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Use of vegetation to increase building energy efficiency: application to a real case study

L Forzani[1], E S Mazzucchelli[1], P Rigone[1]

[1] ABC Department, Politecnico di Milano, via Ponzio 31, 20133 Milan, Italy

enrico.mazzucchelli@polimi.it

Abstract. The research here presented deals with the relationship between vegetation and architecture, and how its presence can influence a building project and performance. In the last years, many ways of integrating green in building envelopes have already been experimented, for their potential of reducing thermal loads; the research investigates a specific solution, the vertical forest, which integrates trees and small bushes in specific permanent planters on balconies of high-rise buildings. The main scope is to understand if trees, treated as shadings, can really affect positively the building energy consumptions. Moreover, other aspects, such as trees mechanical stability, construction issues and maintenance are deepened. Through a particular case study, energy consumptions are analysed using dynamic simulations tools, developed with Grasshopper™ and EnergyPlus™ software, in which trees are considered as special external shadings, characterized by a variable permeability to solar radiation during the year. Results demonstrate that trees can contribute to reduce energy loads, depending on species and orientation, especially in association with traditional shading systems. Eventually, some guidelines on technological and construction aspects, as well as on trees species selection, are given, in order to assure the optimal vegetation life and to maximize its benefits on the building.

1. Introduction

Global warming is the defining issue of our time, and building sector plays a key role, as it is responsible for approximately 40% of energy consumption in Europe [1]. With the UN Sustainable Development Goal 7 in mind [2], a lot of effort need to be put to find ways to increase energy efficiency. Vegetation can help in reaching this goal, as plants have the capacity to modify the surroundings in different ways, among which the energy exchange [3]. This is thanks to change of thermal performances, which are influenced, for example, by plant covering percentage, density and width of foliage, type, size and orientation [4]. In this paper, trees are treated as shadings, in order to understand if vegetation can really help in reducing energy consumption and Urban Heat Island Effect: research focuses on energy-related aspects, leaving others (i.e., architectonic quality and liveability) unexplored. This has been investigated on a specific case study, the so called "Vertical forest" building, which includes trees and small bushes on balconies of each apartment.

2. Methodology and case study

The building taken as case study is a residential tower, composed of 21 floors, placed in Tirana, Albania. It has a rectangular shape (23.7 m in length and 36.4 width) and balconies, where vegetation is placed in permanent concrete planters. Balconies usually are 6.6 m in length and 3 m in depth, with

L-shaped planters of 1-1.4 m in width. The building is currently under construction: analyses conducted have been helpful during design stage.

2.1. Modelling and simulation process

All the simulations have been carried out with Rhino and Grasshopper, a graphical algorithm editor integrated with Rhino's 3D modelling tools (figure 1). The geometries have been created in Rhino, in terms of flat surfaces, which have been integrated lately in the Grasshopper script. In Grasshopper a code for tree forms definition has been implemented, and open source environmental plug-ins such as Ladybug and Honeybee has been employed, to perform radiation and comfort simulations.

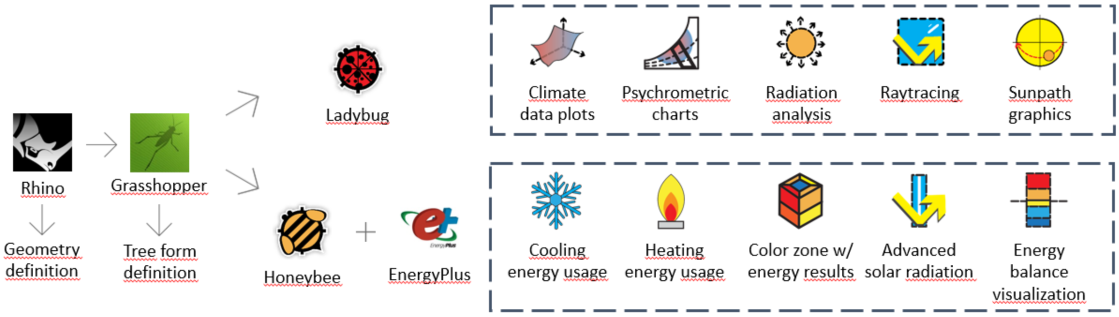

Figure 1. Programs used in the analysis process.

