URBAN CANOPY SHADING: OPPORTUNITIES TO REDUCE COOLING REQUIREMENTS

[1]*García Nevado, E.; [1]Coch Roura, H.
[1]Architecture & Energy, School of Architecture of Barcelona. UPC
Av. Diagonal 649 08028 Barcelona (España)
e-mail: *elena.garcia.nevado@upc.edu

ABSTRACT

As a result of the current economic and energy crisis, it has become necessary to rethink urban planning, starting from a global concept of efficiency and considering buildings not as isolated entities, but as part of an urban system, which consumes energy on a much larger scale.

The connection between urban morphology and microclimate is a widely discussed question, including issues like the urban heat island phenomenon or outdoor comfort in open spaces. However, there is still a lot of work to be done regarding the influence of these microclimatic variations on building energy consumption. In that sense, would it be possible to apply efficient measures of microclimate modification on an urban scale to increase comfort levels in public spaces while at the same time, reducing building consumption?

This paper focuses on urban canopy shading. Its effectiveness as a shading device and its capability to improve outdoor climate in areas with an excess of solar radiation is widely demonstrated. In this case, its effect on indoor climate of is evaluated.

The case study is located in Cordoba (Spain), as an example of a climate with a hot and dry summer (according to CTE, level 4). A complete street canyon model has been created. Two buildings, one on each side of the street canyon, have been tested using an energy simulation software (Design Builder). Model features and simulation settings correspond to real values. Urban canopy shading effectiveness has been analyzed according to cooling demand decrease, taking into account both buildings. Spatial factors (street orientation, width-height ratio, windows-opaque ratio) and material factors (U-values and skin mass, % obstruction) have been considered.

Results show 18% to 45% cooling demand decrease due to the canopy shading. Spatial factors are much more relevant than material factors: windows-opaque ratio is a determining factor, in contrast to mass and U-values. This study shows the importance of evaluating both urban facades, which means working from an urban perspective beyond the local scale of a single building.

Keywords: Microclimate, Cooling demand, Solar radiation, Urban canopy shading

1.- Introduction

In these past few decades, building energy consumption has experienced a progressive increase due to higher comfort expectations and the popularization of air conditioning systems [1].

The current environmental and energy crisis makes it necessary to rationalize the energy waste. In that sense, maximizing the utilization of passive strategies for air-conditioning may be a good step. At mid-latitudes, in many cases, solar energy can be enough to satisfy passively hot water and heating requirements or, at least, by using energy renewable systems. In contrast, giving a passive answer to the cooling demand is a more complex issue, although controlling solar radiation would be a reasonable start.

Residential buildings are responsible for about 46% of final energy consumption in the case of Spain [2, 3]. Even though solar protections are common in dwellings, they rarely go beyond a simple window protection. In climates with high solar radiation, it should be noted that the effects of radiation over the opaque facade should not be neglected. In short, the typical use of solar protections constitutes a local improvement in terms of indoor comfort and cooling demand, but it has little impact on an urban scale.

This paper studies the possibility of reducing cooling demand at the building level by using a street canopy shading, through the reduction of solar radiation impinging on the facades.

2.- State of the art

2.1.- Influence of urban environment on microclimate

Energy balance of a built environment differs far from that of the rural surroundings, due to the changes in the way energy exchanges occur. Summer microclimate features affected by the urbanization were summarized by F.Sánchez de la Flor and S.Álvarez [4]. First, the net exchange of radiation is altered by the urban texture (lower solar radiation gains as a result of self-shadowing, a long-wave radiation trapping). Secondly, closely related to the previous aspect, air temperature rises in densely built-up areas. In addition to the changes in the radiation balance, anthropogenic heat sources, a reduced evapotranspiration potential and a decrease in heat loss through convection were identified as causes of this phenomenon, known as "urban heat island" [5]. Finally, water bodies and / or vegetation have a positive impact in urban summer conditions because of evaporative cooling and a partial radiation absorption according to the same authors.

