# ENERGY PERFORMANCE EVALUATION OF GREEN FACADES IN HIGH-RISE BUILDINGS

P. Bano[1] and S. Dervishi[1]
[1]Department of Architecture, Epoka University,
Rruga Tiranë-Rinas, Km 12, 1039, Tirana/Albania
E-mail: pbano15@epoka.edu.al, sdervishi@epoka.edu.al

## ABSTRACT

Nowadays, green facades have come as a solution providing environmental and socio-economic benefits integrated with high-rise buildings. These facade systems have started to be implemented in the Albanian Mediterranean climate as innovative design strategies. However, a literature gap regarding their quantitative effects on building energy performance exists. Therefore, the present study aims to evaluate the potential of green facade design strategies on thermal and energy performance. For the research purpose, a hypothetical high-rise office building was chosen and several scenarios of green facade strategies have been simulated. The performed simulation results generate a basic framework towards early design decision-making stages.

## INTRODUCTION

At present, in the conditions of intensive urbanization, livability in the dense urban areas has become a focal point of concern. The increase in population has promoted the high-rise building models as an alternative to possibly increase the city-space vertically (Saroglou et al., 2017). Many high-rise buildings have taken advantage of glass transparency in their design to create a clear view to the outside (Pino et al., 2011). However, using a high window-to-wall ratio (ratio of the glazed area concerning the total area of the exposed envelope), does not present a sustainable solution since the extensive use of glass cover materials can cause overheating and increase use of energy is required to ensure indoor thermal comfort. Moreover, a large amount of energy is used for air-conditioning systems and lack of insulation causes heat loss problems (Saroglou et al., 2017). With the rapid economic growth, there has been a growing concern about the energy consumption in buildings, commercial developments office buildings especially, where space cooling and heating are needed throughout the year to maintain the desired thermal comfort levels and indoor air quality for the occupants. As a consequence, considering the economic and environmental benefits that can be ensured, it is essential to find new design strategies that may contribute to the improvement of the building energy performance. To positively contribute to the urban fabric, the design process of the abovementioned building typology requires further research and experimentation, especially the envelope design as the main interface between the indoor and outdoor environment (Saroglou et al., 2017).

In addition, a considerable wall-to-roof ratio is provided by the high-rise typology, offering a large surface area as a valuable potential for greening (Cheng et al., 2010), increasing their efficiency when compared with green roof systems. Furthermore, they act as a barrier that protects the building from radiation and heat penetration (Papadopoulos et al., 2013).

The present research is conducted in the context of Tirana, Albania. As a developing city, Tirana has been involved in a rapid urbanization process. The city has already grown upwards as a response to the increase in population's density and it is expected to have a significant increase in high-rise building construction in the coming years. Reforestation within the city has started to be promoted as a sustainable solution in the conditions of limited land. In the local context, there have been a lot of vertical greenery systems proposed to be implemented in newly constructed high-rise building models. However, there is a literature gap regarding their quantitative effects on building energy performance. Therefore, the developed study aims to evaluate the potential of different green facade designs on thermal performance and energy savings.

## LITERATURE REVIEW

### Green facade typologies

Several authors have provided classifications of green facade systems to better understand and compare their behavior. Perez et.al (2015) classified green facades into traditional, where plants use the facade material as support, double-skin green facade/curtain; using support systems, and perimeter flowerpots; hanging pots planted around building perimeter. Wong et al. (2009) mentioned that the double-skin green facade is suitable for high-rise buildings as the double skin framework can be constructed in modular panels which can easily integrate into the façade design.

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### Impact on building systems and energy efficiency

Vegetation can play an important role in regulating the microclimate of the building (Wong et al., 2009). Several studies on the use of plants for solar control prove their potential in controlling solar radiation, reducing cooling load and improving the indoor and outdoor thermal environment. Some previous studies developed by authors such as; Stec et al. (2005) and Larsen et al. (2013) proved that using plants instead of blinds offers better results in terms of shading performance. In addition, the plant's surface temperature never exceeds 35 °C, while in blinds it can exceed 55 °C. Stec et al. (2005) proved that the temperature increase of blinds is about two times higher than leaves for the same solar radiation. Furthermore, Larsen et al. (2014) mentioned that using plants as shading devices is better than using conventional devices because the plants transform the absorbed solar radiation into sensible and latent heat, while a normal shading device transforms the absorbed solar radiation into sensible heat only, that is why temperature increases more when compared with plants.

