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Bio-inspired outdoor systems for enhancing citizens thermal comfort in public spaces by learning from nature

Marta Chafer[1,2], Cristina Piselli[2,*], Anna Laura Pisello[2,3], Ilaria Pigliautile[2], Gabriel Perez[1], Luisa F. Cabeza[1]

[1]GREiA Research Group, INSPIRES Research Centre, University of Lleida, Lleida, Spain
[2]CIRIAF - Interuniversity Research Centre, Perugia, Italy
[3]Department of Engineering, University of Perugia, Perugia, Italy

** Corresponding email: piselli@crbnet.it*

ABSTRACT

In the last decades a variety of high-energy efficient solutions for building envelopes were developed and tested for enhancing indoor thermal comfort and improving indoor environmental quality of private spaces by learning from nature. To this aim, adaptive solutions, conceived thanks to green and bio inspiration, were designed and constructed in various climate conditions and for a variety of building uses. Given the huge population flow toward urban areas, well-being conditions in the public spaces of such dense built environment are being compromised, also due to anthropogenic actions responsible for massive environmental pollution, local overheating, urban heat island, etc. Moreover, this process is exacerbated by temporary phenomena such as heat waves. Therefore, outdoor spaces are becoming increasingly less comfortable and even dangerous for citizens, especially if they are affected by general energy poverty, with no chance for active systems management for air conditioning, or health vulnerability. In this view, this study concerns the first concept for the development of a simple and adaptive nature-inspired solution for outdoor thermal comfort enhancement and local overheating mitigation for pedestrians. The system will be evaluated in terms of the cradle-to-cradle approach and the initial performance assessment is carried out via thermal-energy dynamic simulation. The final purpose will be to design outdoor "alive" shading system to be applied in open public spaces, with evident physical and social benefits.

KEYWORDS

Bio-inspired solutions; Biomimetics; Biophilic cities; Outdoor thermal comfort; Thermal-energy dynamic simulation.

INTRODUCTION

Nowadays, a topic with increasing relevance is how an exterior space affects physical, physiological, and psychological well-being. The achievement of comfortable outdoor spaces and microclimate in urban environments is, indeed, fundamental since those spaces are where social activities happen, people gather/socialise, but also connect the indoors with nature (sun/green spaces). Architects and designers were inspired by nature since long before the term biomimicry (biometics or bio-inspired architecture) was introduced. In the past, architecture featured ornamental design influenced by nature, and this tendency was accentuated by turn-of-the century Catalan Modernism (Spain) or Art Nouveau (Belgium) as examples. Nowadays, a methodological approach to assess innovation was developed through merging bio-inspiration and sustainability based on the reintegration of basic bio-inspired principles into material systems of humankind (Horn et al. 2018). Biomimetics is a rapidly growing discipline in engineering, and an emerging design field in architecture. In biomimetics, solutions are obtained by emulating strategies, mechanisms, and principles found in nature (Badarnah 2017). Therefore, the study of green infrastructures providing benefits not only in terms of outdoor thermal comfort, but also for the built environment located in their close proximity may represent a further mitigation and wellbeing opportunity.

In this context, plants have also the capability to transform global solar radiation that reaches their surfaces into biomass, oxygen, air humidity, etc. (Pacheco-Torgal et al. 2015). Furthermore, biophilic spaces, those that learn from nature and emulate natural systems, must be considered for the development of cities. In fact, a biophilic city is a city in which residents are actively involved in experiencing nature (Beatley & Newman 2013). Moreover, biophilic urbanism can complement urban greening efforts to enable a holistic approach, which is conducive to comprehensive, intentional, and strategic urban greening (Revee et al. 2015). Different studies about outdoor thermal comfort showed that the sun sensation coming from solar radiation has the most significant influence on human thermal sensation in outdoor spaces (Yang et al. 2013). On the other hand, pedestrians usually inclined to green areas within the urban environment. This increase of vegetation, combined to other solutions, showed the most significant impact in summer overheating mitigation and urban resilience to anthropogenic climate change (Piselli et al. 2018).

