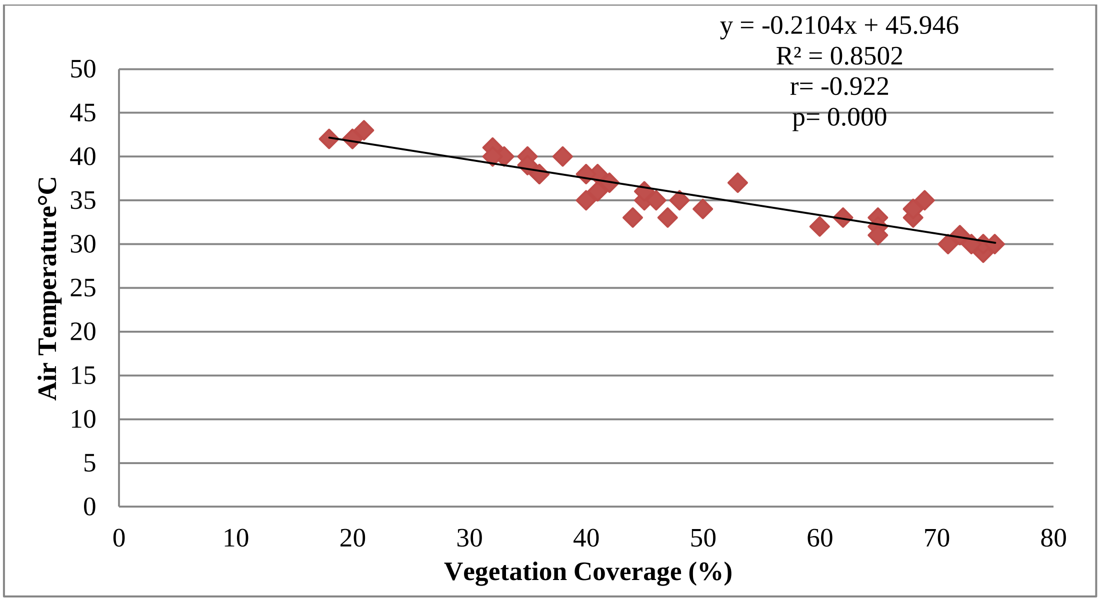

Figure 5. Correlation between overall temperature and vegetation coverage

The regression analysis (Fig. 4) between the overall air temperature and vegetation coverage (r=-0.922 and p <0.01) showed that the relationship between overall air temperature and vegetation coverage was highly significant (at 1% level) and at the same time there was a very strong and negative relationship between them. Lower temperature indicates higher thermal comfort. Therefore, higher thermal comfort was mostly found in the roof gardens with high vegetation coverage (>50%). This indicates that the thermal benefits are caused by the proper shade and dense arrangement of potted plants.

B. Conclusion

The thermal behavior of Rooftop gardens is well documented in this study. The thermal performance result of the rooftop gardens on this research concludes that greenery contributes thermal benefit to both micro climates of the roof environment and surrounding outdoor ambient environment of the building. Hence, rooftop gardens can be an effective option for improving the quality of environment of the prevailing infrastructures.

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