The cooling effect is another benefit that vegetation systems offer to the building envelope due to the evapotranspiration process. The physical process requires energy and depends on the plant type and exposure according to Perez et al. (2015).

### Previous simulation analysis

To develop a better predictive framework for green facade’s thermal performance, the scientific literature has been reviewed and it was concluded that whereas previous research studies have contributed into creating a rich theoretical background on several aspects of green facades, there is a lack of quantitative analyses including simulation studies providing a close examination of green facade’s thermal performance and energy consumption evaluation. Based on the current review it is found that only three of the greenery system simulation studies (Wong et al., 2009; Larsen et al., 2014; Stec et al., 2005) analyzed the impact of green facades on the thermal performance of the building taking into consideration output results that quantify greenery system’s impact on the glazing material parameters rather than opaque walls and most of them use simplified simulation models. Furthermore, no evaluation or simulation study has been previously developed regarding different green facade typologies even though they have already been implemented in buildings worldwide.

Wong et al. (2009) represented the only simulation study that evaluates the thermal impact of greenery systems on the energy performance of a building when the building is fully glazed. The results proved the vertical greenery effectiveness in lowering the mean radiant temperature of a building if the glass facade was fully covered, from 49.94 °C to 45.81 °C max radiant temperature with a 12.45% in energy reduction.

Larsen et al. (2014) made a brief description of heat transfer mechanisms in a green system, proposed and analyzed two alternative simplified models (BS and WSD) for simulating a double skin facade with plants. According to Larsen et al. (2014) WSD (Window shading Device) model offers a more realistic calculation of heat transfer since in this case, plant emissivity is calculated by the user and plant temperature is variable and calculated by the code. Therefore, it is recommended by the author to be used as a simulation model for a green facade, serving as an initiator for future related studies.

Stec et al. (2005) developed building simulations to analyze the thermal performance of the building with plants in the double-skin facade. Results show that the temperature of the inner glass surface of the window is lower for the double skin facade with plants when compared to the incorporation of blinds. Simulations showed that the capacity is reduced by about 18% and energy consumption for cooling is lowered by about 19%.

## METHODOLOGY

### Description of the studied building

For the research purpose, a hypothetical 20 stories high-rise office building, measuring 30 m in length by 30 m in width and 3.5 m floor-to-floor height was developed, with a total floor area of 18 000 m$^2$ as shown in Figure 1. The structure of the reference model is reinforced concrete as one of the most common construction methods in Albania. Moreover, U-values of the construction materials used in the simulation are 0.43 W/m$^2$.K for the insulated roof and 1.95 W/m$^2$.K for the internal floors. Table 1 illustrates the glazing properties for all the simulated scenarios. For the simulation purpose, double clear glazing 6mm/13mm air, Saint-Gobain Glass SGG PLANILUX 6mm (commonly used in Albania for fully glazed facades), has been chosen. Further specifications include an aluminum frame with thermal break, resulting in a solar heat gain coefficient (SHGC) of 0.75, U-value of 2.683 W/m².K and 40% glazing area opening. The infiltration rate is 0.5 ACH.

