UITS Journal of Science & Engineering Volume: 6, Issue: 1
ISSN: 2521-8107, June-2017

A Study on Indoor Thermal Comfort by Roof Top Gardening

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Abstract : ***Roof top gardening is an effective way to ensure the indoor thermal comfort naturally. The objective of the study is to investigate the degree of comfort attained by the roof top gardening and to reduce energy consumption in building. This experiment was conducted on a two-storied urban R.C.C. building. The two main parameters of thermal comfort, air temperature and humidity were measured by 'THERMO RECORDER'. To identify the ability of roof top gardening in reducing indoor air temperature the roof top was covered by greenery and compared with bare roof. The data loggers were placed at ceiling inside the room. To determine the reduction in temperature caused by roof top gardening they were placed under shade made by greenery and bare roof that is exposed to the environment. The temperature and humidity data were recorded every 10 minutes interval. The data obtained from the data logger was used to show the seasonal variation of temperature and humidity in graphical form. The result obtained from the analysis shows that maximum 6.8°C indoor temperature can be reduced by roof top gardening in summer season and 31% of total cost of electricity can be saved.***

Keywords: *Roof top gardening, indoor thermal comfort, energy consumption, data logger thermal comfort parameters.*

1. Introduction

Energy plays the most vital role in the economic growth, progress, and development, as well as poverty eradication and security of any nation. Uninterrupted energy supply is a vital issue for all countries today. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly. In World Energy Outlook 2013, from 2000 to

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2010 total world primary energy demand grew by 26%, and to 2020 it was projected to grow less (by 20% under the Current Policies scenario, and less under other scenarios). Growth to 2035 is 45% under Current Policies, and 33% under a more restrained scenario. If the demand is increasing continuously in such a manner stated above the world will experience an implausible energy crisis as the natural resources is limited. Building sector consume a huge amount of energy to ensure the indoor thermal comfort. The common forms of energy use in buildings are cooking, lighting, fans, coolers, air conditioners, refrigerators etc. According to the International Energy Outlook 2013, the energy use tracker of the US Energy Information System, the building sector accounts for more than one-fifth of total worldwide energy use (International Energy Outlook; 2013). Another study says that, almost 60% of the world's electricity is consumed in residential and commercial buildings. At the national level, energy use in buildings typically accounts for 20–40% of individual country total final energy use, with the world average being around 30%. Per capita final energy used in buildings in a cold or temperate climate in an affluent country, such as the United States and Canada, can be 5–10 times higher than in warm, low-income regions, such as Africa or Latin America [Diana Ürge-Vorsatz; 1964].

Energy and Environment, these two has become one of the most anguished matters for the present world. For the development and economic growth of a country availability of energy is essential. On the contrary, rising use of energy is changing the world climate severely. The exponential increase of energy consumption, since the beginning of the industrial revolution, has produced significant changes in the global environment, chief among which is the increase of the average concentration of carbon dioxide (CO_2) in the atmosphere from 280 ppm in 1750 to more than 390 ppm in 2011. Climatologists predict that this change will cause an increase of the average temperature of the planet (Global Warming), depletion of ozone layer and regional and global and climatic changes. Reducing energy use in building sector is an important way to reduce human's overall environmental impact. Roof top gardening is one of the most effective ways to reduce the energy consumption in building. In recent years the benefits of green roofs as passive systems for energy saving in buildings have been studied in depth. By this technique about 5-6°C temperature can be reduced in day time naturally which greatly reduce the load on air conditioning and also a huge amount of energy saving can be ensured.

