Performance Evaluation of Vertical Greening System of Exterior Wall on Indoor Thermal Environment in Residential Buildings of Dhaka City

Soniha Nuzrat, A S M Shahedur Rahman

Abstract— The application of horizontal and vertical greening has a significant impact on the thermal performance of residential and commercial buildings and on the urban environment. Plants are functioning as a solar filter and prevent the absorption of heat radiation of building materials extensively. Vertical greening can provide a cooling potential on the building surface, which is very important during summer periods in our climatic context of Bangladesh. It has enormous possibilities, especially in the residential sector of Dhaka city, where city dwellers cannot get enough space to plant trees because of the tight urban situation and scarcity of land. The objective of the study is to analyze the impact of vertical green walls on exterior surface of residential buildings to minimize indoor air temperature, to ensure the sustainability and energy efficiency of the building industry sector. In this perspective, combined effort of field study and computer simulation approach will be conducted to measure the temperature in residential multistoried building. A comparison between measurements on a bare façade and a green vegetated façade will be taken, in summer, to understand the contribution of vegetation to the thermal behavior of the building envelope. The results of the analysis will be presented such that vertical greening can be used on the exterior walls of residential buildings to maximize indoor thermal comfort.

Index Terms— Impact of Exterior vertical Green Wall, Residential Building, Indoor Air Temperature, Thermal Comfort, Tropical climate.

1 Introduction

*THE integration of vegetation on buildings, through green roofs or vertical greening, allows obtaining a significant improvement of the building's efficiency, ecological and environmental benefits. Green fa*з*ades and living wall systems (LWS) offer numerous ecological and environmental benefits, can have a positive influence on the comfort and wellbeing in and around the building, besides social and aesthetical value [3]. Thermal Performance of interior spaces, which is an extremely important issue in the context of sustainability in cities [4] is seen to have a significant role for efficient living. In residential areas humans need thermally comfortable environments to rest and revive after the day's work. Where energy or power supply is scarce, like in Dhaka [2], passive climatic control should be applied, for achieving thermal comfort. Overheating is a growing environmental concern for tropical cities like Dhaka [1], though rules and controls, to achieve thermal comfort in residential environments, are non-existent [2]. The ecological and environmental benefits of vertical greening systems, as for green roofs, concern the reduction of the heat island effect in urban areas, the air quality improvement and energy savings. In fact, both the growing medium and the plants themselves provide insulation and shade especially in Tropical area, energy for cooling Green fa*з*ades are based on the use of climbers (evergreen or deciduous) attached themselves directly to the building surface (as in traditional architecture), or supported by steel cables or trellis. Living wall systems, which are also known as green walls and vertical gardens, are constructed from modular panels, each of which contains its own soil or other growing medium (soil, felt, perlite, etc.) [6].*

This research is conducted on thermal performance of various green walls, a key building design element, as this vertical surface receives the solar radiation at summer time in context of Dhaka. Here in this paper 3 sites have been chosen in Dhaka city as case study to observe temperature difference in between bare walls and green walls of residential buildings.

2 Aim of the Study and Research Question

The green surface can help in reducing temperature in hot summer periods and insulate solar radiation in any time period which makes indoor residence spaces more comfortable. Since the aim of this research is to measure the possible reduction of the (air and surface) temperature by different green concepts (direct and indirect), the following research questions have been formulated:

- *Is there a difference between air temperature in between a bare fa*з*ade and a green covered facade?*
- *Does the temperature variation fluctuate on the height of the building with a green vegetated fa*з*ade?*

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3 Literature Review

3.1 Climate of Dhaka

The Inter-governmental Panel on Climate Change (IPCC) predicts a rise of the mean annual temperature of about 3.3°C per century in the world. The effect of climate change is being felt in the tropics, and Bangladesh is one of the most vulnerable countries.

Temperature trends during the last 60 years (1950-2010) shows a tendency of increase in the average day temperature [7]. The mean annual temperature here has increased during the period of 1895-1980 by 0.31°C over the past two decades [8].

