Green Façades for Urban Comfort Improvement
Implementation in a extreme Continental Mediterranean climate

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ABSTRACT: Green façades constitute constructive technologies with a positive influence on sustainability in cities and several urban climate parameters such as thermal comfort, air quality and water management. According to the current research, the implementation of urban greenery contributes to increase the cooling effect and mitigate the urban heat island (UHI) phenomenon. This paper focuses on the role of vegetation in improving the urban environment of Madrid (Spain). The simulation results show that green walls could be more effective in urban morphologies with narrow streets. During overheated periods, the streets with green walls have a higher relative humidity in the surrounding areas than those with trees. The air temperature is found to be a little lower. The reduction of wind speed means a positive effect on urban hygrothermal comfort. Therefore, green walls could be taken into account as suitable tools to modify the outdoor thermal environment in cities with an extreme Continental Mediterranean climate.
Keywords: Green facade, urban comfort, urban heat island, simulation Envi-met.

INTRODUCTION

There are many researchers developed about green envelopes and their interaction with the interior and exterior space. Much of the related research is focused on urban greening performance regarding building energy consumption, solar radiation absorption, thermal mass effect and acoustic absorption [1,2]. Subsequent improvements on indoor environment and energy consumption are particularly significant in summer conditions.

The percentage of solar radiation absorbed or reflected by exposed urban surfaces (roofs, façades, pavement, etc.) also greatly affects the temperature distribution in urban areas. The pavement and the building envelope (horizontal and vertical) are highly exposed to direct solar radiation. In most cases, the materials of these urban surfaces have both high absorptivity and thermal capacity. These characteristics contribute to the urban heat island (UHI) effect, with important consequences in dry climates with high levels of radiation [3].

The solar albedo and infrared emissivity of the materials have a strong impact on the energy balance of the cities. According to several studies [4] the cities work as heat storages during the day, while the stored energy is released into the urban fabric throughout the night. In comparison to rural areas, city centers can achieve temperature differences up to 10 ° C, especially in the Mediterranean macro-climate where radiation is very high [5].

The high temperature during the winter may have positive effects in reducing the heating demand. However, the effect in the summer become negative since the cooling demand is increased and the potencial for passive cooling is reduced overnight. In addition, environmental contamination is favored in two ways: directly, as higher air temperatures increase the amount of urban smog; and indirectly, by increasing energy consumption and gas emissions from industrial plants (CO_2, CO, NOx, SOx, water vapor and methane). Insulation materials and coating of buildings have a higher thermal capacity than water and vegetation [6].

A Review of Urban heat island and its impact on building energy consumption has been researched by Priyadarsini [7]. Other causes than albedo surfaces of this phenomenon are; anthropogenic heat, urban greenhouse effect and evapotranspiration. Dakal and Hanaki [8], analyzed the implications of anthropogenic heat discharges into the urban thermal environment of Tokyo. Nine scenarios were simulated with the help of the DOE-2 building energy simulation model. The maximum improvement in average temperature for daytime was found to be 0.47ºC as a result of greening the areas of Tokyo around the building. Vegetation reduces the material´s temperature and its infrared emissivity by solar absorption and evaporative cooling [9].

The urban heat island effect has a great influence on the diffusion capacity of urban pollutants too. This phenomenon often modifies the local wind circulation. This wind raises the hot air from the center of the city and creates a draught of cold air in the surrounding countryside that penetrates in the urban area. Some authors have demonstrated that using climbing plants in the façades can modify the interaction between the buildings and the atmosphere. In addition to improving the indoor and outdoor environment, the effects on the distribution and accumulation of pollutants in the streets are noticeable [10].

Large cities alter the urban climate as a consequence of temperature increase and wind reduction. Although precipitations like snowfalls are also reduced, rainfall totals are slightly higher in the city than in the surrounding rural areas. Solar radiation and ultraviolet rays are smaller in the city as a result of the screening effect produced by urban pollution [11]. The shape of urban centers, where the heat island effect is more evident, is difficult to modify.

Reducing the impact of UHI means a review of urban strategies and materials in building envelopes. This paper focuses on the role of vegetation in improving the urban environment of Madrid (Spain).