2. Objectives of the Study

Bangladesh has a tropical monsoon type climate, with a hot and rainy summer and a dry winter. The hot seasons commences early in March and continue till the month of august. The maximum mean temperature observed is about 33^{o}C to 36^{o}C during the month of April, May, June and July and the minimum temperature recorded in January about 7^{o}C to 16^{o}C. Sometimes the maximum temperature reaches up to 40^{o}C to 45^{o}C in the month of April, May and June. People feel very warm during summer season and cold during winter season. They use electric fan and air condition in summer to keep themselves cool and comfortable. But there is a scarcity of electric energy in the country. Rooftop gardening may become an effective way to ensure the indoor thermal comfort naturally and to reduce energy consumption. Roof top gardening acts as an insulation device. It does not allow the heat to transmit through the roof and keeps the indoor environment comfortable. This research examines the effect of roof top gardening and in thermal performance of the building in hot and humid region like Bangladesh and reduction in energy consumption.

The main objectives of the study are the followings:

a. To evaluate the thermal performance of rooftop gardening.
b. To save energy by rooftop gardening.

3. Literature Review

A rooftop gardening is a gardening on the roof of a building. Besides the decorative benefit, roof planting may provide food, temperature control, hydrological benefit, architectural enhancement, habitats or corridors for wildlife, recreational opportunities, and in large scale it may even have ecological benefits. During the past few years, a lot of research on green roofs has been done or is still in progress. Literature reports a relatively large number of experiments and computer models that aim to investigate the behavior of green roofs as an integrated building or environmental system. A field measurement revealed that green roofs act as insulation devices rather than cooling the roofs (Wong, 2007). It prevents heat to transmit through the roof thus creating a cooling environment inside. Another field study suggested that greenery over the roof top could reduce indoor temperature 3^{o}C to 4^{o}C than outside temperature (Wong, N.H., et al, 2003). Elean Palomo Del Barrio (1998) conducted a mathematical analysis to evaluate the thermal behavior of green roof that results that a well-designed and managed green roof could behave as a high quality insulation device and reduce the heat flux through the roof in summer. Niachou, A. et al (2001) performed a field measurement of surface and air temperature on a planted roof that complemented by a mathematical approach discovered that the indoor temperature values in the building with green roof are lower during the day period. According to the investigation of Ekaterini Eumorfopoulou (1998) green roofs can contribute to the improvement of thermal performance of building. A field research in Ottawa conducted by Liu and Baskaran (2003) results that the green roof reduces the average daily energy demand for space conditioning due to the heat flow through the roof in the summer by more than 75%. Takakura, K. et al (2000) investigated the cooling effect of various kinds of greenery cover on the roof by both experimental model and computer simulation. Four different types of roof were constructed with different coverings are bare concrete, soil layer, soil layer with ivy and soil layer with turf. The investigation showed that the maximum difference in temperature of the room underneath between the bare concrete roof and the ivy covered roof was around 15^{o}C.

4. Methodology

4.1 Design of Plantation over the Roof Top:

The study was performed on the rooftop of a 2-storied building at Rajshahi University of Engineering & Technology (RUET). To identify the ability of the roof top gardening in reducing indoor air temperature the roof top was covered by greenery and compared with bare roof. Some portion of the roof was covered by bed made with wood and steel frame and some portion by tubs. At first the beds and tubs were placed in suitable location. During the placement of beds about 6-inch clearance between the top of the roof and bottom of the bed was kept to provide sufficient drainage of rain water as well as access of air and light. This will help to prevent dampness of the roof. Then the beds and tubs were filled with soil up to the top level. The soil used was mixed with compost to increase the fertility. Grasses were planted on the bed and Vine Spinach (Puisakh), Pumpkin Leaves and a vine type tree was planted on the tub. A loft was made over the tubs so that the vine trees and vegetables can spread and cover the roof (Fig.1).

