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Analysis of Possible Energy Savings Impacts of Green Walls on Urban Dwellings in Bangladesh

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Abstract: *With enhanced rate of urbanization and the predicted increase in temperature due to global warming, it is anticipated that urban microclimates would deteriorate in future. Hence, for sustainable urbanization, there is an urgent need for mitigating the urban heat island and conservation of energy required for cooling and ventilation. Although a number of studies on green walls in the developed countries have positively asserted their role in mitigating urban heat island, there is a general lack of such studies in the developing countries of the world that receive high solar radiation. This study, conducted on Dhaka City, Bangladesh is an attempt in that direction. The possible impacts of green walls on energy savings during the summer was analyzed by using two analytical methods based on the estimation of evapotranspiration.The analyses show that green façade on a typical building in a typical canopy can decrease the total energy consumption by 16% to 31%. But, if only the energy consumption from cooling and ventilation is considered then the savings would vary between 64%to100%.*

Keywords: *Green facade, Energy savings, Dhaka City, Bangladesh*

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I. INTRODUCTION

Bangladesh, a country having an area of 147,570 km^2 and with a population of about 160 million is the 8th largest populous country in the world. The population is projected to increase to about 200 million by 2050 [1]. As a natural resource-deficient country with agriculture based economy, Bangladesh has made tremendous progress during the past two decades in the alleviation of poverty. But, the progress in the social and economic indices has taken its toll on the meager natural resources like land and water. Due to the high population density and scarcity of land, the country has an immense pressure on the land for urbanization and industrialization. The urban population is expected to increase from about 34% of the total population in 2014 to about 56% by the end of 2050[2]. The 2.4% growth rate of urbanization during the 2010-15 period is one of the highest in Asia.

Leaving aside the increased risk from urbanization, Bangladesh is also considered to be one of the most vulnerable countries of the world to climate change due to its flat terrain and high population density. The impacts of climate change have already emerged and recent studies by the Department of Environment show that in Bangladesh, both the maximum and the minimum temperatures have increased during the last 60 years [3]. Apart from increase in temperature, the country is also going to be adversely affected by the rising sea level. It has been estimated on the basis of 30-years of data that the country has been experiencing6-11 mm/year of sea level rise in the different coastal regions. According to IPCC predictions, the sea level rise along the coasts of Bangladesh by 2100 would vary between 260 to 980 mm, for low to high emission scenarios [4]. Such an increase would have devastating effect on country’s economy as in that case as much as 25% of the country may be inundated and may displace 10-30 million people by the 21st century [5].

Dhaka, the capital of Bangladesh is one of the fastest growing cities of the world and is ranked as the 11th largest city with a population of about 17 million. It is predicted to be the 6th largest city of the world by 2030 with a population of about 27 million [2]. The unplanned and often unauthorized urbanization in the past has caused a significant decline in the wetlands and agricultural lands with a consequent manifold increase in the built-up area. Because of scarcity of land and also to accommodate more people per unit area, the recent trend in urban construction in Bangladesh is to go vertical rather than horizontal. Although such expansion would minimize the use of land, it would not alleviate the deterioration of the microclimate and air pollution. The introduction of green in building design through roof and vertical greening can be an effective way to mitigate the deteriorating microclimate.

Although the studies on green walls have positively asserted their role in energy conservation, they have generally been conducted in the developed countries and also in the temperate climate. In an extensive literature survey on energy savings by green walls, it has been observed that there is general lack of studies on green in the countries of the world that receive high solar radiation [6]. It is necessary to explore the role of green walls in a developing country like Bangladesh and located in a subtropical climate (with hot and humid summer, mild and dry winter and heavy monsoon rain in between).The focus of this research was to study the effects of green walls on urban dwellings in the subtropical environment of Dhaka city. Broadly, the research examines how green are walls going to work on a pre-existing building and what impacts they would have on the microclimate and energy savings?