Dhaka city lies between 23° 40′ N to 23° 55′ N latitudes and between 90° 20′ E to 90° 30′ E longitudes. The climate of Dhaka is having mainly three distinct seasons – the hot dry (March-May), the hot humid (June-November) and the cool dry season (December-February) [4]. Dhaka lies just north of the Tropic of Cancer, displaying characteristics of "Composite" climate, with approximately one-third of the year being hot-dry (mean max 33.6 0C), two thirds warm-humid (mean max 31.3 0C), while there is a cool-dry season [9].

Dhaka has a high rate of residential development, to cater to the huge influx of rural to urban migration [4]. Residential areas form almost 27% (highest) of built areas [10].

In a 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 [11]. 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.

3.2 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 is that the green wall area may be as high as 20 times the roof area [11].

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 faзade*
- *living wall*

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 [11]. Green walls reduce the faзade 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 [11].

3.3 Standards in the Thermal Comfort Assessment for Tropics

Many of the International Standards produced are found to be inadequate for describing the comfort condition in the tropical climate. One of the international standards frequently used for indoor climate condition is ISO7730based on Fanger's predicted mean vote (PMV/ PPD) equation. The equation of the formula is applied to derive a numerical value depicting the comfort conditions based on the ASHRAE scale. The air temperature of 300 Celsius is considered normal for this climate and the air movement of more than 1 m/ s is desirable to relieve the heat. These two figures are set up as the upper limits in the formula. Another reason that may have an effect to the result is the conducting method of the experiment. Most of the measurement is based on the close-lab environment. In reality, such environment is rarely available and in many field studies, a factor of adaptability is part of the factor which is not in the environment that is fully controlled.

4 RESEARCH METHODOLOGY

The chosen greening systems for this research are based on different characteristics such as materials used, plant type and building height. Due to the characteristics of each investigated greening system it is hypothesized that there is a difference on the microclimate (air, surface temperature and wind speed) around and in, behind the green walls. To frame the knowledge base, previous thermal condition researches, relevant to climatic condition of Dhaka have been studied. The study was conducted through two main phases. The first phase was field survey and the second was software-based simulation analysis.

- *The field surveys*
- *Simulation analysis*

Three residences with three types of green surface have been selected for the study. At each spot, measurements of air temperature (average value of four readings) are taken. The study was primarily based on, field data measurement, observations, discussion, comparison and analysis of data. The air temperature difference between the bare surface and green wall surfaces was considered a significant indicator of the performance of the wall surface. Within the limited period of time for the study, residential areas of similar physical features were chosen, to minimize the impact of surroundings on the temperature variations. One of the case building will be simulated with computer-based simulation software to validate the survey data as well. After the simulation the data will be compared with the ASHRAE standard to get best result and *apply this technique in further research and development of building sector.*

Figure 1: Direct green facade with **Climbing Fig**

Figure 2: indirect green facade with **Bougainvillea** plant

Figure 3: Green Facade with ***Epipremnum aureum***

5 Field Survey in Context of Dhaka

The field survey was conducted on 27th August which was a moderate sunny day. the survey date was selected randomly. Temperature data of indoor space (both in green fasade and bare fasade) was taken from 12 pm to 4pm with Hygro-Thermometer. From these data it is observed that indoor temperature of floors in different cases remains higher in bare facade than green fasade of day time (around 12.00 p.m. to 4 p.m.). The cases have green walls on different surfaces according to north south east west position. At each side the temperature count was different form each other. The three survey cases with three different types of surface treatments according to the plant variation are based on the brick wall surface. The survey cases are as below:

5.1 Case Study 1

- *Orientation: South-East Facade*
- *Plant type: Creeping Fig, Ficus pumila: "Tropical Ivy"*
- *Plant condition: Well grown, not completely covered fasade (covering thickness 5 cm)*
- *Plant age: Between 4 and 5 years old*
- *Supporting material: Wall facade*
- *Air cavity between fasade and leaves: 0 cm*
- *Building material fasade: Masonry (clay bricks)*
- *Location: Dense urban area (Dhanmondi residential area)*
- *Roof height:17m*

