The Impact of Green Roofs on Urban Heat Island Effect

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Abstract

Growth of the world urbanization has been extensively accelerated since past few decades. With the increasing urbanization, the land with permeable layers and moist have been altered. As a result, urban heat island phenomenon has taken place, making the temperature in the cities to be higher than the country sides. Heat island effect in cities is mainly because of non natural heat absorbing materials use in buildings and other manmade structures. Natural greenery in the cities was replaced by concrete yards and most of the cities urbanizing with more and more concrete. Since there is no space to grow, adding greenery to cities is also an issue. Having greenery over the roof or planting on roofs are now becoming popular in many countries. Green roofs play a major role as a sustainable solution to minimize the heat island effect. This paper discusses about the effects on the surrounding temperatures, if the existing flat roofs in the Colombo city, the capital of Sri Lanka, are replaced with green roofs. The reduction in the temperature in the atmosphere was calculated using actual measurements on small scale models and computer simulation. These findings were coupled with the energy balance of the city. From the results obtained, it can be clearly shown that there’s a significant reduction in the temperatures, in the city when compared to the prevailing condition. The forecasted condition proves that the foreseeable problem of urban heat island effect with the future developments can be drastically reduced with the introduction of green roofs.

Keywords: Heat island effect, green roofs, sensible heat, energy balance, computer simulation.
1 Introduction

With the recent increasing demands of the population, urban spaces expanded dramatically, much faster and with much more significant changes, than in the previous decades. The large areas that modern cities occupy, their structure, materials and the general lack of vegetation have altered the climatic characteristics of urban spaces. [1] According to the Population Reference Bureau, 50% of the world population (3.4Billion) is settled in urban areas. Also it is predicted that inhabitation in cities will reach 60% (5.0Billion) by 2030, which means around two billion more people will reside inside cities by that year. In addition, the number of cities with population of over one million is expected to increase by approximately 100 from 2005 to 2015. [13] Massive building construction is under way to respond to this overwhelming dwelling demand. This excessive and unplanned growth of urbanization has caused undesired side effects around the world. Urban Heat Island (UHI) as a consequence of urbanization was first documented by Howard in 19th century. [12]

The urban heat island effect is the temperature increase in urban areas compared that with surrounding rural areas. This is caused by the increased use of impervious land surfaces covered by anthropogenic material, the complexity of the three dimensional structures of the surface, and the coincident decrease of vegetation coverage, as well as anthropogenic heat discharge due to human activities.[3] Also due to the lower wind speeds in urban areas, less convective heat losses and less evapotranspiration, yields more energy for surface warming. [2]

Urban heating causes many problems for the inhabitants of cities and areas, in particular those with a tropical environment. Urban heating could deteriorate our living environment, increase energy requirement, elevate ground-level ozone and even increase mortality rates [4]. Installing green roofs is now widely considered as an effective strategy to solve these problems. With the major benefit of green roofs, which is mitigating the urban heat island (UHI) effect, it has other benefits namely improving the energy efficiency of buildings, reducing storm water runoff, increasing biodiversity, purifying water and air, as well as elongating the life span of roofs. Because of the benefits mentioned above, green roofs have become the focus of the current research. [5] This study mainly concerns on analyzing the role of green roofs, on the city temperature in the tropical climatic condition.

For the analysis purposes building energy balance, with the surrounding was used. The envelope that separates them is also the one that determines the magnitude of that, upon permitting a greater or smaller heat transfer. This does not depend only on the own building, however, on the contrary, is seen much influenced by the surroundings, and in general, by the geometric and constructive characteristics of the urban layout in which it is situated.[6] To compensate this condition a considerably large area was chosen in the city. The city was analyzed with the variables, which have the effect on the air temperature.

Many different types of surfaces that make up an urban environment affect the heat balance of cities. Roof surfaces are key interfaces in the volumetric exchange of energy because they constitute a large fraction of urban surface areas, and due to their exposure, they receive considerable solar radiation. [7] Therefore, it is important to understand the heat storage capacities to understand the effect on the air temperature of the city canopy air layer. The study
mainly concentrated on four different types of roofs namely asbestos, tile, flat slab and green roofs. The temperature variation is calculated with the varied properties of these roofs.