METHODOLOGY

Considering the important role that vegetation plays, the objective of this research was analyzing the effects of green walls in the urban microclimate. Simulations with ENVI-met V3.1 were assessed according to the same urban scenario varying the location of green envelopes and the amount of vegetation. Envimet 3.1 has limitations for modeling green walls, and for this reason it was necessary modeling them as a 0.50 meters width and 20 meters high tree very close to the building. The line of trees was 3 meters width and 20 meters high, they were at a distance of 3 meters from the building. The street canyon was 100 meters long. The main input parameters are described in *Table 1*.

Climate

Simulations were done for Madrid, which is considered to have extreme Continental Mediterranean climate, characterized by hot and dry summers with low relative humidity opposite to cold winters with moderately high moisture in air. The average monthly temperatures are very different between summer and winter. The daily fluctuation is also important, with monthly mean amplitudes more pronounced during the summer and lower during the winter.

Madrid has an average daily global solar radiation on a horizontal surface per year of $16.6 \leq H < 18.0$ MJ/m2 and $4.6 \leq H < 5.0$ kWh/m^2. Regarding the building orientation, the level of radiation in South façades is higher during the winter than during the summer. The North facade is the one that receives less radiation. As the East and West façades receive the higher radiation, the implementation of green façades in these cases could be an effective strategy.

Table 1: Selected input parameters for ENVI-met simulations

Area Input File	
City	Madrid
Soil A, Soil B	p/p
Size of grid cell (x,y,z) [m]	0,5/10/3
Dimensions (W,H,L) [m]	20/15/100
Ratio (H/W)	0,75
Model rotation out of grid north	0
Configuration File	
Day	15.7.2009
Start simulation time [h]	6:00:00 h
Total simulation time [h]	10 h
Meteorological inputs	
Wind speed and direction 10 m a.s.l. [m/s]	2/ 0º
Mean roughness length of study area[1] [m]	0,1
Specific humidity al 2500 m a.s.l	7
Relative humidity at 2 m a.s.l. [%]	56
Initial atmospheric temperature [K]	291
Building inputs	
Building inside temperature (K)	291
Mean heat transmission of walls [W/m^{2}K]	0,66
Mean heat transmission of roofs [W/m^{2}K]	0,38
Mean wall albedo	0,2
Mean roof albedo	0,3

Study phases

In the initial phase in order to verify green facade benefits different cases were compared. The same scenario was simulated with a green facade, without one, and with tree lines, varying the next parameters; wind direction and building orientation. The wind direction is important for the human comfort as well as the distribution of particulate matters. The orientation of the facades is an important parameter to vary due to the influence of the building incoming radiation and the absorption or transmission capacity of the constructive materials.

During the next phase different ratios –ratio of street width and building height- were extracted from some representative case studies of the city of Madrid, where the incorporation of green façades was possible, because [12] the implementation of green facades is more appropriate for commercial and residential buildings. The main ratios simulated were 0.5, 0.75, 1, and 1.2.

Urban Comfort analysis

The main factors affecting the human thermal comfort in urban outdoor spaces are temperature (K), relative humidity (%), solar radiation and air movement (m/s).

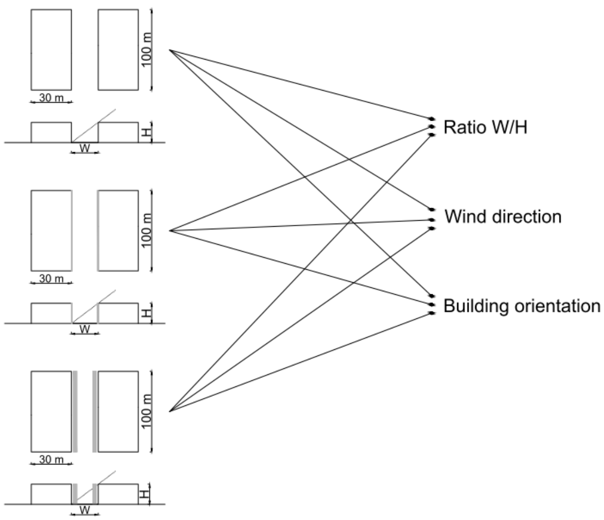

Figure 1: Scenarios (with a green façade, without one and tree line) and parameters (ratio, wind direction and building orientation).