Fig.1: Roof top gardening

4.2: Rationale of selecting vegetation type:

Different kinds of vegetation have different ability in reducing indoor temperature. The selection of vegetation type depends on many other factors such as climatic condition of the area, average rainfall, growth rate of plant, nutrients needed for the plants, soil depth etc. Plants having horizontal leaf distribution and extensive foliage development is mostly suitable for rooftop gardening because they greatly reduce the transmission of heat through the roof (Barrio, 1998). Temperature under thick foliage is lower while higher under spare vegetations or soil only (Wong et al, 2003). In the study grasses were planted on the soil bed having large and dense foliage creating a natural and green environment over the rooftop. Some portion of the rooftop were covered with vine trees, vine spinach and pumpkin leaves having large expansive leaf. Vine spinach and pumpkin are also a great source of fresh vegetables which fulfill the needs of nutrients of the family and save a lot of money to buy vegetables from the market.

4.3 Instrumentation and Data Collection:

The instruments used in field measurement are-

i) Infrared Thermometer
ii) "THERMO RECORDER for Windows"

In the study two thermal comfort parameters such as temperature and humidity were measured. The plan of the building and instrument locations have been shown in Fig.2.

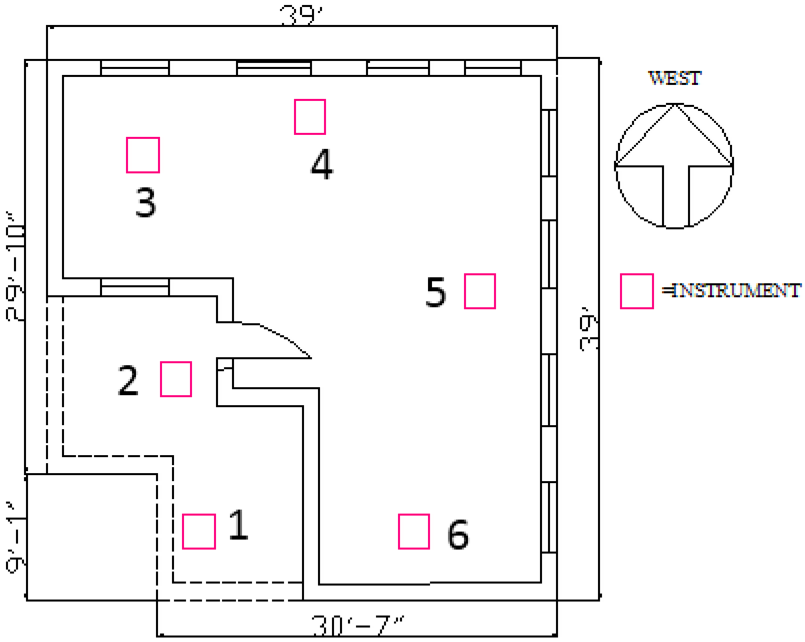

Fig.2: Plan of building and instrument location

"THERMO RECORDER for Windows" (Fig.3) is a software program that enables to easily make recording setting for Thermo Recorder, download recorded data from the recorders and then process that data into graphs, tables or save that data to files or print.

An infrared thermometer (Fig.4) is a thermometer which infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. They are sometimes called laser thermometers as a laser is used to help aim the thermometer, or non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined. Infrared thermometers are a subset of devices known as "thermal radiation thermometers". Infrared thermometers are characterized by specifications including accuracy and angular coverage. Simpler instruments may have a measurement error of about ±2°C/±4°F).

Fig.3: Temperature and humidity recording by "THERMO RECORDER for Windows"

Fig.4: An infrared thermometer (https://en.wikipedia.org)

To compare the temperature and humidity under roof top gardening with bare roof the instruments were installed under the roof top gardening and bare roof. In Fig.2 instrument location at 1 and 2 are under bare roof that is, there is no shading and instrument location at 3, 4, 5, and 6 under the roof top gardening. Before the installation of data logger, the probable location was gauged with the help of Infrared Thermometer. Then data logger was finally installed at suitable location. The temperature and relative humidity data were recorded every 10 minutes' interval.

