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Adapting cities for climate change: an assessment of green roof technology

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Abstract

Green roofs technology is getting popularity globally that has the potential to help mitigate the multifaceted, complex environmental problems of urban centres. Due to altered energy exchange creating an urban heat island, and changes to hydrology. Climate change will amplify these distinctive features. In this study, DOE-2 energy simulation program was used to determine the effects of rooftop garden on the annual energy consumption, heating, cooling load and roof thermal transfer value of a ten story residential building in Dhaka, Bangladesh. The thermal resistances (*R*-values) of shrubs, turfing and trees were estimated using data from site measurements, and the effects on the building energy consumption of a rooftop garden with these three types of plants were simulated. Three soil types with different soil thickness on the building roof were also simulated. The results showed that the installation of rooftop garden on the ten story residential building can result in an average saving of 2% to 8% of total amount of energy used annually. Simulation output also revealed that the increase of soil thickness would further reduce the building energy consumption .In this paper, the implications for an adaptation strategy like green roofs to climate change in the urban environment are also discussed.

Keywords: Climate Change Adaptation; Rooftop garden; Energy consumption; Thermal Comfort; Residential Building

1. Introduction

Climate change is presenting many challenges to cities around the world and they will have to cope with decades of rising temperatures and changing rainfall patterns, among other effects. Some world cities have started to prepare for climate change and are looking for suitable adaptation measures to put in place to manage its impacts. This paper looks at how green roofs can be an effective mechanism to reduce the impacts of climate change in urban areas.

Dhaka city corporations have taken a number of projects to bring their open spaces under greenery coverage through massive plantations as the capital is gradually getting denuded of its greeneries due to unplanned development works. Though a liveable city should have 25 percent greeneries of its total area, the capital has barely five percent greeneries for lack of regular plantation and maintenance of the existing ones, and unplanned urbanization [1].

Dhaka is one of the world's most populated cities with current population of 17 million within a small area of 300 square kilometres [2]. Population is increasing day by day. However, to maintain a pleasant living environment, the balance between green and concrete built-up areas cannot be overlooked. With the fundamental layout of cities unlikely to change for some years to come, city planners and decision makers face the challenge of finding other solution of increasing and enhancing the amount of greenery in city areas.

One sustainable option for dense urban settings is the greening of buildings [3]. Roof gardens, though not a new concept are gaining popularity in Bangladesh due to Dhaka city authority new announcement that, house owners under Dhaka south city corporation (DSCC) will enjoy a 10 percent tax rebate if they do gardening on the rooftop, balcony or the compound [4].

Vegetation, primarily forests, has been identified as an important component of any strategy to reduce greenhouse gas emissions, through the sequestration of carbon in the woody biomass of tress. Rooftop gardens offer many benefits to an urban area. They can reduce energy demand on space conditioning, and hence greenhouse gas emissions, through direct shading of the roof, evapotranspiration and engineered insulation values.

A significant amount of research has also been undertaken in an attempt to improve the performance of green roofs. By comparison, the incorporation of green roofs technology into current design practice through application to local context is still in its infancy phase, with considerable gap with European countries. Nevertheless, the advance research conducted in Europe does provide us with significant insights of green roof technology commonly adopted there.

Despite the growing interest in green roofing in Dhaka, many owners are often held back from including rooftop gardens in the design brief mainly by concerns like high initial costs and structural capacity.

A California based study by Simpson and McPherson showed that tree shade has the potential to reduce the annual energy for cooling by 10-50% and peak electricity use up to 23% [5]. Another research studies have shown, under a green roof, indoor temperatures were found to be at least 3-4°C lower than hot outdoor temperatures of between 25 and 30°C [6].

The main objectives of the study therefore are:

A. To identify the benefits of rooftop garden in reducing the heat gain into a residential building.
B. To examine the quantitative impact of rooftop garden on the building total energy consumption
C. To study the cost savings in cooling energy of building due to the utilization of rooftop garden.

2. Methodology

DOE-2 energy simulation program was used to determine the effects of rooftop garden on the annual energy consumption, heating, cooling load of a ten story residential building in Bangladesh. The building roof had an estimated area is approximately 450 square meter. The ten story buildings rendered view has shown in fig. 1.