## 2 Theory

The urban surface energy balance is expressed as:

\[
Q^* + Q_f = Q_H + Q_E + \Delta Q_S + \Delta Q_A
\]  

(1)

where \(Q^*\) is the net all wave radiation, \(Q_f\) the anthropogenic heat release, \(Q_H\) and \(Q_E\) the sensible and latent heat fluxes, respectively, \(\Delta Q_S\) the net storage flux, and \(\Delta Q_A\) the net horizontal heat advection (representing the net gain or loss due to the transport associated with the spatial heterogeneity of sources and sinks, as well as heat advection associated with local and mesoscale circulation). [1] The term \(\Delta Q_S\) is of particular relevance in the urban environment, because it accounts for almost half of the daytime net radiation in highly urbanized sites. The UHI can develop only under favorable synoptic weather conditions (in a radiative scenario, in presence of light wind), in which the term \(\Delta Q_A\) is negligible.[4]

The energy balance model is applied to the building roof level and the parameters which are measured and unknown are shown in the diagram.

![Simulation Scheme](image)

Figure 1: Simulation Scheme

A system of independent equations are necessary to relate three variables \(T_c\) (skin temperature of the building), \(T_1\) (temperature in the canopy air layer), \(r_c\) (air resistance between canopy and building roof level).

Equation 2 comes after applying the energy balance model to the roof level. Denotation \(c\) is given to represent the building surface level.

\[
Q_s^* + Q_{FC} = D Q_{SC} + Q_{HC}
\]  

(2)

In the study \(Q_{FC}\) is neglected with compared to the radiative heat flux \((Q^*)\) from the sun which is then simplifies as follows.

\[
Q_s^* = D Q_{SC} + Q_{HC}
\]  

(3)
\( \Delta Q_{SC} \) is found by the DEROB modeling values where DEROB is a design tool used to explore the complex dynamic behavior of buildings for different designs. The behavior is expressed in terms of temperatures, heating- and cooling loads and different comfort indices. \( Q_s^* \) is also found by the climatic data input file. The sensible heat flux is calculated by using the equation 3 with the calculated \( Q_s^* \) and \( \Delta Q_{SC} \). The found sensible heat flux is then related to the canopy air layer temperature with the equation number 4. Where \( T_c \) values are obtained through the DEROB simulation, \( r_c \) is the air resistance, \( r \) is the air density, \( C_p \) is the specific heat capacity of the dry air and \( T_1 \) is the temperature of canopy air layer. \([9]\)

\[
Q_{HC} = \rho C_p \frac{(T_c - T_1)}{r_c}
\]

(4)

3 Objective and Methodology

The main objective of this research is to compare the temperature difference of the city canyon air layer by replacing the existing flat slabs with green roofs. The following methodology was used for achieving the above objectives:

- Measuring the temperatures of an actual models, which was created with a green roof where buffalo grass was used as the vegetation media.
- Calculating the flat slab areas in a selected city in Colombo district in Sri Lanka.
- Comparing the temperature difference of the city canyon air layer by replacing the existing flat slabs with green roofs.

3.1 Measurements on Real Scale Model

It was found that the best suitable soil cover in terms of the thermal performance and the growing characteristics is 50 mm. And also, It was noted that the temperature reductions in slab top and the soffit are in the same scale for both having 50mm and 75 mm soil covers and compared that with unprotected slab, the thermal performance can improved drastically by growing grass over the slab.[10]. To measure the top surface temperature of roof slab arrangements with and without grass cover and the amount of heat stored in the system, small scale models were created. Experimental set up it shown in Figure 2. Four models were created to measure the slab top temperature and the soffit temperature of different slab arrangements with greenery. One model was kept as bear concrete (without soil cover) slab and other models were covered with soil layers of 25mm, 50mm, and 75mm respectively. On a typical sunny day the slab soffit temperature and slab top temperature were obtained. The measured slab soffit and outdoor temperature variation for soil layer of 50mm and uncovered slab are shown in the Figure 3.
3.2 Energy balance and heat island effect