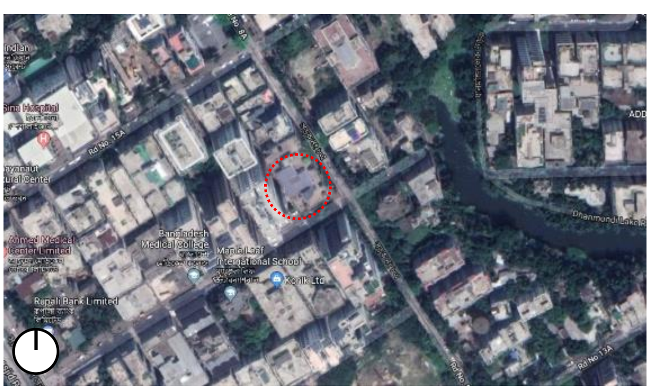

Figure 4: a. Location of the building in google map

Figure 4: b. Building

Figure 5: Plan of the building part covered with green wall

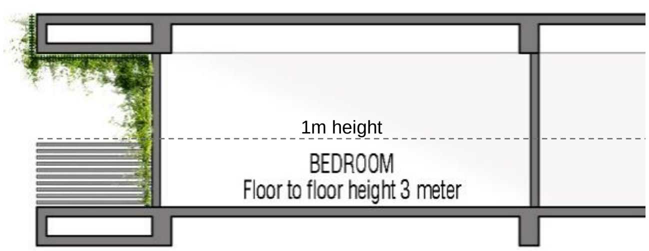

Figure 6: Section of the room with green wall

At this residence the air temperatures are taken on second floor on the south east corner by the meter for indoor spaces. Figure 4 is presented to show that the second-floor data has been collected in the corner room where the green wall has covered the bedroom part. Indoor air temperatures are collected from 1m above the floor level (Figure 6). It was observed that the relative humidity (75-77%) was constant in the data collection time. The green wall-Y and Bare wall-X are marked in the plan Figure 5. To understand the points of temperature count. Maximum indoor temperature on this floor is found 33.30°C on bare fasade and 32.80°C at 2 p.m. on green covered space (Table 1). On the other hand, the Minimum indoor temperature on this floor is found 32.50°C on bare fasade and 32.10°C at 4 p.m. on green covered space (Table 1).

Type of walls	Time 12 p.m.	Time 2 p.m.	Time 4 p.m.
Bare façade(X) Indoor average Temperature (°C)	33.1	33.3	32.5
Green façade(Y) Indoor average Temperature (°C)	32.2	32.8	32.1

Table 1: Measured data from field survey: average hourly indoor temperature in Bare wall and Green wall

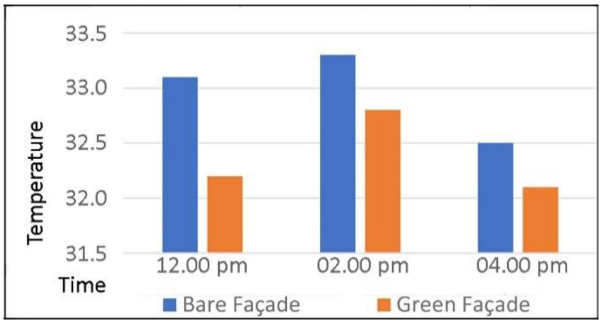

Figure 7: Measured data from field survey: average hourly indoor temperature in Bare wall and Green wall

*The Green Façade is built naturally with ceramic brick wall. The green wall is mainly covered with Climbing Fig or Creeping Fig, **Ficus pumila**: "Tropical Ivy" (Figure 7). **Ficus pumila** (creeping fig or climbing fig) is a species of flowering plant in the mulberry family, native to East Asia (China, Japan, Vietnam) and naturalized in parts of the south eastern and south-central United States. It is also found in cultivation as a houseplant. The etymology of the species name corresponds to the Latin word **pumilus** meaning dwarf, and refers to the very small leaves of the plant. This plant helps to reduce the air temperature and create thermal comfort inside the residence.*

Figure 8: The climbing fig or creeping fig on the wall surface

5.2 Case Study 2

- *Orientation: North corner Facade*
- *Plant type: Climbing Bougainvillea*
- *Plant condition: Well grown, not completely covered façade (covering thickness 5 cm)*
- *Plant age: Between 4 and 5 years old*
- *Supporting material: Green facade consists of a cable system made from jute rope.*
- *Air cavity between façade and leaves:25.4 cm*
- *Building material façade: Masonry (clay bricks)*
- *Location: Dense urban area (Dhanmondi residential area)*
- *Roof height: 21m*