II. GREEN WALLS

Green spaces in a building refer to all the vegetated surfaces of a building and can be broadly classified into two categories: 'horizontal green' or 'green roof' and 'vertical green' or 'green walls'. Leaving aside 'green roofs', in which a roof is fully or partly covered with a layer of vegetation, the 'green wall' is a wall that is partially or completely covered with vegetation, that are either freestanding or stand with support, with their root system either in soil or in some other inorganic or organic growing medium. The potential of walls as green space is much higher than the roof because the extent of surface greening area can be much higher for the walls than the roof. This is especially true for tall or high rise buildings and it isthat the green wall area may be as high as 20 times the roof area [6]. Thus, in the context of greening of a city, the green coverage by walls can potentially be much more than the green coverage during the pre-existing state of urbanization. Green walls can be subdivided into two major groups: green façade and living wall. Green facades are walls where the climbing plants grow either directly clinging to wall with their roots in the ground (called direct façade) or are supported by vertical structure (cables or mesh) for plant development (called indirect façade). Living walls are a comparatively new technology, where pre-fabricated vegetated walls or modules are fixed on the building's façades or walls. There are variations in the living walls mainly because of the use of different types of modules with different construction systems, types of plants used in the modules and their maintenance systems. As pre-planted vegetation may be used for cladding the walls, living walls allow faster coverage of the walls with a more uniform growth.

III. IMPACTS OF GREEN WALLS

As has been mentioned earlier, green walls (both green facades and living walls) can bolster the environmental services in the context of urbanization. Through an extensive review of literature, the effects of green walls have been classified into four groups: shade effect, cooling effect, wind barrier effect and insulation effect [7]. Green walls reduce the façade temperature due to shading and cooling through evapotranspiration. The shading effect results from the interception of the solar radiation by the plants. The cooling results due to evaporation of water from the substrata and from the leaves in addition to the shading by the plants. The wind barrier effect or the reduction in air velocity by the foliage helps reduce the heat flux and air infiltration between the interior and exterior of a building and helps reduce the energy consumption. The insulation effect refers to the insulation characteristics of different substrata used in living walls to hold the moisture or retain the basal temperature.

3.1 Energy savings

Through an extensive review of published literature on energy savings by green walls by different researchers at different countries of the world till 2013 it has been concluded that the reduction in summer temperature varied from 1.7^0 C to 13^0 C, in warm temperate climate [6]. It was also observed that east and west orientations had big impacts on the reduction in temperature but there were no differences in impacts between species used (deciduous and evergreen). For living walls, it was observed thatthe reduction in temperature varied from 12^0 C to 20.8^0 C during the summer. Studies on green walls in Hong Kong (sub-tropical climate) observed that the temperature reduction by 13 vine species of green facades varied from 0.5^0 to 2.5^0 C during a sunny day [8]. In a life cycle assessment of green walls, the energy savings by green walls were reported as 14%, 30% and 40% for London, Barcelona and Dubai, respectively [9]. In a summary of effects of green wall on energy savings with respect location, it has been concluded that green walls would be more effective at high latitudes than at low latitudes [10].

IV. METHODOLOGY

The impacts of green walls (thermal cooling and energy saving) were analyzed by two analytical methods.In the following sections, the study area and the analytical methods selectedfor the analysis of impacts of green walls are presented.

4.1The Study Area

The study was carried out in Dhaka city (23^0 42'N, 90^0 22'E), the capital of Bangladesh.The climate of Dhaka is tropical monsoon and is characterized as hot, wet and humid, with mean monthly temperatures varying from 18.8^0C in January to 29.3^0C in April. The humidity varies from 61% in March to 85% during the monsoon months of June to September.The annual rainfall is about 2000 mm but about 70% of the total falls during the monsoon months of June to September. With a present area of about 360 km^2 and population density of about 45,000 per square km, Dhaka is also one of the densest cities of the world.

The city's unprecedented urbanization during the last three decades along with the high population density had serious repercussions on the environment (land, water, vegetation and the microclimate). Poor and uncoordinated planning and development along with high pressure on land for urbanization, have exacerbated the problem. The land cover change due to urbanization during the 1989-2010 period is shown in Table 1. The table shows that during that period, the water bodies and the vegetation decreased by 53.7% and 16.5%, respectively [11]. At the same time, the built up area has increased dramatically by 118.7%. The built up area in 2010 was about 36% of the total city area. If the present trend of urbanization continues into the future, then it is estimated that the built up area would increase to 49% and 57% of the city area by 2019 and 2029, respectively [12].