The experiment was carried out in a chosen city in tropical climate, which is situated in the Colombo district in Sri Lanka. It is a highly dense area with less vegetation. An area of 0.5 km² was chosen for the experiment to simulate the city canyon. The picture of the chosen area is shown in the figure 4. The three roof types in the area were identified as Tile roofs, Asbestos Roofs, Flat Slabs. The areas of all the roofs in the chosen area were measured through the Google Earth Pro. When measuring the areas, the altitude of the Google Earth is set to zero. The image of measured flat slab roof areas is shown in the figure 5.
The simulation temperature values from the DEROB model were obtained for each hour from 7am to 5pm. DEROB-LTH is a software, which was well proven to do thermal simulation. This is well tested by many researchers and it has a high usage in comparative studies. [14, 15, 16] For each roof type a DEROB model was simulate, with a house of average dimensions in the area, to obtain the surface temperatures. The simulated models are shown in figure 6 and 7. With the obtained temperatures the energy stored in each existing roof types were calculated separately. To calculate the total energy stored by the roofs in the selected area, the energy stored in each roof, which was calculated previously from the simulations, were multiplied by the area of the distinct roof and was added. When calculating the energy stored in the green roofs the fact of 1.2% of energy out of the total solar radiation is stored in soil plant system of the green roof was used. [5].According to the actual temperature data obtained from the metrological department the radiative flux by the sun was obtained by using the climatic file for each hour, and was multiplied by the total sample area to calculate the total radiative flux to the area. [17]

The sensible heat flux was obtained by subtracting the energy stored from the total flux. The canopy air temperature was calculated by the equation 4 where \( C_p \) was 1.01kJ/kgK , \( v \) was 1.29kg/m³, \( r_c \) was 15 sm⁻¹ [11].The same procedure was followed by replacing all the flat slabs in the considered area with properties of green roofs. The temperatures of the two situations were compared.
4 Results and discussion

The air temperatures obtained for each case in considered time period are shown in the Figure 8. There, the case1 represent the air temperatures of the canyon under the prevailing conditions of the roofs and case 2 represent the canyon air temperatures when all the flat slabs in the area are replaced with green roofs. The considered time period was from morning 7.00am to evening 5.00pm because the net all wave radiation is positive only in that period.

According to the figure 8 the temperatures of the canyon air is high under the prevailing condition compared to that the flat slabs replaced with green roofs. When the flat slabs are replaced with green roofs the canyon air temperatures reduces approximately by 1.5 °C than the prevailing condition. This reduction of the temperature can be seen throughout the considered time period.
The magnitude of the canyon air temperature varies with time. From the figure 9 it’s evident that the air temperature is comparatively high in the city canyon in the case 1 than the normal air temperature. This value is maximized at 1.00pm. The canyon air temperature in that hour is 34.47°C where the normal air temperature (ambient air temperature) is only 31.3°C and the difference is more than 3°C. This is called the effect of heat island, which prevails in the compacted cities.

Temperature of the air varies with the solar radiation magnitude. According to the figure 10 the maximum solar flux occurs at 12.00pm and the maximum air temperatures take place at 1.00pm. It can be clearly stated that the maximum temperature of the canyon air occurs just after one hour from the maximum solar radiation taking place.
Other than the solar radiation magnitude, the canyon air temperature varies with the energy storage capability of roofs. The comparison of each roof’s ability to store heat is shown in the figure 11. It’s clearly shown that the flat slabs emit energy to the air after 2.00pm and this causes the sensible heat in the air to increase and the temperature to increase. But in green roofs it emits heats only after 4.00pm and yet again which is also in small amounts.

With all the results above it’s proven that green roofs can reduce the air temperature of the city in the day time by reducing the heat island effect.

Measured flat slab area in the selected city is 38418.3m².

5 Conclusion

With the increasing demand for the city dwells the city is compacted with buildings. The impervious faces are increased and the city temperatures increase compared to the temperature in rural areas. Green roofs are identified as a solution for the above mentioned problem. The experiment was carried out to compare the effect of green roofs on the canyon air temperatures.

Experiment was carried out by simulating two conditions. Namely the prevailing city condition and the predicted city condition, which is all the flat slabs replaced with green roofs. The comparison was done for two conditions to compare the city temperatures. With proven results it can be stated that canyon air temperature can be reduced by 1.5°C when all the flat slabs are replaced with green roofs. This difference can be maintained throughout the day time. The findings are very important when considered the future development to be made. If the future constructed buildings are coupled with green roofs, the temperature issues that would have aroused due to impervious surfaces can be reduced. Other than the temperature benefits the visual benefits are also there with the increased greenery in the city.

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