Figure 9: a. Location of the building in google map

Figure 9: b. Building

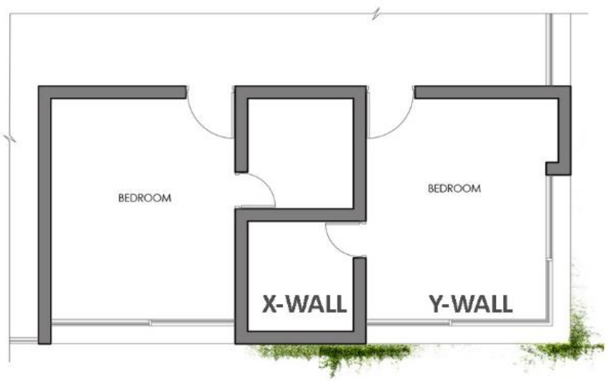

Figure10: Plan of the building part covered with green wall

Figure11: Section of the bedroom space of Temperature count

*At this case residence the air temperatures are taken on Second floor on the north west corner fa*з*ade by the hygro-meter for indoor spaces. Figure 9 is here to present that the data has been collected in the corner room where the green wall has covered the bedroom part and the bedroom beside it which is almost in the north west part of the building. Indoor air temperatures were collected from 1m above the floor level (Figure 10). It was observed that the relative humidity (79%) was constant in the data collection time. The green wall-Y and Bare wall-X are marked in the plan Figure 9. To understand the points of temperature count. Maximum indoor temperature on this floor is found 33.10°C on bare fa*з*ade-X and 32.70°C on green covered space-Y (Table 2) at 2 p.m. On the other hand, the Minimum indoor temperature on this floor is found 32.60°C on bare fa*з*ade and 32.10°C at 4 p.m. on green covered space (Table 2).*

Type of walls	Time 12 p.m.	Time 2 p.m.	Time 4 p.m.
Bare Façade(X) Indoor average Temperature (°C)	32.1	33.1	32.6
Green Façade(Y) Indoor average Temperature (°C)	31.5	32.7	32.1

Table 2: Measured data from field survey: average hourly indoor temperature in Bare wall and Green wall

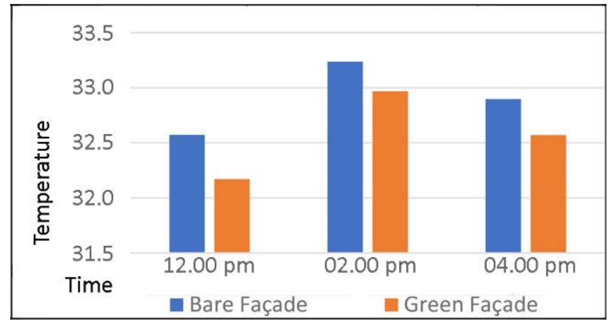

Figure 12: Measured data from field survey: average hourly indoor temperature in Bare wall and Green wall

Bougainvillea is the plant which has grown over the brick wall in this building. Bougainvillea is a genus of thorny ornamental vines, bushes, and trees with flower-like spring leaves near its flowers. Different authors accept between four and 18 species in the genus. The vine species grow anywhere from 1 to 12 m (3 to 40 ft.) tall, scrambling over other plants with their spiky thorns. The thorns are tipped with a black, waxy substance. They are evergreen where rainfall occurs all year, or deciduous if there is a dry season. This tree is growing very fast in this building. The air cavity is created here because of the in between gap of the wall surface and plants. The temperature creates a little variation for the presence of the plant in the wall surface.