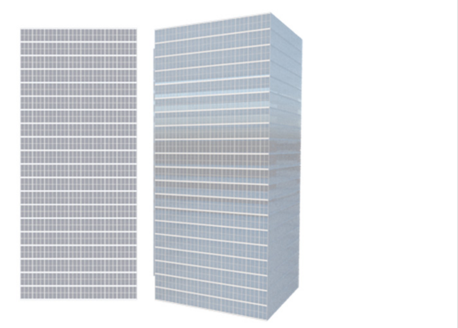

*Figure 1: Base case scenario*

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*Table 1:*
*Glazing properties*

| GLAZING PROPERTIES | |
|---|---|
| Glazing type | Double clear 6mm/13mm air Saint - Gobain SGG Planilux 6mm. |
| Frame properties | Aluminum window frame with thermal break |
| SHGC (Total solar transmission) | 0.75 |
| U-value [W/m$^2$.K] | 2.68 |
| Opening position | Top |
| % glazing area opens | 40 |
| Airtightness [ac/h] | 0.5 |

### Climate characterization

The building is assumed to be located in the urban context, in Tirana, Albania. Tirana is located at 41.33° latitude north and 19.82 ° longitude east and around 100 m above sea level, being at the Mediterranean climatic zone. The average annual temperature is 16.2 °C. Due to geographical position, the mean annual temperatures in Tirana typically oscillate between 7.5 °C in January to 25.6 °C in July. Figure 2 illustrates in a more specified way daily temperature variations of the city. Tirana receives average solar radiation of 1586 KWh/m$^2$ yearly (611 KWh/m$^2$ diffused radiation). In terms of the precipitation amount, the city receives the majority of precipitation from November to March and the least amount from June to September. The weather file was downloaded from METEONORM v.7.3 (2016) providing hourly weather observations in the weather format (.epw).

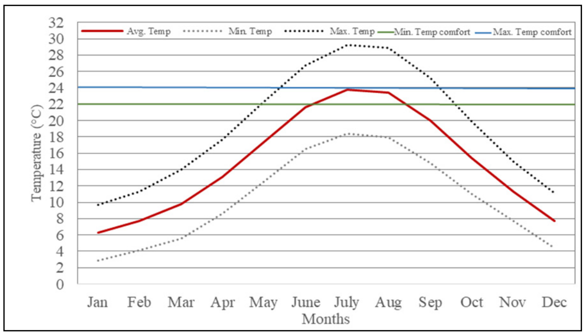

*Figure 2: Annual temperatures for the city of Tirana,*
*Source: Meteonorm software v.7.3*

### Simulation parameters

As an important part of the model development, the input parameters for the energy simulation process were chosen based on an in-depth evaluation of the relevance of input parameters mentioned or applied in previous research studies. DesignBuilder software (2019) was selected to perform the simulations. The parameters under evaluation consist of indoor air temperature hourly calculated during summer typical week, exterior and interior surface temperature for the south-oriented facade, calculated for a reference day in summer (25th June). The study analyses and evaluates the monthly energy cooling and heating load for the entire building. The building is simulated under air-conditioned conditions according to specified schedules for heating and cooling set points specifically in relation to current heating or cooling seasons and working schedule occupancy Monday to Friday, 8:30 to 17:30, based on observational data. For obtaining more realistic results, internal gains such as people, lighting, computer equipment are included in the simulation

Furthermore, a passive based scenario (no internal heat sources) is applied to evaluate the indoor air temperature, radiant temperature, interior, and exterior surface temperature to purely determine the effects of vertical greenery systems.

Table 2 represents a summary of the simulated input parameters used. Ventilation schedules have been assumed in accordance with HVAC operation and local climate conditions. Its frequency has been increased when no internal heat sources are applied in order to avoid the greenhouse effect. All the conditioned zones in the building have set points 22 °C for heating and set back 18 °C. The cooling set point temperature is 24 °C during the day and this was set back to 28°C. Natural ventilation set point temperature was set 15 °C. Night ventilation is used in the simulated buildings as a strategy towards decreasing cooling energy demand strategy (Pino et al., 2012). Furthermore, the use of night ventilation is estimated as appropriate for buildings without night occupation, like offices buildings, and for high- temperature changes during cooling periods of the year. For the study purpose, night ventilation by windows is assumed.