Figure 1: Rendered View of 10 Story Residential Building with Rooftop Garden

In these simulations, different types of vegetation and variation of soil thickness were simulated. The concepts of roof thermal transfer takes into consideration three basic components of heat gain: heat conduction through opaque roof, heat conduction through skylight, and solar radiation through skylight. The maximum permissible RTTV is set as 50 W/m^2 [7].

The RTTV formula is given as follows:

$$RTTV = 12.5(1-SKR)U_r + 4.8(SKR)U_s + 485(SKR)(CF)(SC) \quad (1)$$

Where

RTTV: roof thermal transfer value (W/m^2)

SKR : skylight ratio of roof (skylight area / gross area of roof)

U_r : thermal transmittance of opaque roof (W/m^2 °K)

U_s : thermal transmittance of skylight area (W/m^2 °K)

CF : solar correction factor for roof

SC : shading coefficient of skylight portion of the roof

Comparison was made in the basis of different thickness of the soil on the rooftop (200-600mm thick) for the ten story residential building. In order to provide a common basis for comparison, the building materials used for the wall , roof , floor and ceiling , infiltration rate, lighting requirements , occupancy schedule of the building and the air conditioning system, etc. were the same throughout the simulations. The R-value of dry clay soil and moist clay soil of different thickness are shown in Table 1.

Table 1. Detailed calculation of R-values of different soil thickness

Soil Thickness (mm)	R value of Dry Clay Soil (W/m^2)	R value of Moist Clay Soil (W/m^2)
200	2.251	2.001
400	2.771	2.062
600	3.183	2.112

The estimation of equivalent R-values of three species of plants: turfing, shrubs and trees, was based on data collected in the field measurements on a rooftop garden of a high-rise building in February 2016. (Figure-2)

Figure 2: The rooftop garden of a high-rise building

The measurements were carried out on both vegetation and hard surface areas, and then surface temperature measurements were implemented in the indoor and outdoor environments respectively. All parameters were measured and recorded at 20 min interval.

In this research, surface temperatures measured on the bare soil surface, under three types of vegetation cover: turfing, shrubs and trees, and on the soffit surface were used in the calculation of equivalent R-values of these three types of vegetation: turfing, shrubs and trees. These R-values were used in the subsequent simulations.

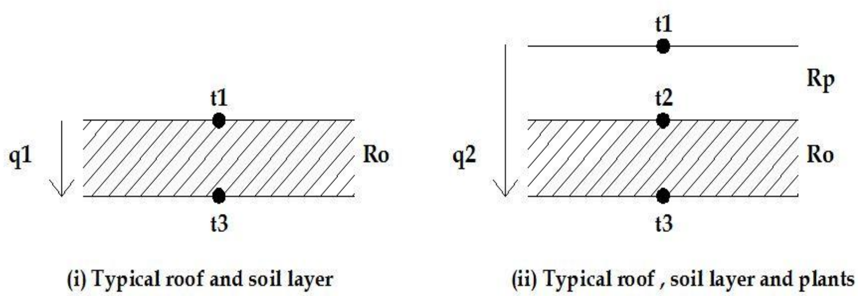

Figure 3: Description of calculation of plants thermal resistance (i, ii)

Fig.3 shows the calculation of plants thermal resistance. Fig.3 (i) shows the rooftop without vegetation, which is composed of the typical flat roof and 300 mm clay soil. In Fig.3 (ii), the vegetation was assumed to be an additional homogenous layer and the temperature gradient of t_1 and t_2 was caused by the presence of the homogeneous layer.
In Fig. 3, t_1 is the measured mean surface temperature of soil without vegetation cover ; t_2 the measured mean surface temperature of soil with vegetation cover ; t_3 the internal surface temperature of roof ; q_1 the rate of heat per

unit area through roof without vegetation cover ; q_2 the rate of heat per unit area through roof with vegetation cover ; R_p the thermal resistance of vegetation; and Ro is the sum of thermal resistance of the roof.