5.3 Case Study 3:

- Orientation: North Facade
- Plant type: Climbing Golden Queen
- Plant condition : Well grown, not completely covered façade
- Plant age: Between 2 and 3 years' old
- Supporting material: Green facade on the wall surface
- Air cavity between façade and leaves: 5cm
- Building material façade : Masonry (clay bricks)
- Location: Dense urban area (Banani residential area)
- Roof height: 13m

Figure 13: a. Location of the building in google map

Figure13: b. Building

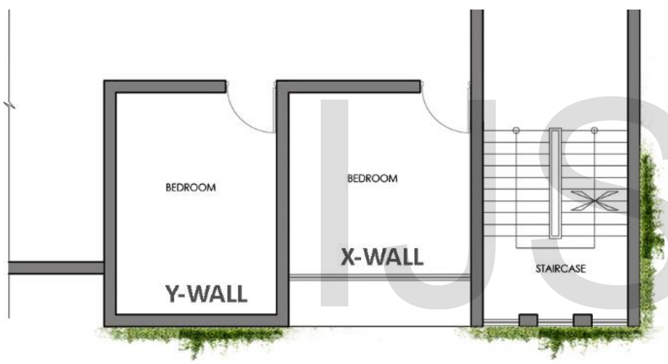

Figure 14: The temperature is taken in the green façade-X wall and Bare Façade-Y wall

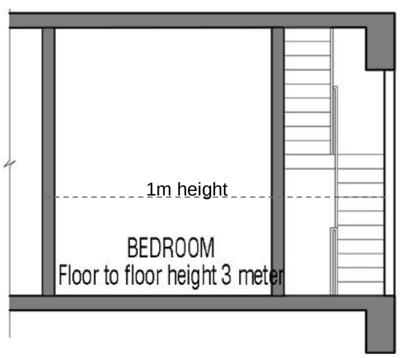

Figure 15: Section of the bedroom space of Temperature count

At this case residence the air temperatures are taken on first floor on the north west corner fasade by the hygro-meter for indoor spaces. Figure 13 is here to present that the data has been collected in the corner room where the green wall has covered the bedroom part and the bedroom beside it which is almost in the north part of the building. Indoor air temperatures were collected from 1m above the floor level (Figure 15). It was observed that the relative humidity (76%) was constant in the data collection time. The green wall-Y and Bare wall-X are marked in the plan Figure 14. To understand the points of temperature count. Maximum indoor temperature on this floor is found 32.40°C on bare fasade-X and 31.50°C on green covered space-Y (Table 3) at 2 p.m. On the other hand, the Minimum indoor temperature on this floor is found 29.50°C on bare fasade and 29.70°C at 4 p.m. on green covered space (Table 3).

Type of walls	Time 12 p.m.	Time 2 p.m.	Time p.m.
Bare Façade(X) Indoor average Temperature (°C)	30.5	32.4	29.5
Green Façade(Y) Indoor average Temperature (°C)	29.8	31.5	29.7

Table 3: Temperature shown in Bare wall and Green wall

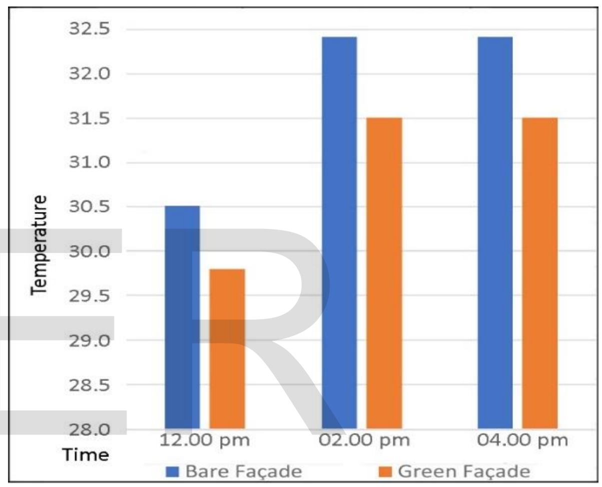

Figure 16: Measured data from field survey: average hourly indoor temperature in Bare wall and Green wall

Figure 17: ***Epipremnum aureum***

Epipremnum aureum is a species of flowering plant in the family of Araceae, native in Mo'orea, French Polynesia. This plant is in this case study building's north wall. The species is a popular houseplant in temperate regions, but has also become naturalised in tropical and sub-tropical forests worldwide, *Including northern Australia, Southeast Asia, South Asia, the Pacific Islands and the West Indies, where it has caused severe ecological damage in some cases. The plant has a multitude of common names including golden pothos, hunter's robe, ivy arum, money plant, silver vine, Solomon Islands ivy and taro vine. It is commonly known as money plant in many parts of the Indian subcontinent.*

6 Comparative Analysis of the Temperature Data

Tables (1,2 and 3) are showing the changes of temperature of indoor spaces in both the condition of outer Bare surface and outer green surface for the summer period in the three cases. As there were variations in the temperatures of the different time of the survey day, exact temperature values were not used for the analysis. In this condition, the differences between the bare fa3ade temperature and green wall surface temperature in residential units were observed.