*Table 2:*
*Summary of the input parameters used in the simulation*

| INPUT PARAMETERS | |
|---|---|
| Total floor area [m$^2$] | 18000 |
| Occupancy density [P/m$^2$] | 0.11 |
| Latent fraction | 0.5 |
| Workday profile [h] | (8:30- 17:30) Mon-Fri |
| Fan coil unit | (4 pipe) water-cooled chiller, waterside economizer |
| Heating system seasonal [CoP] | 0.83 |
| Cooling system seasonal [CoP] | 1.67 |

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*Figure 3: Simulated scenarios for different green facade design strategies; $S_1B$, $S_1C$, $S_1D$, $S_1E$*

$S_1A$ represents the base-case scenario as illustrated in Figure 1, with a bare facade without greenery system, with the glazing properties as specified in Table 1.

$S_1B$ up to $S_1E$ represent different design strategies/alternatives, conceptualized as improvement scenarios/upgrading the base case $S_1A$.

$S_1B$ involves the incorporation of the greenery system in building facades, using meshes as support systems, positioned in all four orientations.

$S_1C$ involves the incorporation of the greenery system in building facades, using external louvers as support systems, positioned in all four orientations (deciduous plants, LAI 3 and 0.1m plant height).

$S_1D$ involves the incorporation of the greenery system in building facades, using planting pots that serve as overhangs modeled as shading elements, 1.5 m in width, positioned in all four orientations. (0.1 m plant height, LAI 3)

$S_1E$ involves the incorporation of planting pots 1.5m for large plants around 2 m in height, LAI 3, in balconies 3 m in width, positioned in all four orientations.

The parameters used for simulating greenery systems in scenario $S_1B$ are based on Larsen et al. (2014) research on thermal simulations of double skin facades with plants (Window Shading model considered) as illustrated in Table 3. While for developing scenarios $S_1C$, $S_1D$, $S_1E$ simplified 3d model and local shading option is used and with the greenery parameters based on Stav et al. (2012) studies as shown in Table 4. To evaluate the thermal and energy performance of the greenery systems, a base case scenario as shown in Figure 1 and a set of four scenarios with greenery applied were established as shown in Figure 3.

*Table 3:*
*Set up properties* based on Larsen et al. (2014)

| **INPUT PARAMETERS** | |
|---|---|
| Solar transmittance | 0.2 |
| Solar reflectance | 0.3 |
| Visible transmittance | 0.06 |
| Visible reflectance | 0.09 |
| Thermal emissivity | 0.95 |
| Thermal transmittance | 0 |
| Thickness [m] | 0.001 |
| Conductivity [W/m.K] | 0.59 |
| Shade to glass distance [m] | 0.3 |
| Top opening multiplier | 1 |
| Bottom opening multiplier | 1 |
| Left-side opening multiplier | 1 |
| Right-side opening multiplier | 1 |
| Airflow permeability | 0 |

*Table 4:*
*Vertical greenery system parameters for energy simulation processing*

| **INPUT PARAMETERS** | |
|---|---|
| Height of plants [m] | 0.1 |
| Leaf area index | 3 |
| Leaf reflectivity | 0.25 |
| Leaf emissivity | 0.98 |
| Minimum stomatal resistance [s/m] | 180 |
| Roughness | Medium smooth |
| Thickness [m] | 0.08 |
| Conductivity of dry soil [W/m.K] | 0.4 |
| Density of dry soil [kg/m$^3$] | 641 |
| Specific heat of dry soil [J/kg.K] | 1100 |
| Thermal absorptance | 0.95 |
| Solar absorptance (soil) | 0.8 |
| Visible absorptance | 0.7 |
| Saturation volumetric moisture content of the soil layer | 0.4 |
| Residual volumetric moisture content of the soil layer | 0.01 |
| Initial volumetric moisture content of the soil layer | 0.2 |
| Moisture diffusion calculation method | Simple |
| Irrigation type | Smart |
| Irrigation rate [m/h] | 0.003 |
| Irrigation schedule | 7:00-9:00 AM everyday |

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## SIMULATION RESULTS

Figures 4-10 below represent all the simulation results for all the parameters under evaluation, analyzing energy and thermal performance of all the chosen scenarios; for the base case scenario with the bare facade $S_1A$ and all scenarios $S_1B$, $S_1C$, $S_1D$, and $S_1E$ when the green facade is applied. Specifically, Figures 4-6 illustrate the comparison of simulated energy cooling, heating and total energy demand (kWh.m$^2$Y$^{-1}$) of the simulated scenarios. Figures 7-10 illustrate the thermal performance of all the simulated scenarios.