2.2.- Effect consumption microclimate

The link between urbanization and microclimate has been studied at length. In contrast, the research on the influence of microclimate over building energy performance is much more recent. Several works show that the changes in microclimatic conditions surrounding the building affects directly its energy consumption, especially related to air conditioning and lighting. In all this research, the importance of incoming and outgoing radiation, as a central issue for microclimate and building energy performance understanding, is emphasized, but the approach to the subject varies depending on the latitude analyzed in each study.

The relationship between urban density and energy consumption in office buildings in Copenhagen was discussed by Stromann and Sattrup [6]. At high latitudes, global building consumption grows with urban density for any guidance due to higher lighting and heating demands.

According to the case study of Basel conducted by Allegrini, Dorer and Carmeliet [7]. cooling requirements for a building in street canyon are always higher than for a stand-alone one, but this demand decreases the denser the urban tissue. The key role of street aspect ratio (Width-to-Height ratio) regarding radiation phenomena is highlighted.

At a mid-latitude, characterized by higher solar elevation angles, F.Sánchez Flor and S.Álvarez [4] studied the potential for a decrease in cooling requirements by controlling solar radiation. It should be pointed out that these researchers collaborated on the outdoor spaces design at the 1992 Seville Universal Exposition, where awnings, vegetation and evaporative towers were combined.

2.3.- Energy simulation software

In general, energy simulation computer programs can be classified into two groups, depending on the scale it focuses their calculations.

The first group, building energy simulation programs (BES), aims at calculating theoretical building energy consumptions (or demands). Crawley, Hand and Griffith [8] compared the particular characteristics of the top 20 programs: DOE-2.1E, EnergyPlus, TRNSYS, ECOTECT... These programs consider the building to be a system exchanging energy with an environment whose characteristics are prefixed by its geographical location, barely corrections. Bozonnet [9] shows that the building consumption simulations in summer situation may vary more than 30% providing the air temperature for calculations comes from a weather station or real measurements.

The second group of programs, microclimate simulation software, tries to define the environmental conditions of urban space, but does not evaluate their impact on building consumption. Urban Weather Generator (UWG) and ENVI-met stand out in this group much less numerous than the former.

A coupling process between both kinds of simulation tools is needed. In 2011, Bouyer [10] stressed that "no tool is dedicated to the direct evaluation of the microclimate influence on the building energy consumption" and, nowadays, the situation has hardly changed. Several studies about the interaction between microclimate and energy demand have been developed recently, but there is a still a long way to go in order to get a comprehensive view of the complete phenomenon. Yang's work [11] about the influence of microclimate temperatures of surfaces would be an example of this line of research.

3.- Methodology

The aim of this paper is to quantify the potential decrease in building energy demand for space cooling by modifying urban microclimate. Specifically, this work focuses on the control of solar radiation at a street canyon scale though a canopy shading, a solar protection device capable of modifying the canyon radiation balance, and thus, urban microclimatic conditions. Fig. 1 depicts the methodology used for this study.

In order to assess the effectiveness of the urban canopy shading, cooling demands of the model are compared between two situations, with or without urban canopy shading, for a residential use and a one-week period. It should be noted that every analyzed demand includes individual demands of the two faced buildings modelled in the street canyon. Therefore, cooling demand of canyons composed by north + south facades (N+S), east + west facades (E+W), northwest+ southeast facades (SE+ NW) or symmetrical ones are compared in this work.

The study case matrix is created by modifying materials and spatial aspects from a base model. Besides, each case will be simulated for two situations: with and without shading device.

The spatial variables considered are: a) width-to-height street ratio [W/H= 0.4/ 0.7 /1]; b) orientation of the canyon facades [N+S / E+O / NO+SE]; c) Window-to-wall ratio [WWR =15%/30%]. The material variables taken into account are: a) % solar obstruction [80% / 50%]; b) skin mass [walls of 820 Kg / m2 / 190 Kg / m2]; c) skin thermal transmittance [U=2.51 W/m^{2}ºC / 0.84 W/m^{2}ºC].