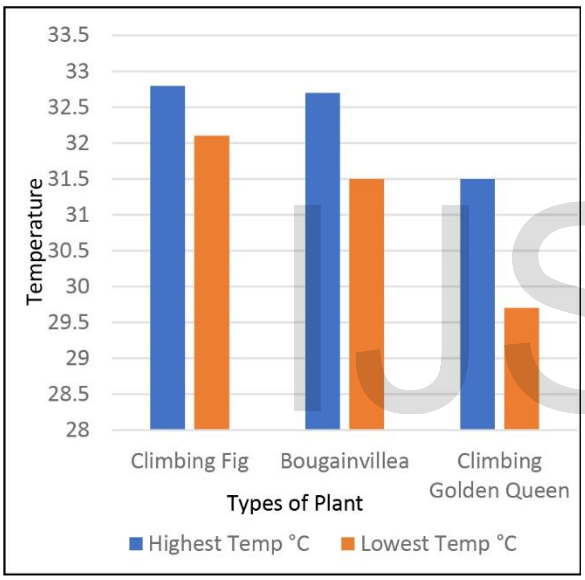

Figure 18: Comparison of the measured data collected from three case study with different types of plants

The comparison in between the charts clearly show that the north fa3ade green wall contains lower temperature then other surfaces. But if we focus on the south wall, it's clear that the temperature is lower in the green fa3ade wall. Also, the climbing fig lessens the temperature with the depth of wall thickness almost 1′-6". The second case study has bougainvillea which had air cavity in between wall and green surface. The wind velocity may vary in this point. The temperature variation is not much in this case. The third case study is done on the north fa3ade of the wall where the temperature difference is also noticeable. This type of plant can also be a good option for green fa3ade.

Undoubtedly, the most significant result comes out from the first case study which was conducted on the south fa3ade of the building. Also, the climbing fig is more effective than other two plants. The temperature variation shows that the climbing fig is more effective of building fa3ade which keeps the indoor air temperature low. If the survey will be done in detail it can be an intense research topic to be solved. The other two green fa3ade contain air cavity. If the air velocity is measured in detail then it will be clearer in further research.

7 Simulation Studies

A simulation study was undertaken to assess the effects of vegetated walls on the thermal performance of a building. A thermal model of climbing plants was formulated using AUTODESK ECOTECT environmental simulation software and was validated against the data obtained by field measurements. The simulation model is based on the average weather data for Dhaka over the last 10 years, collected from Bangladesh Meteorological Department. The computational simulation control factors include the solar azimuth, the building location & distribution of solar irradiation for the subjected building with green fa3ade treatment on south side. This model was applied to a further simulation study and the results showed that plant cover improved indoor thermal comfort in both summer and winter, and reduced heat gains and losses through the wall structure.

For the simulation here the first case study building is selected. Green facade is like a shading device. The panel of Visible Transmittance same as green fa3ade is applied here for the simulation purpose. Using some kind of Ivy and would have the same transparency all year long. In this simulation process the transmittance of 20% is used as the green fa3ade by creating a layer in distance of 30mm from the main model marked in figure 10_image 02. One thing it will not account though, is the potential cooling effect that plants can have on their micro-environment due to higher levels of humidity.

Figure 19: Image 01_ Case Building selected for simulation without any green façade Image

Figure 19: Image 02_ Case Building selected for simulation assumed with green façade on south wall of the building

8 Result and Analysis

From the simulation data, it is observed that wall surface installed green decreases the indoor temperature of most floor in a large amount.