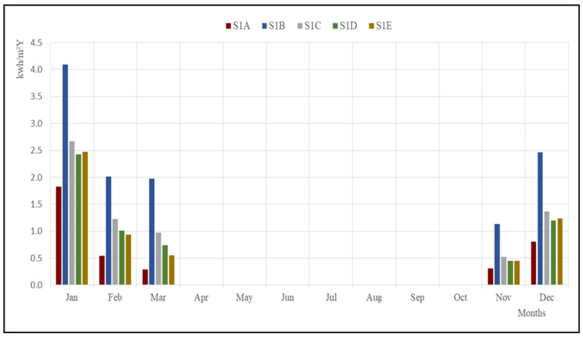

*Figure 4: Comparison of simulated energy heating demand (kWh.m$^2$Y$^{-1}$) of the simulated scenarios*

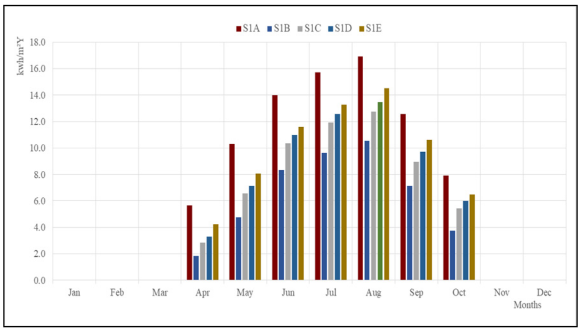

*Figure 5: Comparison of simulated energy cooling demand (kWh.m$^2$Y$^{-1}$) of the simulated scenarios*

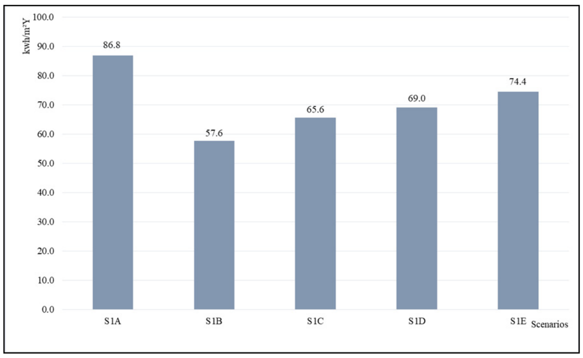

*Figure 6: Comparison of simulated total yearly energy demand (kWh.m$^2$Y$^{-1}$) of the simulated scenarios*

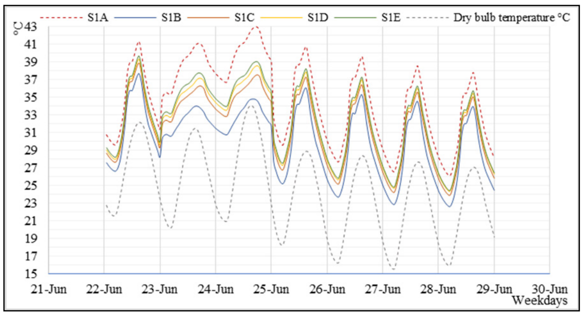

*Figure 7: Simulated indoor air temperature and dry-bulb temperature from the weather file, for the summer typical week (22 June-29 June)*

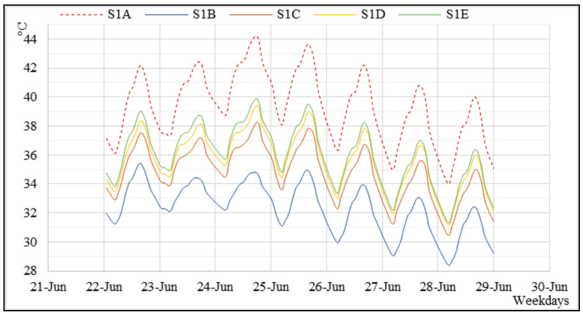

*Figure 8: Simulated radiant temperature, for the summer typical week (22 June-29 June)*