The change is land cover, especially the dramatic increase in built up area by converting the water bodies and vegetation, has advertently affected the microclimate. Fig. 1 shows the changing pattern of city temperature during the 1989-2009 period. It can be seen from the figure that the city area did not experience any temperature above 30^0C before 2009. In 2009, about 5% of the city area experienced temperatures above 30^0C. If the present trend of urbanization continues into the future, then it is estimated that the area experiencing temperatures above 30^0C would increase to 56% and 87% of the city area by 2019 and 2029, respectively [12]. Thus, increase in

Table1: Land cover change in Dhaka city during 1989-21010 period [11].

Land Cover Type	Year	
	1989 (km^2)	2010 (km^2)
Water body	76.0	35.2
Vegetation	105.2	87.9
Built up area	59.4	129.9

urbanization by another 13% and 21% by 2019 and 2029 (from 36% in 2010), respectively, would increase the temperature in 51% and 83% of the city area (from about 5% in 2009) above 30^0C. Thus, the clarion call of the time for planners and architects of Bangladesh is to adopt mitigation measures while designing built up areas, so that, the urbanization may continue unabated without increasing the heat island.

4.2 Assessment of Impact through Energy Conservation by Green Facades

Through extensive review of literature, two methods have been considered for the analysis. Both the methods are theoretically sound and have been developed and tested in three different regions of the world. Brief descriptions of the selected methods are presented in the following sections.

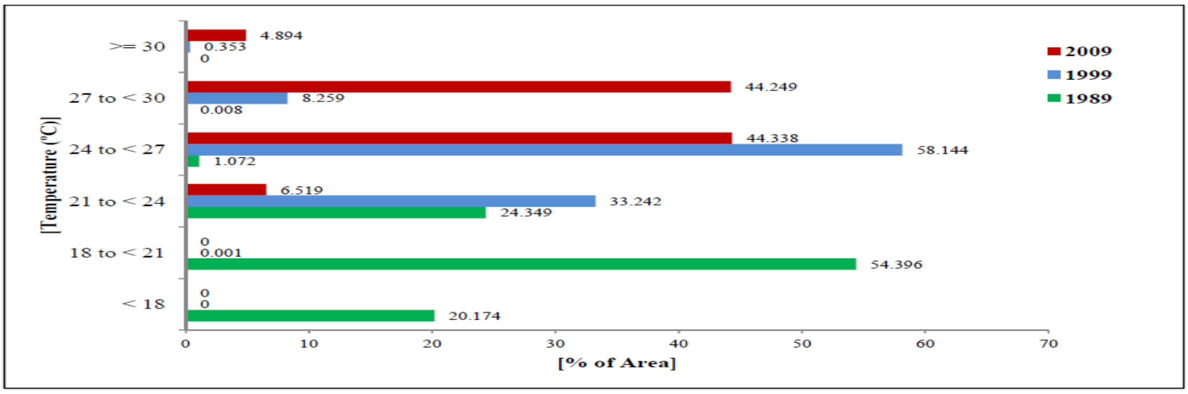


Figure 1: Changing pattern of Dhaka city temperature during 1989-2009 period [12].

4.2.1 Method 1

The method is based on the principle of absorption of heat by a green space from the surrounding air through plant evapotranspiration. During the process of evapotranspiration, the heat absorbed by the plants from the surrounding atmosphere is the latent heat of vaporization. The evapotranspiration from the plants can be calculated by the Penman-Monteith equation as follows:

$$ET = (\Delta(R_n - G) + \rho_a c_p (\delta_e) g_a) / (\Delta + \gamma(1 + g_a/g_s))\ L_v(1) \quad (1)$$

Where:

ET = Water volume evapotranspired (mm s^{-1})

Δ = Rate of change of saturation specific humidity with air temperature. (Pa K^{-1})

R_n = Net irradiance (W m^{-2}), the external source of energy flux

G = Ground heat flux (W m^{-2}), usually difficult to measure

c_p = Specific heat capacity of air (J kg^{-1} K^{-1})

ρ_a = dry air density (kg m^{-3})

δe = Vapor pressure deficit, or specific humidity (Pa)

g_a = Conductivity of air, atmospheric conductance (m s^{-1})

g_s = Conductivity of stoma, surface conductance (m s^{-1})

γ = Psychrometric constant ($\gamma \approx 66$ Pa K^{-1})

L_v = Volumetric latent heat of vaporization. Energy required per water volume vaporized. (L_v = 2453 MJ m^{-3})

The use of Penman-Monteith equation for the calculation of evapotranspiration has been suggested by [13] and they have used the concept for the assessing the impacts of green walls on urban microclimate by implementing it into a software called 'SOLENE'. The model was tested with experimental data from Geneva, Switzerland and the results showed good correlation.