In case of Bare fasade, the temperature in 2nd and 6th floors are shown in the table 4 on 27th august day time of the summer period. The temperature is taken in different hours of the day. The highest temperature is 33.9°C and 34.5°C respectively on 2nd floor and 6th floor at 3 p.m. The lowest temperature is measured at 9 a.m. which is 30.5°C and 31.2°C respectively on 2nd floor and 6th floor.

Time	Indoor Average Temperature (°C) on Bare Façade at 2nd floor	Indoor Average Temperature (°C) on Bare Façade at 6th floor
9 a.m.	30.5	31.2
12 p.m.	32.2	32.9
3 p.m.	33.9	34.5
5 p.m.	30.6	31.3

Table 4: Simulation Result in Bare Façade on 2nd floor and 6th floor

In case of Green fasade, the temperature in 2nd and 6th floors are shown in the table 5 on 27th august day time of the summer period. The temperature is taken in different hours of the day. The highest temperature is 32.3°C and 33.1°C respectively on 2nd floor and 6th floor at 3 p.m. The lowest temperature is measured at 5 p.m. which is 29.5°C and 30.1°C respectively on 2nd floor and 6th floor.

Time	Indoor Average Temperature (°C) on Green Façade at 2nd floor	Indoor Average Temperature (°C) on Green Façade at 6th floor
9 a.m.	29.8	31.0
12 p.m.	31.5	32.2
3 p.m.	31.9	33.1
5 p.m.	29.5	30.1

Table 4: Simulation Result in Green Façade on 2nd floor and 6th floor

Maximum average indoor temperature is found highest at 3 pm, which is 33.90°C in bare facade. Maximum average indoor temperature is found highest at 3 pm, which is 31.80°C in green covered fasade on 2nd floor. Maximum average indoor temperature is found highest at 3 pm, which is 33.10°C in green covered fasade on 6th floor. Here average temperature difference in hourly temperature profile is found 1.20°C in the presence of green fasade. So undoubtedly, it's clear that the temperature difference in 2nd floor is greater than the 6th floor temperature.

The comparison of the simulation results of 2nd floor and 6th floor is shown in figure 20 and figure 21 respectively.

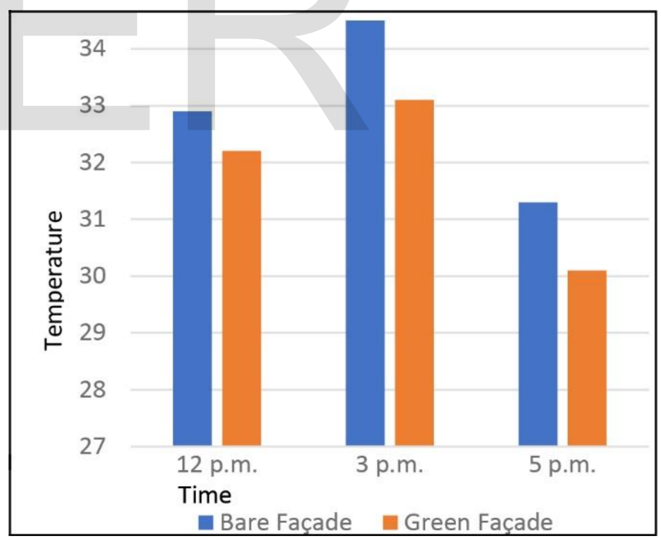

Figure 20: Comparison of the Simulation results shown in Bare wall and Green wall on 2nd floor

The comparison (Figure 22) of the temperature of indoor space of this simulation with green fasade and without green fasade clearly state that, on the second floor the temperature difference is noticeable than the 6th floor. As the roof temperature is another fact for this in the 6th floor. Significantly, using the green surface on the outer wall in the context of Bangladesh the indoor temperature can be reduced.