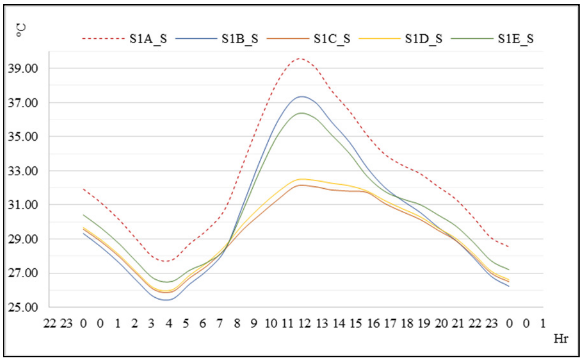

*Figure 9: Simulated exterior glass surface temperature for the south-oriented facade, in a typical summer day, 25 June*

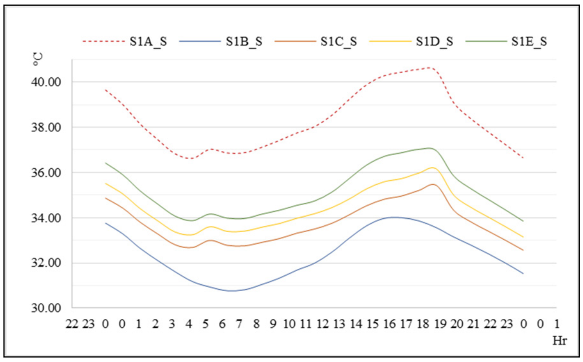

*Figure 10: Simulated interior glass surface temperature for the south-oriented facade, in a typical summer day, 25 June*

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## DISCUSSION

### Heating and cooling loads

As illustrated in Figure 4, one major observation is that incorporating plants in the building envelope significantly increases heating demand when compared with the base case scenario (without greenery). The highest heating demand increase is observed in January, the coldest month from 1.8 kWh.m$^2$Y$^{-1}$ in $S_1A$ scenario to 4.1 kWh.m$^2$Y$^{-1}$, in $S_1B$ scenario. Moreover, the annual energy heating load is more than twice higher (increased by 210.7%) in the second scenario, when applying greenery using mesh support systems. It is followed by $S_1C$ scenario with a 79.8% increase, $S_1D$ with a 55.1% increase and $S_1E$ with a 49.8% increase.

Referring to Figure 5, comparing the five scenarios we understand that greenery systems represent an effective strategy towards significantly reducing cooling demand. The highest reduction is observed in August, the hottest month, from 16.9 kWh.m$^2$Y$^{-1}$in $S_1A$ scenario to 10.5 kWh.m$^2$Y$^{-1}$ in $S_1B$ scenario. Simulations showed that the capacity of the cooling system and yearly energy consumption is reduced for the building with plants in the double-skin facade. Table 5 shows a comparison of the greenery effectiveness of the simulated scenarios. The highest greenery effectiveness is achieved in $S_1B$ scenario with the addition of greenery systems in building facades, using meshes as support systems. The annual energy consumption for cooling is reduced by 44.7% in the S1B scenario. It is followed by $S_1C$ scenario with a 29.1% reduction and $S_1D$ with a 23.9% reduction. The lowest greenery effectiveness is reached in $S_1E$ scenario when incorporating planting about 2 m in height, in balconies 3 m in depth. Cooling energy consumption is lowered by 17.1% in the $S_1E$ scenario. As illustrated in Figure 6 and Table 5, $S_1B$ is the most efficient scenario with 57.6 kWh.m$^2$Y$^{-1}$ total energy consumed and 33.6% greenery effectiveness, followed by $S_1C$ with 65.6 kWh.m$^2$Y$^{-1}$ total energy consumed and 24.4% effectiveness and $S_1D$ scenario with 69 kWh.m$^2$Y$^{-1}$ total energy consumed and 20.5% effectiveness. While $S_1E$ resulted the least efficient scenario with 74.4 kWh.m$^2$Y$^{-1}$ total energy consumed and 14.2% greenery effectiveness.