For steady-state conditions, the rate of heat flow per unit area through a compound element can estimated as

$$q = \Delta t / \sum R \qquad (2)$$

Where q (W/m^2)is rate of heat flow per unit area through a compound element, $\sum R$ (m^2K/W) the total resistance , Δt (K) the surface temperature difference.

And for steady-state conditions the rate of heat per unit area between each surface must be the same [8] then in fig.3 (ii),

$$q_2 = (t_1 - t_3)/(R_p + R_o) \qquad (3)$$

The calculated R-values of turfing, shrubs and trees are 0.31, 1.42, 0.39 m^2 K/W respectively.

3. Data Analysis and Discussion

3.1 Comparison of energy simulation results for different soil thickness

A comparison of the annual energy consumption, space cooling load and peak space load between the different thicknesses of soil layers from 200 to 600 mm was carried out and two soil types; dry clay soil and moist clay soil (40 % moisture content) were considered in this assessment (Fig-4-6).

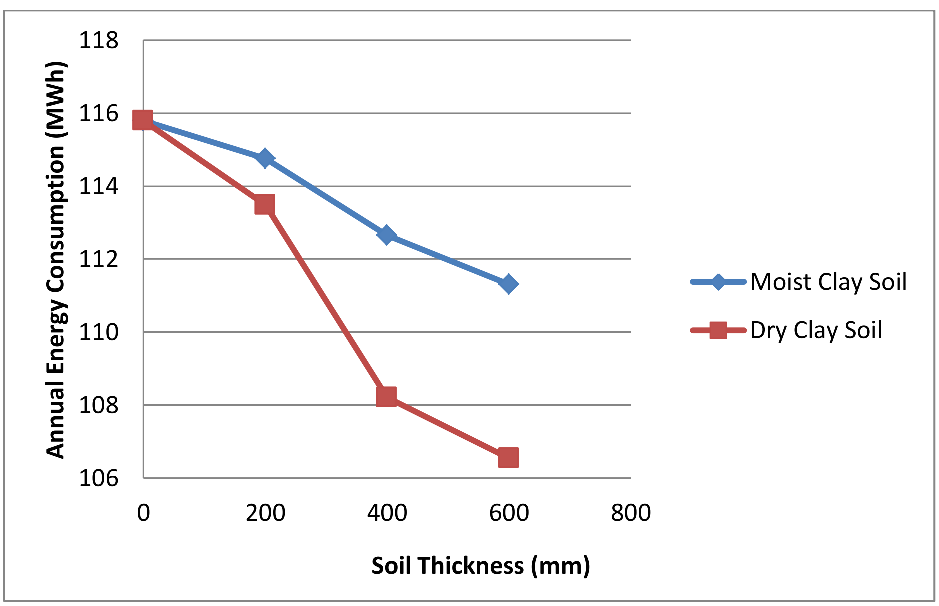

Figure 4: Comparison of Annual Energy Consumption for Different Soil Thickness

The Comparison between different thickness of dry clay soil layer shows that the increase in soil thickness has significantly reduced the heat gain into the building. A reduction by 2.5 MWh (2%) for soil thickness of 200mm to 9 MWh (8%) for soil thickness 600 mm was observed in the simulated energy consumption (fig-4). The space cooling loads reduced by 3 MWh (10%) for soil thickness of 200 mm to 9 MWh (30%) for soil thickness 600mm (fig-5).