Within this background, there is a lack of information about how greenery shading systems can influence outdoor thermal comfort in the inter-building space. Therefore, the purpose of this work is to study a simple and adaptive system of bio-inspired architecture connected to the building for the improvement of thermal comfort in the outdoor inter-building space. Therefore, this strategy is able to mitigate the build environment and the urban heat island phenomenon (UHI) as bottom-up approach. The other aim of the paper is to simulate the outdoor thermal comfort with greenery, since there are no previous studies concerning that. Moreover, the selected materials are meant to produce the minimum impact in terms of cradle-to-cradle vision.

METHODS

Description of the concept

The design was created with different spaces that can provide thermal comfort to outdoor users (Figure 1). Two main objectives were pursued: (i) to reduce the incidence of the direct solar radiation to achieve higher visual comfort, and (ii) to mitigate surface temperatures of the connected buildings and the air temperature in the inter-building space to achieve thermal comfort. In fact, the system did not seek to create a stand-alone piece at the outdoor. On the contrary, the intervention tried to strengthen the key assets of surrounding buildings, creating an extension of the existing buildings that it may be.

Figure 1. The shading system proposed.

The shading system was composed of two interwoven systems of ropes running freely between the two buildings. The ropes connected on the middle creating a bench where people could sit. The new three-dimensional surfaces created shadings of varying densities that reconfigure the original outdoor space into a more confined and enclosed space. The confined space changed constantly with shadows produced by the rope and greenery systems (using deciduous plants) depending on the season since the solar irradiance is different for each one. Thus, the inter-building space became an ever-changing stage that responded to the movement of the visitor, the changing patterns of light through the day, and the outdoor thermal comfort depending on the season. The selected specie, i.e. Boston Ivy (Parthenocissus Tricuspidata), is a deciduous specie well adapted to the Mediterranean Continental climate.

The performance of the system was simulated in this study to demonstrate its potential in sites requiring context-specific real-time responses. The system was modelled under the case study climate context of Lleida, Spain, with Continental-Mediterranean weather conditions, i.e. Csa (warm temperate, dry and hot summer) zone according to Köppen-Geiger climate classification (Kottek et al. 2006). To improve the efficacy of the proposed system in terms of cradle-to-cradle, the materials selected for the prototype corresponded to: (i) Wood structure to support the shadow shading system. This wood structure includes a bench integrated in the basement structure with a substrate for the climbing plants that will grow on it. (ii) Ropes made of natural fibres for the shading system. (iii) Climbing deciduous plants.

Thermal-energy dynamic simulation

For the system modelling and thermal-energy assessment, EnergyPlus v8.1 simulation engine (Crawley et al. 2000) with DesignBuilder v4.7 graphical interface (DesignBuilder software Ltd, 2016) were selected. The following steps were followed in the simulation process:

- Building geometry modelling based on the designed drawings and technical specifications.
- Characterization of the architectural elements and their thermal properties.
- Proposed shading system modelling and characterization: the rope-based shading system with greenery was modelled as a solid obstacle, characterized by rope properties. This configuration was considered an acceptable approximation due to the unavailability in the software of a model for stand-alone green infrastructures implemented in outdoor areas, i.e. not integrated in the building envelope.
- Run of hourly simulations for the hottest week in summer (i.e. July 15th to July 23rd), with the more regular outside temperatures along the season.
- Analysis and comparison of the performance of different scenarios for the outdoor shading system in terms of thermal conditions under the shading and external surface temperatures of the shaded buildings.

The statistical weather file of the city of Lleida from the EnergyPlus database (U.S. DOE BTO, 2016) was used for triggering the model in the calculations. Different scenarios were defined for the proposed system in order to evaluate the impact of shading percentage of the system, i.e. the amount of vegetation growth on the rope-based system. To this aim, the different scenarios were modelled by varying the transmittance capability of the solid obstacle. Therefore, the studied scenarios (Figure 2) were those proposed by Ng et al. (2012):

- Covered 0%: Without greenery, i.e. solar radiation transmittance equal to 1.
- Covered 33%: With greenery covering 33% of the structure, i.e. solar radiation transmittance equal to 0.67.
- Covered 67%: With greenery covering 67% of the structure, i.e. solar radiation transmittance equal to 0.33.
- Covered 100%: With greenery covering 100% of the structure, i.e. solar radiation transmittance equal to 0.