*Table 5:*

*Annual simulation results obtained for all the scenarios with greenery system applied*

| **Scenarios** | **Heating reduction [%]** | **Cooling reduction [%]** | **Total energy reduction [%]** |
|---|---|---|---|
| **$S_1B$** | -210.7 | 44.7 | 33.6 |
| **$S_1C$** | -79.8 | 29.1 | 24.4 |
| **$S_1D$** | -55.1 | 23.9 | 20.5 |
| **$S_1E$** | -49.8 | 17.1 | 14.2 |

Simulation results suggest using deciduous plants for maximum efficiency in both winter and summer periods. They create the possibility of applying a self-adjustable shading system. During cold periods these plants will shed leaves. In the winter the solar radiation will go through the facade and will generate the heat to cover the heat losses. (Stec et al., 2005) In the summer, plants will serve as a barrier that prevents extensive solar radiation allowing just daylight entering the office space. (Stec et al., 2005)

### Air temperature

As shown in Figure 7, the air temperature results are lowered for the scenarios with plants when compared with the bare facade scenario. Scenario $S_1A$ shows that a full glass facade building may result in an uncomfortable and inhabitable environment, where air temperature reaches 43 ˚C on 24 June during summer typical week. The presence of greenery systems applied using mesh support systems is able to lower the air temperature values from 43 ˚C to 35 ˚C, resulting in an 8˚C temperature reduction. It is followed by $S_1C$ 37.4 ˚C, and $S_1D$ 38.4 ˚C. Also, the lowest temperature reduction is observed in $S_1E$ scenario from 43 ˚C to 39 ˚C, resulting in a 4 ˚C temperature reduction, when incorporating plants around 2 m in height, in balconies 3 m in depth.

### Radiant temperature

As illustrated in Figure 8, radiant temperature results are lowered for the scenarios with plants when compared with the bare facade scenario. The highest reduction is observed in $S_1B$. In scenario $S_1B$, the presence of greenery system helps in reducing the radiant temperature significantly, with a maximum of the radiant temperature of 35 ˚C compared to 44 ˚C from $S_1A$ scenario, on 24 June during summer typical week. Furthermore, as the envelope is mainly composed of double clear glass, solar radiation remains the main heat source, and shading is an important parameter to consider. The results are followed by $S_1C$ 38 °C and $S_1D$ 39.4 °C. Also, the lowest temperature reduction is observed in the $S_1E$ scenario from 43 °C to 40 °C, resulting in a 3 °C temperature reduction, when incorporating plants around 2 m in height, in balconies 3 m in depth

### Exterior and interior glass surface temperature

*Table 6:*

*Summary of the simulation results for the exterior and interior surface temperature calculated*

| **SOUTH ORIENTATION, PEAK HOUR: 12:00** | | | |
|---|---|---|---|
| | Exterior | Interior | ΔT |
| $S_1A$ | 39.12 | 38.52 | 0.6 |
| $S_1B$ | 37.07 | 32.48 | 4.59 |
| $S_1C$ | 32.07 | 33.75 | -1.68 |
| $S_1D$ | 32.45 | 34.45 | -2 |
| $S_1E$ | 36.13 | 35.13 | 1 |

Based on the hourly simulation results of the glass surface temperatures in a typical summer day 25 June, as shown in Figures 9-10, for the south-oriented facade, in all cases, the highest exterior surface temperature is reached during midday, when the incident solar radiation is maximum. $S_1C$ results the most efficient scenario where the surface temperature is 32.07 °C, or 7.05 °C lower when compared with the base case scenario with the bare window (39.12 °C). However, it is the second most efficient scenario when comparisons are made for the interior surface temperature, 33.75 °C or 4.77 °C lower than base case scenario 38.52 °C, with 1.68 °C temperature difference (exterior-interior).