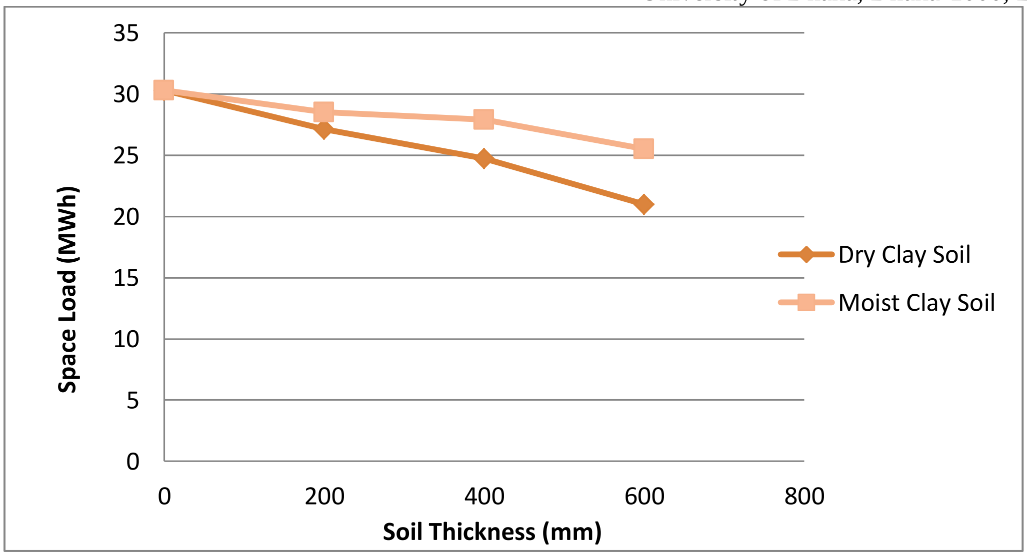

Figure 5: Comparison of Space Load for Different Soil Thickness

The peak space load reduced by 2.85 kW (20%) for 200mm soil thickness to 6.6 kW (45%) for 600mm soil thickness (fig-6).

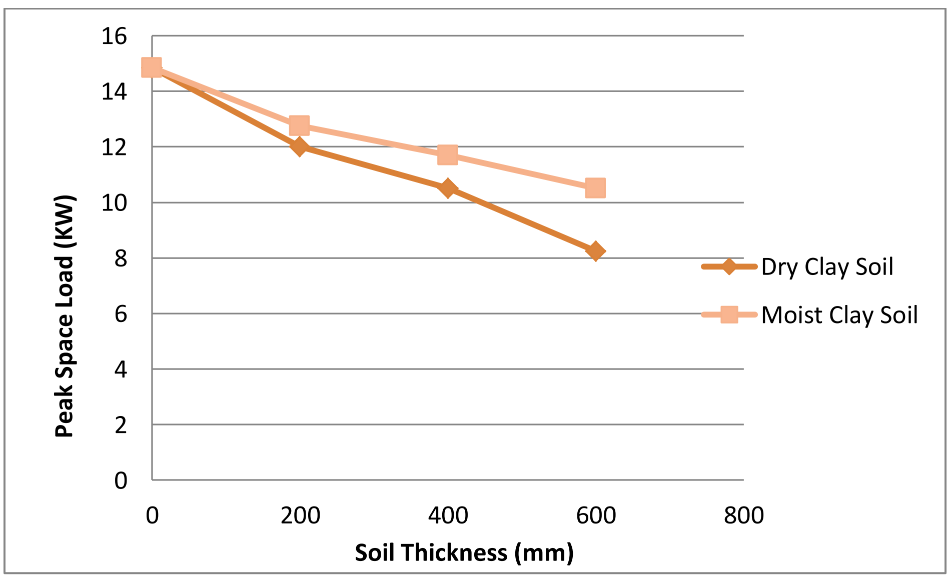

Figure 6: Comparison of Peak Space Load for Different Soil Thickness

A comparison of the peak RTTV was carried out and the results are shown in Table 2 and Figure.7

Table 2. Comparison of peak Roof Thermal Transfer Value for Different Thickness of Soil

Soil Type	Soil Thickness (mm)	Sensible Cooling Load (kW)	Area (m^2)	Peak RTTV (W/m^2)	Reduction (%)
No Soil		7.0	450	18.0	-
Dry Clay Soil	200	5.0	450	15	16.7

	400	4.0	450	14.1	21.7
	600	3.3	550	12.1	32.8
Moist Clay Soil (45% Moisture)	200	6.8	550	17.1	5
	400	6.3	550	15.4	14.4
	600	5.8	550	13.1	27.2

Due to the installation of rooftop garden the peak RTTV value has decreased significantly. As shown in Table 2 and figs. 7, there was a significant reduction occurred as the thickness of the soil surface increase for both dry clay soil (from 16.7 to 32.8%) and moist clay soil (5 to 27.2%).