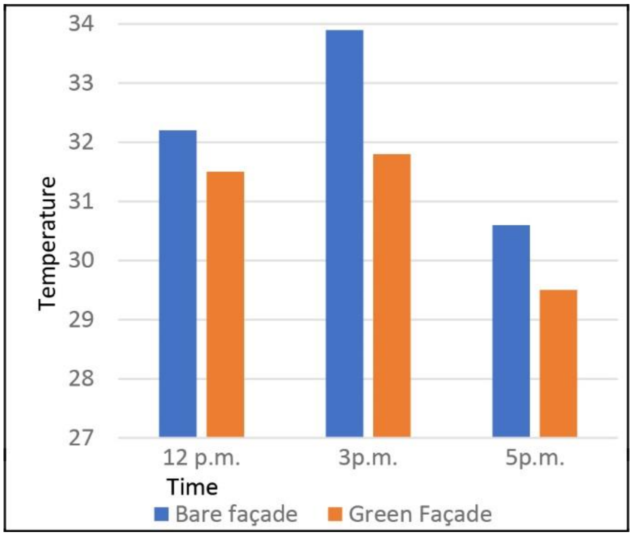

Figure 21: Comparison of the Simulation results shown in Bare wall and Green wall on 6th floor

Floor	With or Without Green surface	Highest indoor Temperature (°c)
2nd Floor	With Green Surface	31.9
2nd Floor	Without Green Surface	33.9
6th Floor	With Green Surface	33.1
6th Floor	Without Green Surface	34.5

Table 5: Highest indoor temperature on 27th august for 2nd floor and 6th floor of this residence with and without green surface on outer wall

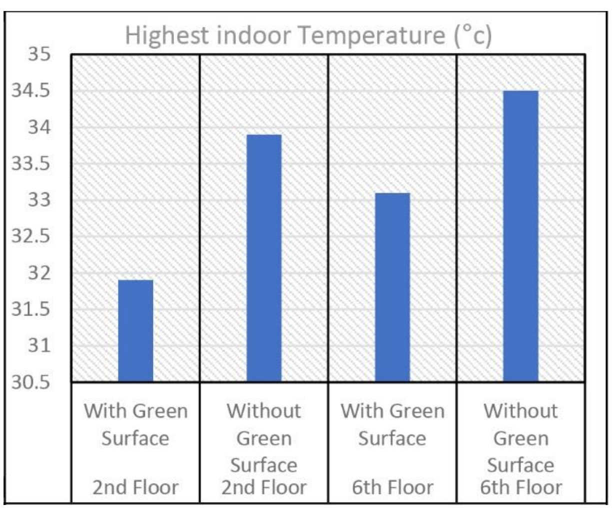

Figure 22: Highest indoor temperature on 27th august for 2nd floor and 6th floor of this residence with and without green surface on outer wall

12 Discussion

According to the ASHRAE standard, the air temperature of 300 Celsius is considered normal for this climate and the air movement of more than 1 m/s is desirable to relieve the heat. From the field survey and simulation analysis we have got a clear output that the outer wall covered with green or vertical vegetation can reduce the indoor temperature of a residential building and increase comfort for the users.

From the table 6 it is noticeable that the temperature in the 2nd floor reduces up to 20C and on the top floor it can reduce up to 1.40C, which is very much effective in the summer period and also winter period in the tropical context of Bangladesh.

10 Conclusions

Green envelope model was integrated in the transient building simulation program ECOTECT. The model, already validated alone with experimental data, is coupled to a building model. The coupled model developed here gives good agreement with summer conditions' experimental data. The thermal dynamic simulation study done for various conditions, with the proposed model, highlights the significant impacts on temperature reduction, especially in tropical climate. The green walls decrease the surface heat transfer from indoor to outdoor and the fa3ade surface temperature. As a result, the green walls will contribute, also, to the urban microclimate mitigation. In addition, real meteorological data should be used to be able to make absolute comparisons. This work is ongoing, and a specific model of urban canyon is under development so as to use realistic microclimatic data.

In the study process the indoor air temperature is measured to compare in which condition the comfort can be achieved. According to the standard the tolerable temperature is 30oC for tropical climate. After the survey and simulation, it can be ensured that green surface can reduce the indoor temperature of residence buildings in Dhaka city. Though further details research is needed to justify this topic more and use it for design process in the residential and commercial buildings as well. This vertical greening system of green surfaces can contribute to reduce temperature in the urban level of Dhaka city now a days.

11 Dedication

I dedicate this research work to my family and friends who always inspire me most. A special gratitude to my parents who have never left my side and always give support and encouragement.

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