3.1.- Model definition and study variables

The geometrical definition of the urban canyon model is detailed in Fig.2. Two control buildings are modelled in the midpoint of the street canyon. Their roof, facade and floor in contact with soil are considered non-adiabatic, unlike the rest of their interior horizontal and vertical partitions. The different street aspect ratios (W/H) are obtained by varying the street width (W) with a constant height of the buildings (H).

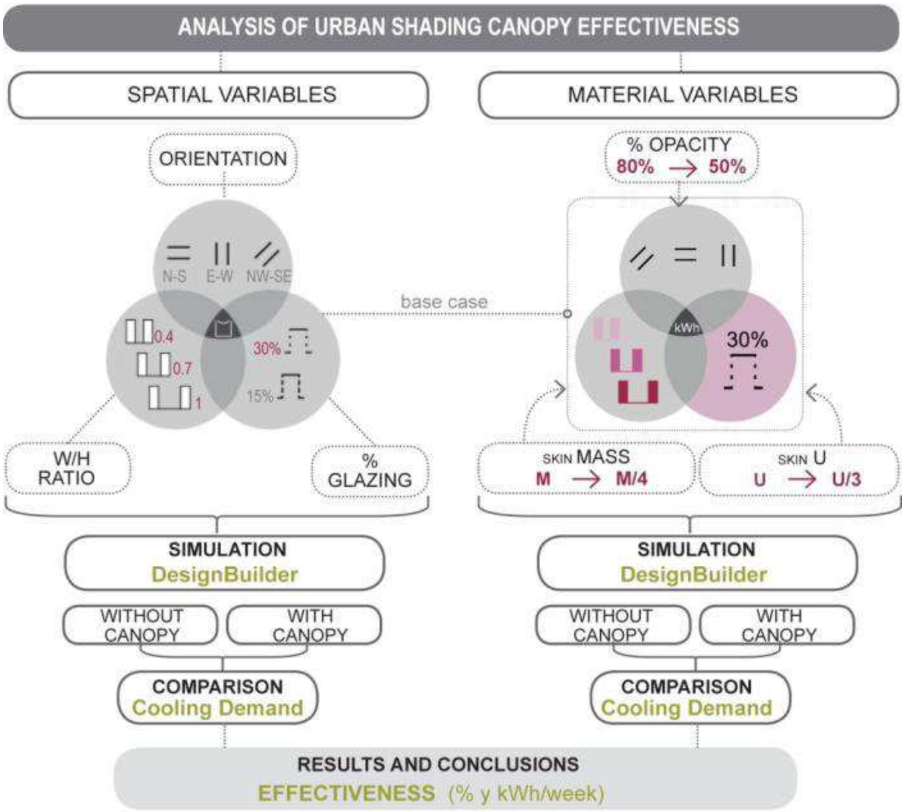

Fig.1 "Methodology diagram". Source: The author

3.2.- Simulation parameters

Cordoba (Spain, 37º 53'N), a city with a warm and dry summer, has been chosen as the case study. A SWEC file with Cordoba's climatic data is used as input for building energy simulation. The week of 24-30 july was selected as simulation period, because of its warm temperatures up to 40ºC almost every day.

DesignBuilder has been used as energy simulation tool. The activity templates match the residential templates of the IDAE document "Acceptance conditions for alternative procedures to Lider and Calener". The occupancy template considers a maximum occupancy of 0.04 persons/m^2. It is scheduled as follows: on weekdays, 100% from 23 to 7h, 25% from 7 to 15h, 50% from 15 to 23h, and on weekend, 100% all day long. A 26ºC setpoint temperature and fresch air supply rate of 10l/person are settled. The HVAC system considered is a "Split" (COP=1.83), scheduled to run from 9 to 2h.

The urban canopy is modeled in DesignBuilder as a component block, light gray colour and a 0.5 absorptance value. This device is scheduled to run from 8 to 20h.