Although the Penmen-Monteith equation requires lot of data to calculate the evapotranspiration (which are generally not available from the local weather stations), FAO has developed a software called 'CropWat', which is based on the equation. The 'CropWat' (http://www.fao.org/nr/water/infores_databases_cropwat.html) software is widely used worldwide by the hydrologists and engineers for estimating the evapotranspiration of crops. The advantage of using the software is that it does not require all the data as shown in equation 1, as they are in-built into the software, provided the location of the place (latitude and longitude) and altitude of where evapotranspiration rate is to be calculated, is provided as inputsinto the software. In this study, the 'CropWat' software was used for the computation of evapotranspiration.

If the evapotranspiration rate can be determined from the model, then the energy saving can be calculated by multiplying the rate of evapotranspiration with the latent heat of vaporization, λ_v (also known as enthalpy of vaporization) which has value of 2257 kJ/m^3[14]. Thus, the energy saving from 1 m^2 of green façade can be calculated as:

$$E = \text{Evapotranspiration (m/day)} \times \text{Area } (1\ m^2) \times 2257 \text{ (in kJ/}m^3\text{)} \quad (2)$$

Where: E is the energy saving in kJ/day for 1 m^2 of green façade.

4.2.2 Method 2

While modeling the heat transfer for energy simulation of green roofs, an equation has been developed that can be used to estimate the transpiration from the plants [15]. The equations have been validated with experimental data carried out in the U.S. The equation uses 'leaf area index' or LAI (the ratio of leaf surface are to the underlying land area) as an important parameter. For well watered and fully grown plants within a green space, the LAI value is generally high and in such case the evapotranspiration would only be in the form of transpiration. This is because for a fully covered green space, very little of the underlying land would be exposed to the atmosphere and hence there would be little or no evaporation. The evaporative cooling by transpiration under such condition can be estimatedas [15]:

$$Q_T = LAI\ (PC_p)\ (e_{s,\ plants} - e_{air}) / \gamma\ (r_s + r_a) \quad (3)$$

Where:

Q_T = energy saving due to evaporative cooling, W/m^2

P = atmospheric pressure, kPa

C_p= the air specific heat J/Kg. ^{0}K

γ = the psychometric constant, kP/^{0}C

r_a=aerodynamic resistance to mass transfer, s/m

r_s= stomatal resistance to mass transfer, s/m

$e_{s,\,plants}$= the air vapor pressure in contact with the leaves of plant, kPa
e_{air} = air vapor pressure, kPa

The psychometric constant, γ can be determined as:
$\gamma = PC_p/0.622\lambda_v$(4)

where, $\lambda_v$is the latent heat of vaporization (2257 kJ/m^3).
The r_s in equation 3.4 can be estimated as:

$$r_s = r_{stomatal\ min} * f_{solar} * f_{VPD} * f_{VWC} * f_{temperature} / LAI \quad (5)$$

where:
$r_{stomatal\ min}$ = minimum value of stomatal resistance to mass transfer
f_{solar} = function for solar irradiance
f_{VPD} = function for vapor pressure
f_{VWC} = function for volumetric water content in substrate
$f_{temperature}$ = function for plant temperature

The values of the functions can be obtained from the equations provided by [15].
$e_{s,\,plants}$ of equation 3 can be estimated as:

$$e_{s,\,plants} = 0.6108 * \exp(17.27.\ (T_{plants} - 273.15) / (T_{plants} - 273.15 + 237.3) \quad (6)$$

Where, T_{plants} is the average temperature of plants, ^{0}K

As equation 3 computes the energy savings, the equation can be directly applied with known values of the parameters/variables.

4.3Selection of Study Site

As has been mentioned earlier, the study was carried out in a typical building of a typical canopy of Dhaka city. A Google image of the Shiddeshwari Ward of Dhaka city and a photo of a canopy in the ward is shown in Figs. 2 and 3. The city comprises of 90 such Wards. A schematic diagram of a typical building in the canopy with south, east and west facades are shown in Fig.4.