The modelling process is the following: as a first step, case studies and trees are defined geometrically, and modelled as closed surface; second, seasonally tree shade factors (derived from databases [5]) are applied, as transparency schedule [6], to simulate the changing of foliage during the year; third, energy simulations and radiation analysis are performed; then, analysing incident radiation throughout the year an optimized tree form will be found. For each case study, eighteen simulations have been run, with these variables: two orientations (South and West); four tree types, plus the baseline (unshaded situation) to compare with; one or two trees placed simultaneously. Comparison with traditional shading systems is reported in [7]. Four trees species have been selected, all suitable in the project area and different for shape, dimension and shade factor (table 1).

Table 1. Tree names, geometrical shapes, dimensions and shade factors.

						Shade factor			
Number	Name	Crown shape	Bole height (m)	Total height (m)	Crown diameter (m)	Winter	Spring	Summer	Autumn
1	Acacia melanoxylon	Cylindrical	1.2	3.8	1.6	0.37	0.55	0.73	0.55
2	Elaeagnus angustifolia	Upside-down paraboloid	1.2	4.6	4.2	0.42	0.57	0.83	0.57
3	Olea europaea	Horizontal ellipsoid	1.4	3.5	2.5	0.81	0.81	0.81	0.81
4	Ginkgo biloba horizontalis	Horizontal ellipsoid	1.2	3.3	1.2	0.34	0.53	0.67	0.53

2.1.1. Model description. The room is 6.7 x 3.1 m, with height of 3.3 m. All walls and floors are set as adiabatic except the one in contact with the outdoor, which has a window of 4.4 x 2.5 m. Trees are 2.3 m away from the window (at the centre in case of one tree, equally spaced from the corners in case of two trees, as shown in figure 2 and figure 3). The HVAC system is set to provide cooling or heating air to a zone in sufficient quantity to meet specified thresholds.

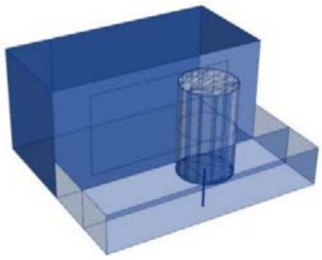

Figure 2. Room model, with one tree.

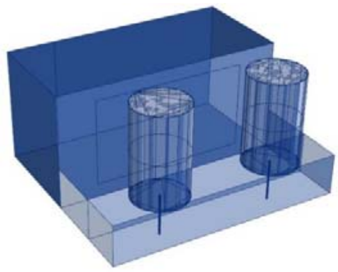

Figure 3. Room model, with two trees.

2.1.2. Assumptions and limitations. Complexity of light rays bouncing is limited, and no wind or evapotranspiration process is considered.

3. Results

3.1. Room results

The results are expressed in cooling loads (Wh), monthly averaged (figure 4 and figure 5).

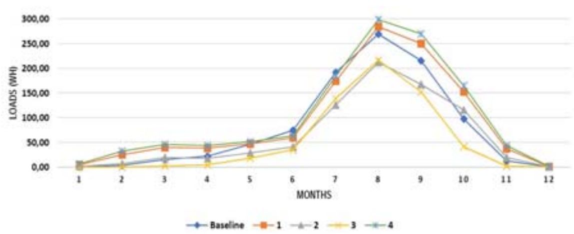

Figure 4. Cooling loads in South orientation.

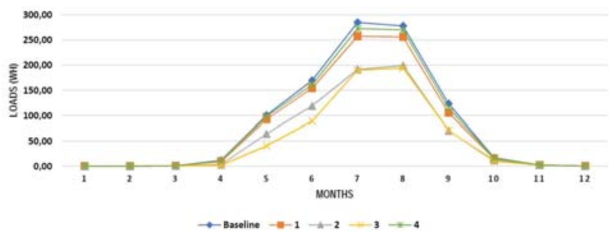

Figure 5. Cooling loads in West orientation.