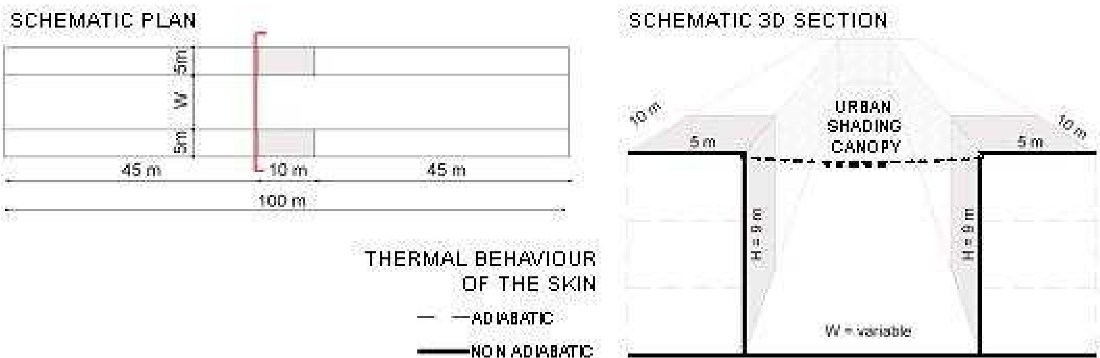

Fig.2 "Urban canyon model definition". Source: The author

4. Results and discussion

4.1.- Analysis of the spatial variables

4.1.1.- Street orientation

Fig. 3 shows that the higher cooling demand for the unshaded situation, the greater effectiveness of the urban shading device is shown due to the main role played by solar contribution to the global gains. Therefore, the urban canopy is more effective in street canyons with E+O facades, followed by SE+NO and SO+NE ones, and far from N + S ones.

Significantly, the presence of this kind of urban shading ensures very similar cooling demands for all facade orientations (Fig.3).

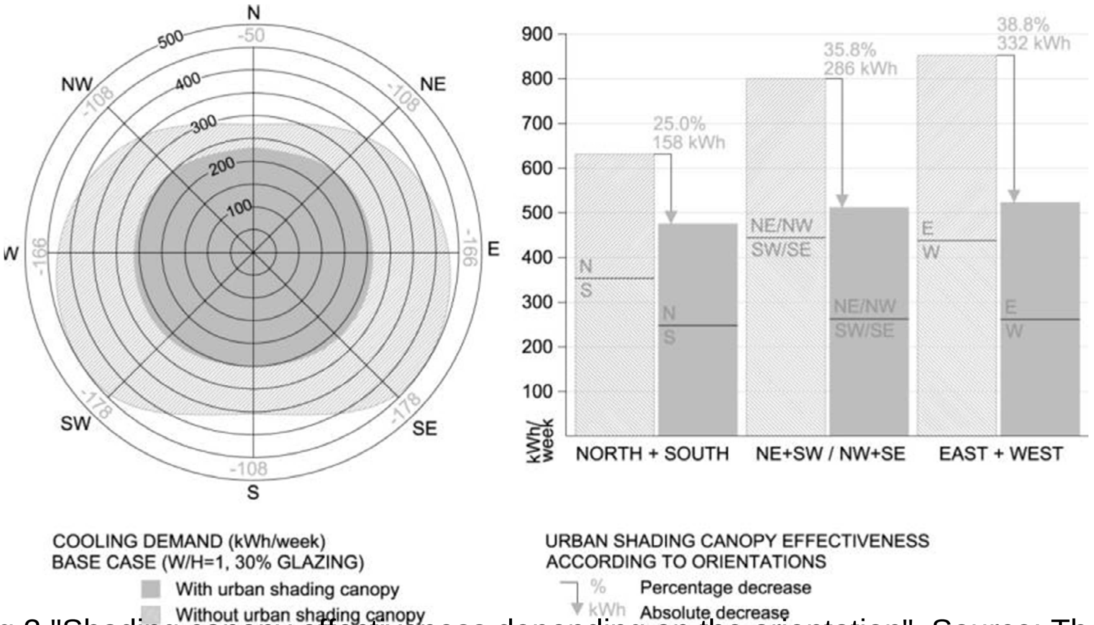

Fig.3 "Shading canopy effectiveness depending on the orientation". Source: The author