Bio-Climatic Charts facilitate the analysis of the climatic characteristics of a given location from the viewpoint of human comfort. Their function is to provide information on the different design strategies that exist. By superimposing on them the specific climatic conditions of a case study, they show which strategies are more suitable to be implemented.

The Olgyay Bioclimatic Chart has relative humidity as the abscissa and temperature as the ordinate [13]. The comfort range is plotted on the chart. It is bounded by a fixed lower temperature and by humidity-dependent upper temperature limit. Firstly, the index of clothing, the activity and weather data corresponding to a particular time of the year were incorporated in this chart, and then the appropiate corrections were implemented. In this case, summer clothing is 0.5 clo and a medium activity, people walking or seated, is selected. *Figure 1* is constituted by different zones. Human comfort is delimited by 40 to 60% of relative humidity. It determines the hygrothermal comfort for a minimum of 90% of people and the moisture conditions adequate for the human welfare.

In the months of June, July and August shading areas are needed from midday until late in the day. During the early hours of the morning it is possible to be in comfort.

Natural ventilation is used as a strategy eliminating overheating and reducing the sensation of heat. Different mechanisms are used to move air, be it independently or in combination: difference in temperature, density, speed, and wind pressure.

Ventilation complemented by increasing moisture atmosphere is called evaporative cooling, that is more effective in places like Madrid, in which the relative humidity in the summer months is very low.

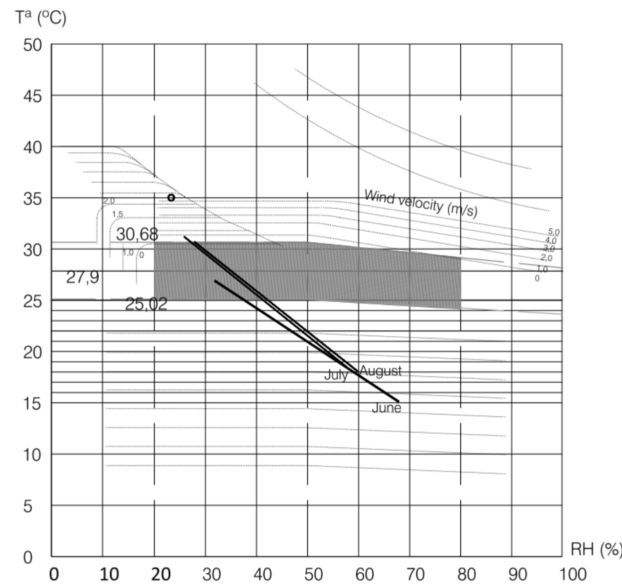

Figure 2: Bioclimatic chart of Madrid.

During July the relative humidity reaches 27% during the day coinciding with the peak of temperature. This value approaches the limit of people comfort. The Bioclimatic chart also shows that although it does not reach the relative humidity lower limit (20%), the green facade could be a positive strategy in the hottest hours because it increases moisture.

RESULTS

The results were analyzed according to the average values of the three scenarios in a three-hour interval, at 9:00, 12:00 and 15:00. Then, maximum and minimum values for each scenario and every hour were assessed. These results were analyzed at 1.2 meter high.

The main parameters studied were as follows: relative humidity, temperature, wind speed, levels of CO2 and particulate matter for each parameter in both the xz plane (parallel to the street section) and the yz plane (cross section the street). Their time data were compared with results for each parameter. All the parameters tend to diminish their value, whereas the temperature increases.

Analyzing the first results, the factors with greater differences among averages are the relative humidity, wind speed and CO_2. In this case, the wind direction is parallel to the length of the street.

Figure 3 shows wind speed and CO_2 along a cross section of the street. The lowest values of CO_2 and wind are achieved with the green façade. The average CO_2 is similar in both cases (urban trees and green façade); however, there is a slight decrease in wind speed with the green façade. The street without vegetation gets worse results in any case. Comparing the values of relative humidity and wind speed, the green façade has higher relative humidities and lower wind speeds. According to the bio-climatic charts, these data mean an improvement in thermal comfort.