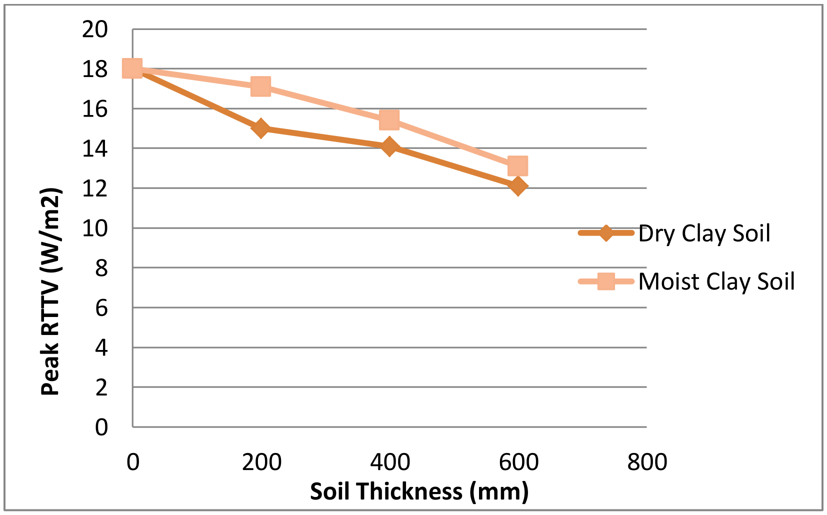

Figure 7: Comparison of Peak RTTV to Different Soil Thickness

The installation of rooftop garden has significantly reduced the peak heat transfer through RTTV. As shown in Table- 3 reductions 13.2 % (turfing) to 53.2 % (shrubs).

Table 3. Comparison of peak RTTV to Different Types of Vegetation

Types of Roof	Sensible Cooling load (kW)	Covered Area (m^2)	Peak RTTV (W/m^2)	Reduction (%)
Typical Bare Roof	7.0	450	19	-
Roof Covered by Turfing	6.0	450	16.5	13.2
Roof Covered by Shrubs	3.8	450	8.9	53.2
Roof Covered by Trees	4.9	450	10.4	45.3

Fig-8 Shows that, due to use shrubs in the rooftop garden reduction in peak RTTV is the maximum.

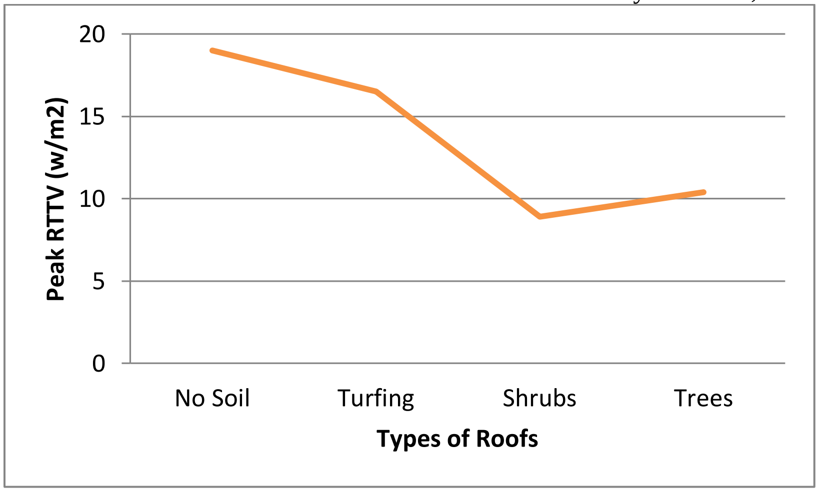

Figure 8: Comparison of peak roof thermal transfer value for different rooftop coverage

3.2 Comparison of cost of consumption

The annual energy consumption of the ten story residential building was converted into monetary unit to understand the savings with the installation of rooftop garden. The peak rate of 9.98 BDT obtained by the *Bangladesh Energy Regulatory Commission* [9] was used in the calculation. The results are shown in the Tables 4 and 5.

The simulation results showed that installation of rooftop garden does contribute to the energy cost saving. The installation of rooftop garden covered by shrubs could save 74850 BDT as compared to a bare roof.