4.4 Cooling Load Calculation of Air Condition:

In this experiment the energy savings was found by the process of cooling load calculation of air condition. Cooling load is the rate at which a cooling system or process must remove heat from a conditioned zone to maintain it at a constant dry bulb temperature and humidity. The cooling load is calculated to select HVAC equipment that has the appropriate cooling capacity to remove heat from the zone. To simplify cooling load calculations, the total cooling load is divided into a number of individual loads according to the sources to heat supplying the load. The summation of these individual loads is the total cooling load on the equipment. The total cooling load is divided into four separate loads i.e. the wall gain load, the air change load, the product load and the miscellaneous load.

The Wall Gain Load:

The quantity of heat transmitted through the walls per unit of time is a function of three factors whose relationship is expressed in the following equation:

Q = A * U * TD …………………………… (1)

Where,

Q = Quantity of heat transferred in Btu/hr

A = The outside surface area of the wall (square feet)

U = The over- all coefficient of heat transmission (Btu/hr/sq ft/^{o}F)

TD = Temperature difference (^{o}F)

The Air Change Load:

When the door of the air-conditioned space is opened, warm outside air enters the space to replace the denser cold air which is lost from the air-conditioned space through the open door.

The Heat which must be removed from this warm outside air to reduce its temperature to the space temperature becomes a part of the total cooling on the equipment. The part of the total load is called the air change load. In air conditioning applications, the air change load is called either the ventilating load or the infiltration load.

The Product Load:

The product load is made up of the heat which must be removed from the air conditioned product in order to reduce the temperature of the product to the desired level. The term product as used here is taken to mean any material whose temperature is reduced by the air conditioning equipment and includes not only perishable commodities but also such items as masses of concrete, plastics, rubber and liquids of all kinds.

The Miscellaneous Load:

The miscellaneous load, sometimes referred to as the supplementary load, takes into account all miscellaneous sources of heat. Chief among these are people, lights, other electrical equipment operating inside the space.

5. Analysis and Results

5.1 Variation of temperature and humidity due to roof top gardening:

The variation in temperature in June and July is shown in Fig.5 and Fig.6. The maximum temperature difference is 6.8^{o}C in June and 3.2 ^{o}C in July. This difference has been possible due to the proper shading by roof top gardening.

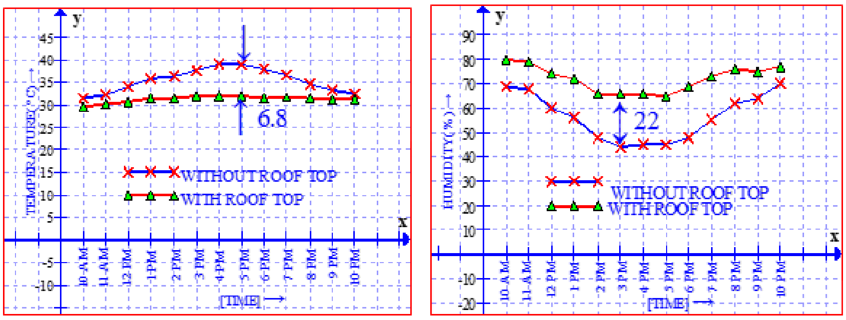

Fig.5: Temperature and humidity variation in June

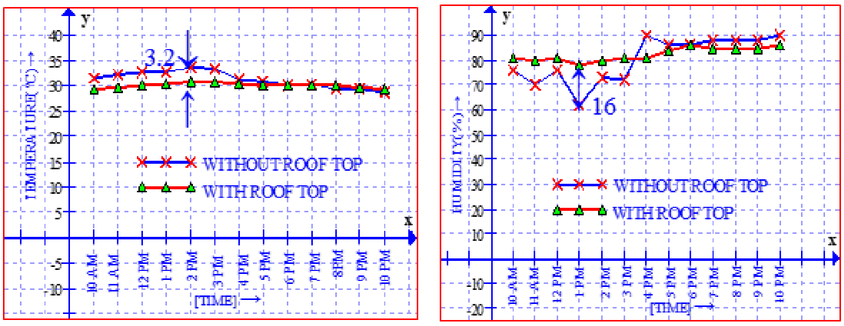

Fig.6: Temperature and humidity variation in July

5.2 Cooling Load Calculation:

Table 1: Cooling loads when roof top gardening is present and when absent.