The second most efficient scenario is $S_1D$ with the greenery systems applied in building facades, using planting pots 1.5 m that serve as overhangs for shading, where the surface temperature is 32.45 °C, or 6.67 °C lower when compared with the base case scenario. However, it is the third most efficient scenario when comparisons are made for the interior surface temperature, 34.45 °C or 4.07 °C lower than base case scenario 38.52 °C, with 2 °C temperature difference (exterior-interior).

The third most efficient scenario is $S_1E$ with the greenery systems applied in building facades using planting pots 1.5 m for large plants around 2 m in height, in balconies 3 m in-depth, where the surface temperature is 36.13 °C, or 2.99 °C lower when compared with the base case scenario. However, it is the least efficient scenario when comparisons are made for the interior surface temperature, 35.13 °C or 3.39 °C lower than base case scenario 38.52 °C, with only 1 °C temperature difference (exterior-interior) as shown in Table 6.

The least efficient scenario is $S_1B$, with the greenery systems applied in building facades using support systems (meshes), where the surface temperature is 37.07 °C, or 2.05 °C lower when compared with the base case scenario. However, it is the most efficient scenario when comparisons are made for the interior surface temperature, 32.48 °C or 6.04 °C lower than base case scenario 38.52 °C, with 4.59 °C temperature difference (exterior-interior) as shown in Table 6.

## CONCLUSION

Although green facades have already been integrated into building designs for aesthetic reasons, their application as a technology to regulate internal building temperatures is novel. The case study of green facades presents an invitation to initiate an analytical and quantitative approach on the green facade thermal and energy performance, hoping to be continued in the future. The present research aims to evaluate the potential of different green facade designs on thermal performance and energy savings.

Simulation results showed that incorporating plants in the building envelope significantly increases heating demand when compared with the scenario without greenery, while on the other hand it positively influences cooling loads. The results suggest using deciduous plants for maximum efficiency in both the winter and summer periods. The highest greenery effectiveness is achieved in $S_1B$ scenario with the addition of greenery systems in building facades, using meshes as support systems. The highest greenery effectiveness is achieved in $S_1B$ scenario, where the annual energy consumption for cooling is lowered by about 44.7% and 33.6% total energy consumption.

Also, results show that the presence of greenery systems applied using mesh support systems can lower the air temperature values from 43 °C to 35 °C, resulting in an 8 °C temperature reduction and also it helps in reducing the radiant temperature significantly, with a maximum of the radiant temperature of 35 °C compared to 44 °C in $S_1A$ scenario.

For the south-oriented facade, in all cases, the highest exterior surface temperature is reached during midday, when the incident solar radiation is in its maximum value. $S_1C$ is the most efficient scenario where the surface temperature is 32.07 °C, or 7.05 °C lower when compared with the base case scenario with the bare window where the temperature reaches 39.12 °C.

Simulated results highlight that there are promising thermal and energy benefits from green facade applications. To further establish the study results, experimental studies on actual building facades should be performed, so that simulation results can be discussed and compared for a better understanding. Therefore, several priority areas are suggested for future inquiry.

In the present research, as the results of the present study do not seek to design HVAC systems, tentative schedules for heating, cooling, natural ventilation, occupancy, and set-point parameters were designed by authors based on evaluating the current literature on this matter and by taking into consideration the local climate. Therefore, future work needs to be done specifically related to HVAC systems and schedule design, to make further comparisons between several studies.

Furthermore, much work is needed to enhance the understanding of the physiological and morphological traits of plants and to inform the selection of new species for green facades. Therefore, an effort should be done into establishing an interdisciplinary approach between architecture, engineering, plant biology, and horticulture, to avoid research design problems. Also, a few improvements and updates to the software should be performed to avoid limitations. Case $S_1B$ uses a simplified model (Window shading device object) based on parameters and available options offered by the simulation software as illustrated in Table 3. Unfortunately, there is no option for designing/ simulating the meshes as green facade support systems in DesignBuilder (software limitation).

All in all, although simulation and evaluation through software may face limitations due to the inability to make comparisons with real-life situations, the developed study represents an effective and well documented first step towards an analysis approach on the green facade performance, hoping to be continued in the future.

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