4.1.2.- Street aspect ratio (W/H)

In general, cooling demand for the unshaded case increases with the street aspect ratio because of a reduction in the shadows created by the urban morphology itself. As it was mentioned above, higher initial cooling demands are related to a higher effectiveness of the urban shading device. Consequently, the lower aspect ratios, the less effectiveness of the canopy shading should be expected, but with remarkable differences depending on the orientation.

A street aspect ratio variation does not affect all orientations in equal measure in terms of cooling requirements. As noted in Fig. 4, the cooling demand for canyons with E+O and NO+SE / NE+SO facades are considerably influenced by the street aspect ratio. On the contrary, canyons with N+S facades show a weaker dependence on this parameter, due to the fact that their main solar gains occurs with higher solar elevation angles.

It should be noted that, variations of this parameter are much more significant for lower W/H ratios than for higher ones. In fact, from a certain W/H ratio on, this variable becomes hardly irrelevant. For all of these reasons, significant differences are observed in absolute values of cooling demand reduction due to the shading device regarding to the street aspect ratio.

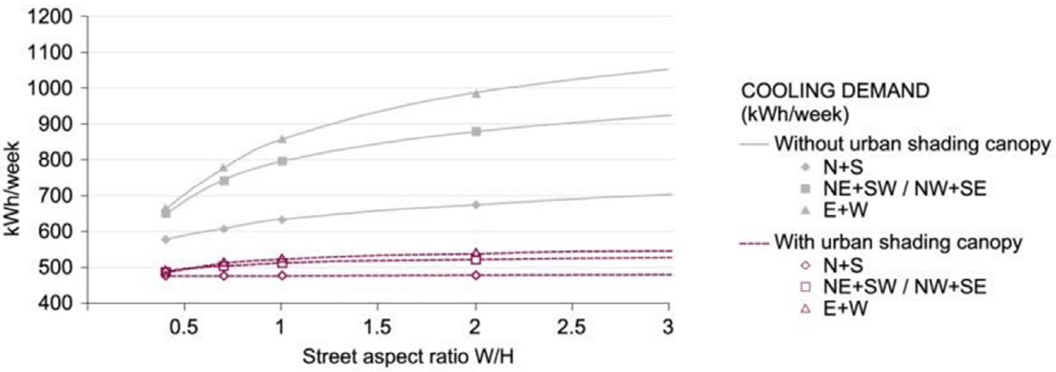

Fig.4 "Shading canopy effectiveness depending on the aspect ratio". Source: The author

4.1.3.- Window-to-wall ratio (WWR)

A halving of the glazing of the buildings diminishes the cooling demand for the unshaded location between 22-30% (Fig.5), due to lower solar and thermal gains through the windows (U_{wall}=2.5 W/m^2ºC, U_{glass}=5.7 W/m^2ºC).

As a consequence, the lower WWR of the street buildings, the lower effectiveness of the canopy, and vice versa. The shading canopy effectiveness is between a 6.6% and 8,1% higher for streets canyons with a 30% of WWR compared to the 15%WWR case.