Load Parameters	Cooling load(Btu/24hr)	
	Without Roof Top Gardening	With Rooftop Gardening
Air change load	55031.4	45279
Heat gain through east wall	153170.4	91599.8
Heat gain through north wall	156225.6	93427
Heat gain through south wall	137985.6	82519.1

Heat gain through west wall	204706.3	135983.5
Heat gain through roof	556022.6	406362.1
Heat gain through floor	88646.4	53012.9
Load of people (Design people 25)	377400	377400
Miscellaneous Load	93350.4	93350.4
Total load	1822637.9	1378933.8

Note: Reference book of cooling load calculation (Dossat R. J., 1961, "Principles of Refrigeration" John Wiley & Sons, Inc. New York & London).

5.3 Energy Saving and Corresponding Cost Reduction:

<u>Without Roof Top Gardening</u>

Summation of total load = 1822637.9 Btu/24 hr.

We know a 1-ton air conditioner can remove around 12000 Btu (British Thermal Units) of heat per hour.

So, Required cooling capacity = {1822637.9 ÷ (12000×24)} =6.3 ton ≈ 7 ton

We can choose two 2-tons and two 1.5-tons AC.

A 2-ton AC consumes 2.4 unit of electricity per hour and a 1.5-ton AC consumes 1.5 unit of electricity per hour.

So, total energy consumed per hour = 2*2.4+2*1.5=7.8 unit.

Cost per unit Electricity (For residential building, 1-75 unit) = 3.8 Tk. ≈ 4 TK. **(Source: DESCO)**

Cost per hour =7.8*4=31.2 ≈ 31 TK.

<u>With Roof Top Gardening</u>

Summation of total load = 1378933.8 Btu/24 hr.

We know a 1-ton air conditioner can remove around 12000 Btu (British Thermal Units) of heat per hour.

So, Required cooling capacity = {1378933.8 ÷ (12000×24)} = 4.79 ton ≈ 5 ton

We can choose one 2-ton and two 1.5-tons AC.

A 2-ton AC consumes 2.4 unit of electricity per hour and a 1.5-ton AC consumes 1.5 unit of electricity per hour.

So, total energy consumed per hour = 1*2.4+2*1.5=5.4 unit.

Cost per hour =5.4*4=21.6 ≈ 22 TK.

So, Savings of energy per hour= 7.8- 2.4= 2.4 unit

Cost of 2.4-unit electricity= 2.4 * 4= 9.6 TK. (31% of total cost)

6. Conclusions

The results obtained from the study shows that the practice of roof top gardening can effectively reduce the indoor air temperature of the building and contribute to a significant amount of energy saving during summer period. The maximum temperature difference is 6.8°C in summer season (June) and 3.2°C in rainy season. Actually, this difference has been possible due to proper shading by roof top gardening. The cooling load of air conditioning depends greatly on indoor air temperature. If indoor air temperature is more, the cooling load will be higher and vice versa. By application of roof top gardening a satisfactory amount indoor air temperature can be reduced. The study shows AC of 7-ton is required when roof top gardening is absent and 7.8-unit electricity is consumed per hour which costs 31 taka per hour. On the other hand, 5-ton AC is required when roof top gardening is present and 5.4 units of electricity is consumed per hour which costs 21.6 taka per hour. So total saving of energy is 2.4 units per hour whose price value is 9.6 taka. This shows total saving of cost is 31% of total cost.

7. Recommendations

In this study energy calculations were carried out considering the maximum temperature reduction but the reduction in temperature is not same all time. So future work may be done considering all the variation in temperature and humidity to get a more accurate and exact results.

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