The purpose of the numerical simulation was to study the influence on the surface temperatures of the buildings connected and shaded by the system (east and west walls were selected since are those which receive more solar radiation in summer) and to study the variation of temperatures below the system depending on the coverage. To this aim, the inter-building area below the shading system was modelled as an internal thermal zone, characterized by thin air layer envelope and high air infiltration and ventilation to approximate outdoor conditions to the best.

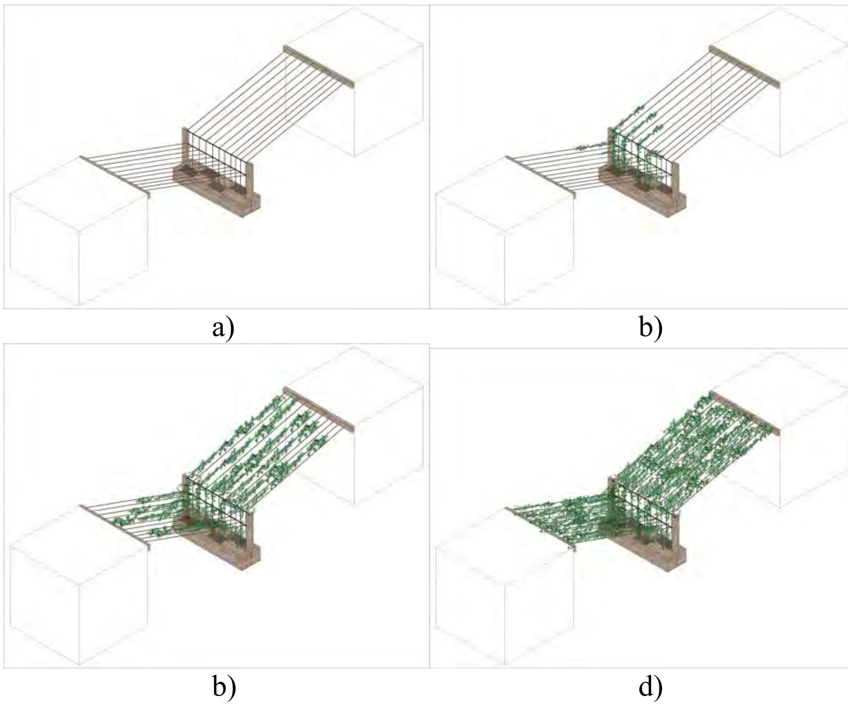

Figure 2. The four different scenarios of the shading system. a) Without greenery, b) With greenery covering 33%, c) With greenery covering 66%, d) With greenery covering 100%.

RESULTS AND DISCUSSION

As the external wall surface concerns (Figure 3), significant differences were observed between the four scenarios. More in detail, the maximum variation in the surface wall temperatures was found in the west facade, since among the considered orientations it is the one that receives the highest solar radiation in summer (Pérez et al. 2017). The peak temperatures showed significant variation depending on the shading scenario, while the minimum temperatures were similar.

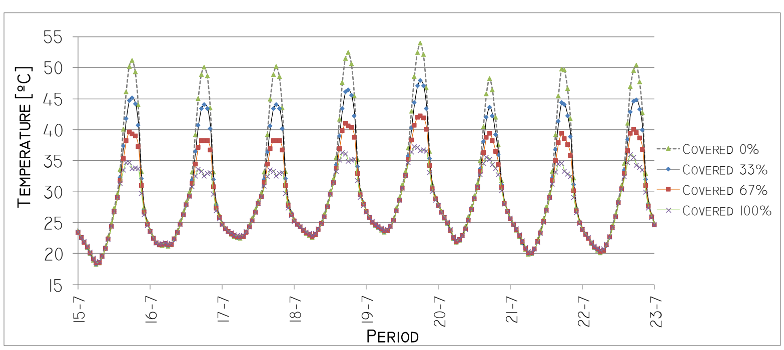

Figure 3. Daily variation of west facade temperature.