Table 4. Comparison of total cost of consumption for different types of roofs

Types of Roof	Annual Energy Consumption (MWh)	Peak Rate (BDT/KWh)	Total cost of consumption (BDT	Total Saving (BDT)
Typical Bare Roof	115.8	9.98	1155684	-
Roof Covered by Turfing	113.2	9.98	1129736	25948
Roof Covered by Shrubs	108.3	9.98	1080834	74850
Roof Covered by Trees	110.8	9.98	1105784	49900

Due to increase of soil thickness saving also increased. The maximum saving was 92415 BDT for 600 mm dry clay soil layer.

Table 5. Comparison of total cost of consumption for different soil thickness

Soil Type	Thickness of Soil (mm)	Annual Energy Consumption (MWh)	Peak Rate (BDT/KWh)	Total cost of consumption (BDT	Total Saving (BDT)
Bare Roof	-	115.8	9.98	1155684	-
Dry Clay Soil	200	113.48	9.98	1132530	23154
Dry Clay Soil	400	108.2	9.98	1079836	75848
Dry Clay Soil	600	106.54	9.98	1063269	92415
Moist Clay Soil	200	114.75	9.98	1145205	10479

Moist Clay Soil	400	112.65	9.98	1124247	31437
Moist Clay Soil	600	111.3	9.98	1110774	44910

4. Green Roofing for Climate Change Adaptation

Dhaka, the capital city of Bangladesh is considered as one of the most vulnerable cities of the world to climate change. A recent study reveals that, climate change will cause an increase in rainfall, temperature and weather related extremes in Dhaka city. However, the most imminent impacts of climate change in Dhaka city will be due to the rise of temperature and related extremes, which may include frequent outbreak of tropical diseases, scarcity of water, increased power failures, etc. It is necessary to incorporate climate change adaptation guidelines into the planning, design, construction, operation and maintenance of urban infrastructure of Dhaka city [10].

Our climate is changing due to man-made emissions of greenhouse gases, and we are faced with many years of continuing unavoidable change. Climate change is presenting many challenges to cities around the world and they will have to cope with its impacts. Even if we were to make significant reductions in greenhouse gas emissions tomorrow, the inertia in the climate system means that we will need to cope with a changing climate for the next 40-plus years, due to emissions we have already put into the atmosphere. Action needs to be taken both to mitigate emissions and adapt to inevitable climate change. There is no choice between mitigation and adaptation – complementary actions on both needs to be pursued. Some world cities have started to prepare for climate change and are looking for suitable adaptation measures to put in place.

Climate change is already leading to increasing temperatures. Higher average temperatures are being experienced and also more extremely hot days. Summer heat waves are becoming more frequent and more intense. Higher temperatures are aggravated in cities by the Urban Heat Island effect. Green roofs are one mechanism by which these overheating risks can start to be addressed. Green roofs reduce summer overheating by reducing building heat loss and increasing evapotranspiration.

Other benefits of green roofs include creating natural green spaces in urban areas, benefits for biodiversity and reduced air pollution. Extended roof life is a further advantage, since a green roof protects a roof's waterproofing membrane, almost doubling its life expectancy.

5. Conclusion

This research has shown that the installation of rooftop garden in a ten story residential building at Bangladesh could result in a saving of 2 to 8% of total annual energy consumption, 10% to 30% of space cooling load and 20% to 45% amount of in the peak space load.

The study also shows that an optimum reduction of 5% to 32.8% on roof thermal value, 13.2% to 53.2% on peak RTTV with different soil thickness of 200-600mm.

The optimum type of soil is the roof with the dry clay soil.

In terms of energy cost saving , a saving of up to 74850 BDT per year in total cost of consumption of a ten story residential building with an estimated area of rooftop area of 450 square meter by planting shrubs . However, the maximum saving caused by the rooftop garden with 600mm thick dry clay soil is 92415 BDT.

A green roof provides cooling in summer and thermal insulation in winter, they also result in reduced energy consumption, greenhouse gas emissions and fuel costs.

Only flat roof considered in this study because slope roofs are very rare in Dhaka city. Further study could be conducted with slope roofs. Cost reduction is possible by tax rebate which has recently announced by Dhaka city corporation authority for green roofing.

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