It is evident from the figures that the buildings in the Shiddeshwari Ward canopy have been developed without following any planning standard and regulation. The façade of the building is placed near the street and did not follow the set-back rule. As observed, the high concentration of buildings and consequent lack of open space in the Ward have resulted in excessive heat build-up during the day and required artificial cooling and ventilation during the summer months [16].

Figure 2: Google image of Shiddeshwari Ward of Dhaka city.

The development trend in the canopy is characterized by high density units without provisions for open space and greenery. High urban density (high ratio of height of buildings to the distance between them: H/W) means less view of the sky. As a result, the buildings are deprived of natural light and air flow and have high demand for ventilation and air conditioning. Heating during the winter is not a serious problem as the winter lasts for at most two months with mean daily temperatures in the low twenties. Most of the buildings are medium rises (5-6 storied), with the façade of the building very near to street line and constructed ignoring the setback rule.Although there are rules and regulations for urban development and codes for building construction [17], they are neither implemented, nor enforced. The canopy street is narrow (4 to 6 m) and congested and without any sidewalk.

4.4 Plant Selection for Green facade

The most common plant that can be used for green façade in Bangladesh is the Devil's ivy, locally known as money plant, (*Epipremnum aureum*). It is a robust and sturdy evergreen plant and can grow in adverse conditions with very little maintenance. It is a common decorative indoor plant which can be up to 50 m in height with bushy 8 to 20 cm heart shaped leaves. Considered as a very suitable climbing plant on trellis and wires, it can also be used as a green façade. A photo of Devil's ivy is shown in Fig. 5.

V. ENERGY SAVINGS BY GREEN FAÇADE

The two analytical methods that are used for assessment of energy savings by devil's ivy as green façade have been explained in article 4.2. In the following sections the computed savings are explained in detail.

5.1 Assessment of energy savings by Method 1

Using the Penmen-Monteith method (as discussed in article 4.2.1), the evapotranspiration of Devil's ivy in Dhaka city can be calculated by using the CropWat software. The climatic data required for running the CropWat model for Dhaka city (monthly maximum and minimum temperatures, relative humidity, wind speed

Figure3: Photo of a typical canopy in Shiddeshwari Ward.

and sunshine hours) and the output of the model as monthly evapotranspiration rate (ET_0 in mm/day) are given in Table 2.The climatic data have been collected from the Bangladesh Meteorological Department (http://www.bmd.gov.bd/?/p/=Climate). It can be seen from the table that the maximum and the minimum evapotranspiration for Dhaka city occur in the months of April (6.1 mm/day) and December (2.5 mm/day) and average annual value is 4.0 mm/day (ET_0 values in the last column of the table).

Considering the average annual evapotranspiration rate of 4.0 mm/day for Dhaka city, the average energy saving by Devil's ivy as green façade (in 1 m^2) can be calculated as (using equation 2):

$E = 0.004(m/day) \times Area\ (1\ m^2) \times 2257\ (in\ kJ/m^3) = 9028\ kJ/m^2\ day = 104.5\ W/\ m^2$

The average ET_0 during the summer months of March – June is 5.24 mm/day and the average energy saving during the summer months can be calculated as:

$E = 104.5 \times 5.24 / 4 = 136.9\ W / m^2$ (for the summer months)

5.2 Assessment of energy savings by Method 2

The psychometric constant, γ can be determined as (equation 4):

$\gamma = PC_p/0.622\lambda_v = 1.0 \times 101.3/ 0.622 \times 2257 = 0.072\ kP/^0C$

where $P = 101.3$ kPa, $C_p = 1.0$ kJ/Kg and $\lambda_v = 2257$ kJ/Kg^{0}C

The r_s in equation 3.5 can be estimated as:

SOUTH/ FRONT ELEVATION

Figure4 (a): Sketch of a typical building in a typical canopy ofShiddeshwari Ward(southern elevation).