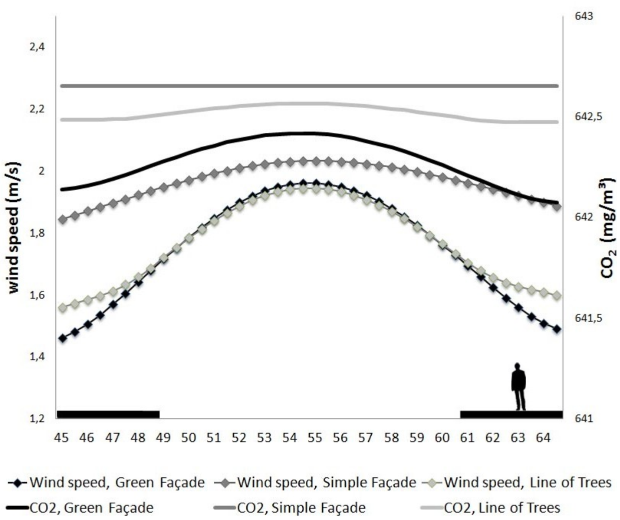

Figure 3: Wind Speed and CO2, Madrid 15 july at 3:00 p.m. Envimet 3.1

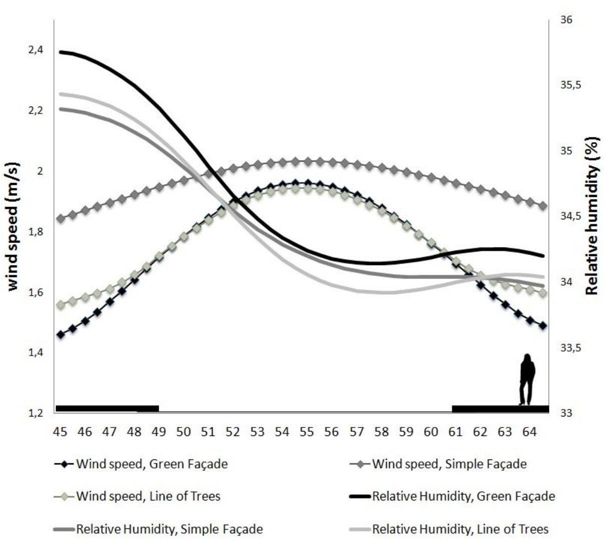

Figure 4: Wind Speed and Humidity, Madrid 15 July at 3:00 p.m. Envimet 3.1.

The next parameter was the street ratio whose dimension was changed. The analysis was longitudinal and transversal. The improvement of the green facade is higher when the ratio of the street is more than 0.75 for the next parameters: relative humidity, temperature, wind speed and CO_2. In contrast, there is a greater dispersion of suspended particles as the width of the street increases. The differences are minimal among the scenarios.

Figure 5 shows the trend of wind reduction in narrow streets and a maximum difference of 0.25 m/s between the wider street and the narrower street.

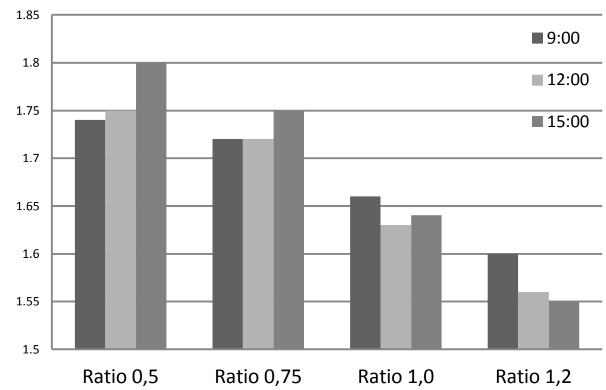

Figure 5: Average values of wind speed across the street with green façade.

The transversal results, in the middle of the street (x = 64.75 meters) near to the green facade, are similar to the longitudinal results, CO_2 could be related to the street ratio. The higher the ratio, the better the results. The others parameters are constants.

The wind direction was modified from north to west, for this reason, the wind speed was reduced in these simulations inside the urban street canyon. Reducing the wind speed could be a great decision during the hottest hours, but it is more difficult to reduce the particulate matters levels.