In South orientation, in June the maximum reduction of cooling loads reached is about 53.1% respect to the baseline, with an annual saving of 35.6% for cooling [7]. Not all trees provide an improvement: this could be due to the fact that direct energy in summer hits the glazing with a high angle of inclination, it is reflected, hits the tree which reflects it again, causing these increases. Each tree has a different shading potential: differences lie on shapes and shading factors, but the relationship between loads and incident radiation is not linear. Facing West, the percentage decrease in cooling loads is of 47.5% in May, with an annual saving of 39.4%. All the trees are useful, but some of them can shade a wider area and get better results [7].

Table 2. Percent decrease of annual cooling loads from one tree to two.

	1	*2*	*3*	*4*		*1*	*2*	*3*	*4*
South	3.6%	84.8%	51.2%	-3.5%	**West**	2.9%	25.9%	45.6%	17.2%

Comparing simulations with one and two trees, it is possible to say that the second option is preferable in South, as it gives significant improvements, and it could be useful in West (table 2).

3.2. Optimization process

The critical analysis was aimed to understand the potential of vegetation. The further step was to find an optimized tree, in terms of shape and shading factor, which can achieve better savings. The solution has been performed by acting on tree geometry, by changing bole height, crown height and crown diameter in both direction, and shading factor. Several simulations have been performed, and the following table summarizes the results achieved. In this case, the output is the sum of cooling and heating loads, in order to consider the negative effect that the presence of trees can have of heating needs in winter.

Table 3. Percentage of improvement of annual cooling and heating loads, respect to baseline.

	South	*West*		*South*	*West*
1 tree	8.2%	17.7%	**2 trees**	15.5%	20.8%

From the data it is clear that trees are able to reduce loads (table 3), reaching savings of 15.5% in a year when exposed South, and 20.8% when oriented West [7].

3.2.1. Discussion. After this analysis, it is possible to some draw up some considerations. In South orientation, the best is to choose trees with circular base profile of crown, with bole arriving up to ¾ of the window and with broadly vase-shaped crown, higher than the window; two trees can almost double energy savings respect to only one. In West orientation, the best option is to select trees which can cover a great area of the window, with crown covering more than half of the window area, with particular attention in covering the gap between tree trunk and façade. The research was conducted on a hot-summer Mediterranean climate, and it can apply wherever there is need of shading devices. Moreover, the methodology developed is applicable everywhere by changing climate inputs.

4. Guidelines on technological and construction aspects

From an energy performance point of view, vegetation can lead to significant benefits when it is considered by design and construction phases. Vegetation is characterised by growth and changes, which must be controlled setting limits and ranges. Aspects to be controlled are: (1) mechanical stability of the building structure, as vegetation causes a high dead load, subjected by changes due to moisture content; (2) safety, as breakage of trunk could occur due to wind; (3) construction methods; (4) water supply and collection, to guarantee an adequate irrigation and water disposal; (5) maintenance, necessary to guarantee tree health, must be designed in earlier stage of the design process.

References

[1] European Commission [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings.
[2] UN Sustainable Development Goal [Online]. Available: https://www.un.org/sustainabledevelopment/sustainable-development-goals/.
[3] Akbari H 2009, *Cooling our Communities. A Guidebook On Tree Planting And Light-Colored Surfacing*.
[4] Oke T R, Crowther J M, McNaughton K G, Monteith J L, and Gardiner B 1989 The Micrometeorology of the Urban Forest [and Discussion], *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 324, no. 1223, pp. 335–349.
[5] Mcpherson E G, Xiao Q, S. van Doorn N, Johnson N, Albers S, and Peper P J, Shade factors for 149 taxa of in-leaf urban trees in the USA *Urban For. Urban Green.*, vol. 31, no. February, pp. 204–211, 2018.
[6] Hes D, Dawkins A, Jensen C, and Aye L, A modelling method to assess the effect of tree shading for building performance simulation, *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association.*
[7] Forzani L, Use of vegetation to increase building energy efficiency. Application to a real case study. MSc Thesis, Politecnico di Milano.