$r_s = r_{stomatal\ min} * f_{solar} * f_{VPD} * f_{VWC} * f_{temperature} / LAI$

$= 700 \times 1 \times 202.3 \times 1.3 \times 1.9 / 3 = 116{,}952$

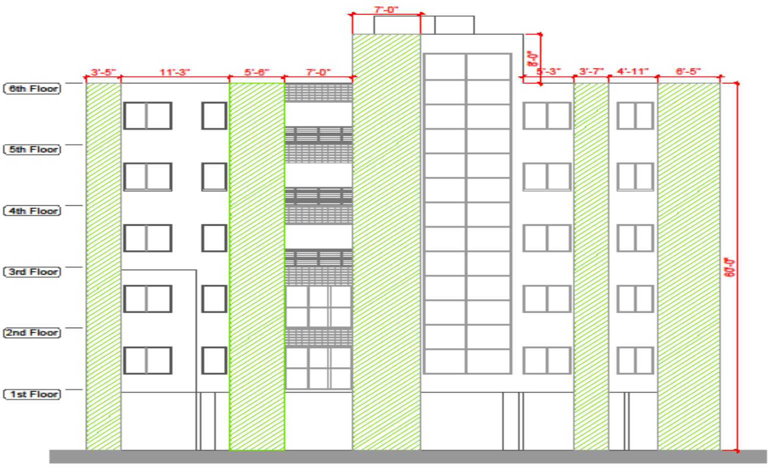
Where: $r_{stomatalmin}$=700 s/m, r_{solar}=1.0, f_{VPD} = 202.3,f_{VWC}=1.3, $f_{temperature}$= 1.9 values were collected from Tabares-Velasco andSrebric (2012). For Devil's ivy plant, the LAI has been considered as 3.0.

The $e_{s,\ plants}$can be estimated as (Tabares-Velasco andSrebric, 2012):

$e_{s,\ plants} = 0.6018 \times \exp[(17.27 \times (T_{plant} - 273.15) /(T_{plant} - 273.15 + 237.3)]$

$= 4.24$ (for T_{plant}=30^{0}C)

With e_a= 2.3 kPaand r_a=142 (Tabares-Velasco andSrebric, 2012), the energy saving from evaporative cooling



EAST ELEVATION

Figure 4 (b): Sketch of a typical building in a typical canopy ofShiddeshwari Ward (east and west elevations).

Figure 5: Image of Devil's ivy (money plant)to be used as green façade (Source: https://commons.wikimedia.org/wiki/File:Money_plant_(Epipremnum_aureum).jpg)

Table 2: Screen shot of calculated average monthly and annual evapotranspiration for Devil's ivy in Dhaka city by CropWat model (http://www.fao.org/nr/water/infores_databases_cropwat.html).

Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Dhaka.pem

Country: Bangladesh — Station: Dhaka

Altitude: 9 m. — Latitude: 23.78 °N — Longitude: 90.39 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	12.3	25.3	69	106	7.9	15.4	2.63
February	15.1	28.3	63	138	8.4	18.0	3.58
March	20.1	32.6	61	224	8.4	20.3	5.24
April	23.5	33.9	70	364	8.3	21.8	6.10
May	24.7	33.0	78	328	7.5	21.2	5.35
June	25.9	31.8	84	320	4.9	17.4	4.27
July	26.2	31.2	85	314	4.6	16.8	4.05
August	26.2	31.4	84	277	5.3	17.4	4.16
September	25.8	31.6	83	194	5.5	16.6	3.91
October	23.6	31.2	79	111	7.3	17.1	3.74
November	18.6	29.1	74	80	8.1	16.0	3.08
December	13.7	26.2	72	79	8.1	14.9	2.52
Average	**21.3**	**30.5**	**75**	**211**	**7.0**	**17.8**	**4.05**

by Devil's ivy can be calculated by equation 3 as:

$Q_T = LAI\ (PC_p)\ (e_{s,\ plants} - e_{air})\ /\ \gamma\ (r_s + r_a)$

$= 3 \times 101.3 \times 1000 \times (4.24 – 2.3)\ /\ [0.072 \times (116,952 + 142)]$

$= 69.73$ W/ m^2= 6024 kJ/m^2day

5.3 Assessment of the Impact of Green Façade on Energy Savings in a Building

By using both Methods 1 and 2, it is possible to assess the impact of green facades on the energy savings due to evapotranspiration. Although the estimates of savings vary between the two methods (Method 1 estimate is 1.5 times higher than that of Method 2), it is acceptable because both the methods are based on different assumptions and parameters and also uses different sets of equations. Moreover, the evapotranspiration estimated by Method 1 is for ideal crop growth condition - disease-free, well-fertilized crops, grown underoptimum soil water conditions [14]. Thus, the two methods give a range of values of energy savings that may be achieved through green façade. The energy saving due to green façade was estimated from the decrease in energy requirement of a building with and without a green façade as:

$$Q_E = Q_T / Q_C \quad (7)$$

Where:Q_E is the energy savings in %, Q_T is the energy savings due to green facade and Q_C is energy consumption of a building without green façade (all expressed in W/m^2 day).