Changing the ratio street, the results of the parameters are more similar than the other simulations, except CO_2 and PM10. These were very constant during the day, but if the wind direction is changed the results were opposite for the same green façade (Figure 6).

The CO_2 results at 1.5 meter high near to the green façade are better with a wind direction perpendicular to the building. And if we analyze the CO2 results for the entire height of the model (40 meters) at 8:30 a.m., the values are different up 25 meters high.

The amount of particulate matter is worse for all the green scenarios because the vegetation hinders its dispersion.

Air temperature results were analyze near the building façade at different heights (Table 2), next to the pavement at 0.3 meters high, 1.5 meters due to human comfort, 4.5, 13.5 and 25.5 meters high because of heat distribution and it´s possible indoor transference. It was compared at 6:30 a.m. as a consequence of urban heat island effect, at this time the air temperature between rural and city is different. It is important to reduce city temperature during the night and the first hours of the morning. All the air temperatures are better with a green façade, even near to the pavement. The maximum difference value is 0.13 Kelvin at 10.5 meters high between a green façade and without it.

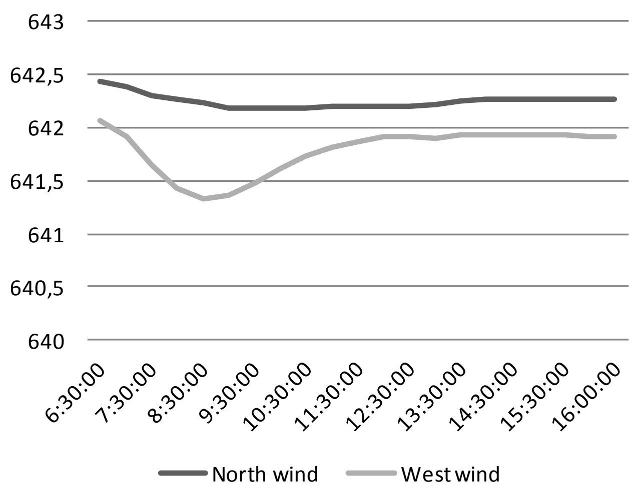

Figure 6. CO_2 levels with different wind direction near the green façade at 1.5 meters high.

Table 2. Air temperature (Kelvin) at different height at 6:30 a.m.

Height (m)	Green facade	Tree line	Without green
0,3	290,98	291,01	291,07
1,5	290,98	291,01	291,07
4,5	290,95	290,99	291,06
7,5	290,94	290,98	291,06
10,5	290,93	290,98	291,06
13,5	290,99	291,02	291,08
25,5	291,24	291,24	291,24

CONCLUSION

Several studies indicate that a significant reduction in energy consumption can be achieved by urban modifications, and this research is on the same direction. The results are expected to serve as design guidelines for sustainable urban development. The contribution of urban greening affecting the microclimate of the urban environment was evaluated so as to determine and select the most promising scenario for implementation and incorporation in urban design.

Temperature

This research made for a reduce scale shows improvements of 0.11ºC. Most of the studies related to the energy implications of urban heat islands were based on numerical simulations and long-term measurements. These measurements show improvements in the cities with vegetation (trees) from 3ºC to 13ºC depending of the amount of green envelopes, but the best result of some simulations is 0.48ºC [8]. The present research have simulated a micro scale scenario, so it expect reaching temperature 0.13ºC lower at district scale with green façade.

Wind speed

The green façade can reduce 0.25 m/s of wind speed. This factor is important for urban human comfort, but this modeling shows that it is very important for air quality too, as well as the wind direction, especially for the particulate matter distribution and the levels of CO2 concentrations.

Relative humidity

Urban tree lines are not a strategy valid for all the street canyons. The relative humidity values can be increased during the summer with green façades for narrow streets and improve human comfort.

FUTURE WORK

This is the first step of the research that studies basic scenarios, the next phases should research more complicated urban typologies, with different ratio and urban sections (Sky View Factor). But most importantly, research the same scenarios but not in a urban canyon, it is necessary to analize scenarios at district scale. The comparison with other scenarios is important too, like high albedo materials façade and roof use.

The economic analysis is another aspect to focus on, the improvement of all parameters at the human comfort and air quality are going to be analyzed in terms of saving costs.

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