In particular, a difference of 16ºC was found between the scenario without shadow (i.e. Covered 0%) and the one totally Covered (i.e. Covered 100%), where the surface temperatures reached 54ºC and 38ºC, respectively. Concerning the scenarios Covered 33% and Covered 67%, the maximum surface temperature reached 48ºC and 42ºC, respectively. These results highlight that the external temperatures of the walls of existing buildings can be reduced thanks to the implementation of the proposed shading system. Accordingly, this is expected to be associated to a significant decrease in the indoor ambient temperature.

On the other hand, in the east facade, a difference of 7ºC was found between the scenario Covered 0% and the Covered 100% (with peak temperatures up to 43ºC and 36ºC, respectively). In this facade, each day shows two peaks, the first following the solar incidence and the second one corresponding to the maximum outside air temperature. As expected, the solar incidence has a stronger influence when no shadowing system is used (wall temperatures reaching up to 39ºC), while with the system this temperature decreases up to 22.5ºC. When the solar incidence decreases, the outside temperature effect is very strong, but in this case all scenarios reach similar temperatures (around 34-35.5ºC).

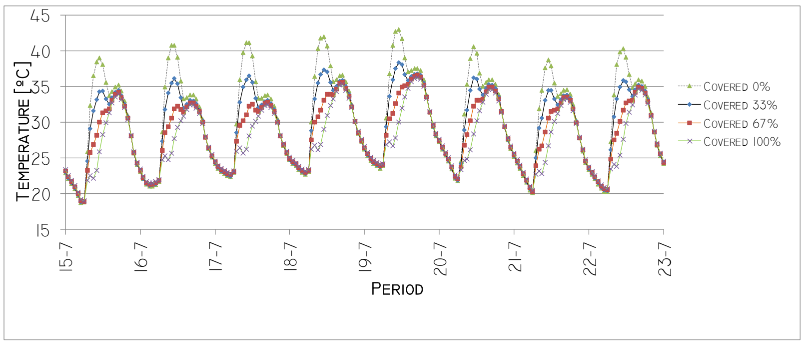

Figure 4. Daily variation of east facade temperature.

Regarding the air temperature in the inter-building space, i.e. under the shading system, the maximum temperatures ranged from 33ºC for the Covered 100% scenario, to 34ºC for the Covered 67%, to 36ºC for the Covered 33%, up to 38ºC for the system without greenery, i.e. Covered 0%. Therefore, the shading effect associated to the implementation of the greenery was able to provide an outdoor air temperature reduction up to 5ºC.

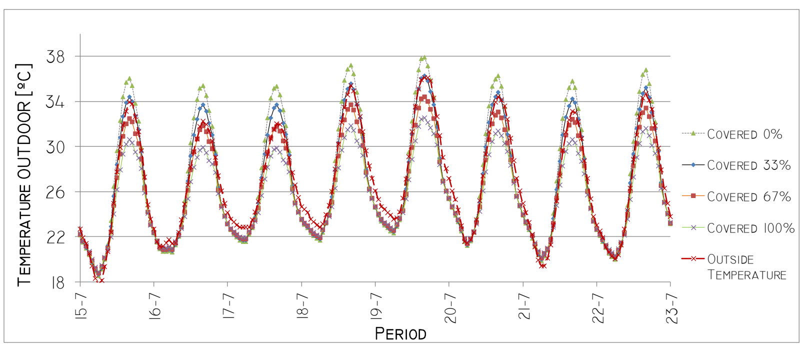

Figure 5. Daily ambient temperature under the shading system.

CONCLUSIONS AND FUTURE DEVELOPMENTS

This study presented the concept of a simple and adaptive bio-inspired vegetated shading system for inter-building spaces. The purpose of the study was to analyse the effect of varying the greening percentage on the shading system on the air temperature of the inter-building area covered by the system and the connected buildings surfaces, through numerical modelling tools usually considered for indoor thermal-energy dynamic simulation. Simulations showed, as expected, that both the wall surface temperature and the air temperature under the shading system decreased when percentage of covering due to the greenery increased. Therefore, the theory of the benefits of a greenery system in summer is confirmed also for inter-building spaces. Since this study was carried out via numerical simulation, more exhaustive experimental research is needed to confirm these results. Therefore, reliable data will be available for architects, urban planners and engineers on the implementation of new concepts inspired by nature for both indoors and outdoors well-being.

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