For the energy based assessment using equation 7, it is necessary to know the value of Q_C, which is energy consumption of a building without green façade (W/m^2 day). There has been a very recent assessment of such consumption in Dhaka city [18]. Their study showed that for the residential apartment buildings, the average energy consumption varied between 57.5 to 136.4 W/m^2 day. The study also showed that the higher consumption is in areas where the ratio of open space to built-up area is low (1.6 compared to 3.3).

For the typical building of Shiddeshwari Ward canopy as shown in Figure 4.3, the total floor area is 19.81x 24.39 = 483.2 m^2(65' x 80' = 5200 ft^2). From personal communication with the local developers it was clear that out of the total floor area, about 25% to 30% of the area is taken up by the common spaces (elevator, stairs, landings etc.). Hence, the actual apartment floor area is about 362.4 m^2 (assuming 75% of floor area). Since the building has five floors, the total floor area is 1812 m^2. As the energy consumption varied between 57.5 to 136.4 W/m^2 day, the total energy consumption of the building for a month would vary between 104.2 KW-h to 247.2 KW-h. Since Shiddeshwari Ward is in a highly built-up area, the energy consumption for a month would be in the higher side and may be considered as 200 KW-h.

Now, if green façades are introduced in three facades of the building (east, west and south) as shown in Figure 4.3, except for the north, the total green area can be calculated as 457.3 m^2.No green area is provided in the north façade as it is at the backside of the building and normally has the service and utility lines/pipes. This facade also faces the backside of the building of the opposite canopy.

Thus, the energy saving from the green façade of 457.3 m^2 would vary between:

457.3 x 136.9 = 62.5 KW-h from Method 2 during the summer months

E = 62.5 / 200 = 31.3% of the total energy demand (equation 4.4)

457.3 x 104.5 = 47.8 KW-h from Method 2 for average condition

E = 47.8 / 200 = 23.9% of the total energy demand (equation 4.4)

457.3 x 69.73 = 31.9 KW-h from Method 3

E = 31.9 / 200 = 16.0% of the total energy demand (equation 4.4)

Out of the total energy consumption of 200 KW-h, if it is assumed that 25% of it is for cooling and ventilation during the summer months (from personal communication), then the green façade can save the energy consumption by:

457.3 x 136.9 = 62.5 KW-h from Method 2 during the summer months

E = 62.5 / 50 ≈ 100% of the total cooling and ventilation energy demand (equation 4.4)

457.3 x 104.5 = 47.8 KW-h from Method 2 for average condition

E = 47.8 / 50 = 96% of the total cooling and ventilation energy demand (equation 4.4)

457.3 x 69.73 = 31.9 KW-h from Method 3

E = 31.9 / 50 = 64.0% of the total cooling and ventilation energy demand (equation 4.4)

Thus, it is evident that the green façade on three sides of a typical building in a typical canopy can decrease total energy consumption by 16% to 31%. But, if only the energy consumption from cooling and ventilation is considered, then the savings would vary between 64% to 100%.

VI. CONCLUSIONS

Although a number of studies on green walls in the developed countries have positively asserted their role in energy conservation, there is a general lack of such studies in the developing countries. This study, conducted on Bangladesh, is an attempt in that direction, but it is in no way comprehensive and holistic, and can only be considered as indicative. In this study the possible impacts of green walls on energy savings during the summer was analyzed by using two analytical methods. Although the performance of the two methods could not be validated because of lack of field data, the Penman-Monteith method based 'CropWat' model has an advantage that being developed by FAO, it is tested and also recommended worldwide for the estimation of evapotranspiration. The average energy savings by the CropWat model was found to be 50% higher than the other model. Such variation is expected because of the use of different assumptions and parameters by the two methods. But, because of worldwide acceptability of the 'CropWat' model, the output of the model may be considered as realistic. The energy based assessments based on 'CropWat' model show that the energy savings from cooling by green façade during the summer months would be about 31% of the total energy consumption. But, if it is assumed that the energy consumption for cooling and ventilation is 25% of the total energy consumption, then the savings from the green facade may be 100%.

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