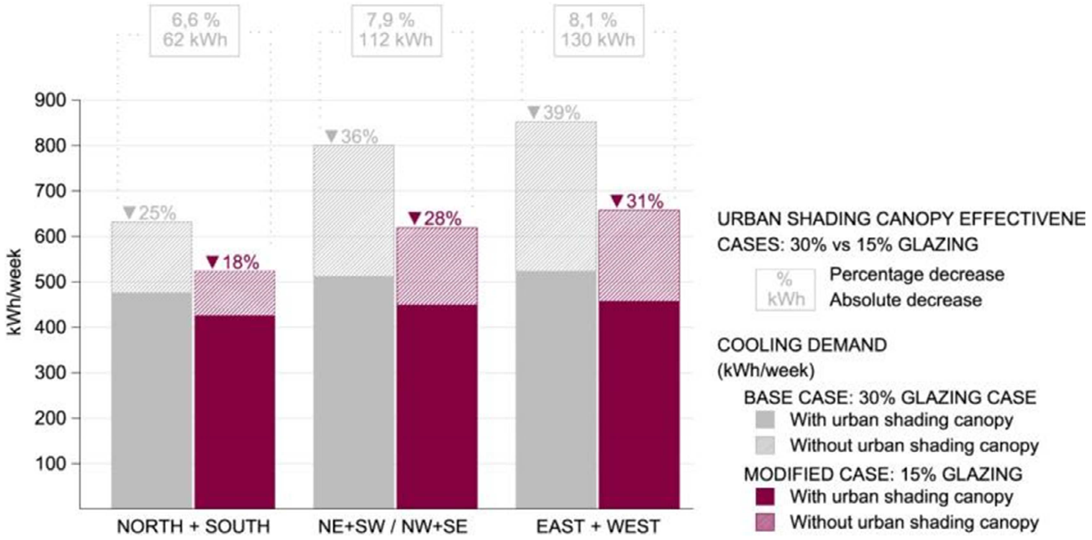

Fig.5 "Shading canopy effectiveness depending on the WWR". Source: The author

4.2.- Analysis of the material variables

4.2.1.- % Solar obstruction of the shading device

When a 30% reduction in solar obstruction of the shading canopy is settled, its effectiveness decreases by between 6% and 19%. These apparently low percentages imply a substantial fall in the device’s effectiveness (between three and four times less effective) and could make it little competitive compared to solar protections at a local scale.

Finally, it should be noted that the less opaque the canopy, the greater the differences that exist between cooling demands for all orientations and aspect ratios.

4.2.2.- Mass and thermal transmittance of the building envelope

In this section, the effects of simulating a four times lighter facade and a three times more isolated envelope are evaluated in connection with the shading canopy effectiveness. Both skin changes affect the way heat exchanges occur by conduction, while the urban shading device affects exchanges by radiation. Without changing the shading canopy features, its effectiveness in absolute terms is not related to a variation of the mass or the thermal transmittance because the amount of solar energy avoided is the same in any case.

This mass reduction barely alters the cooling demands (less than 4%), while a triple insulation generates a significant decline in the cooling requirements (22-40%) compared to the base case.

In the thermal transmittance modified case, the relative importance of solar contributions to the total gains would be significantly higher compared to the baseline. As a result, the shading device would be about 10% more effective.

5.- Conclusions

This paper demonstrates that it is possible to reduce cooling demand in individual buildings by acting at an urban scale. Results show an 18 to 45% decrease in cooling demand due to the urban shading canopy. The effectiveness ranges of this device reflect only the fall in cooling requirements due to the reduction of solar gains (direct and reflected radiation). However, other second-order effects are not taken into consideration in these results (surface temperature or air temperature changes).

A scale of relative importance between the study variables has been established (Fig.6). Except orientation, all variables have been partially assessed. Therefore, this scale can only be illustrative under similar circumstances to the case study.

In general, the shading device effectiveness depends more on the spatial variables than on the material ones. Orientation and street aspect ratio, purely morphological parameters, are shown to have a key role regarding effectiveness of the urban canopy. As for the impact on the configuration of the facade for this study, the importance of window-to-wall ratio is shown, as opposed to the mass and the transmittance of the enclosure with a minor role.

It should be noted that the implementation of this strategy would allow to balance cooling demands between the two sides of the urban canyon or even, between different parts of the city.

Finally, the results of this work highlight the importance of evaluating both urban facades, that is, the key role of analyzing consumptions from a perspective beyond the local scale of a single building.

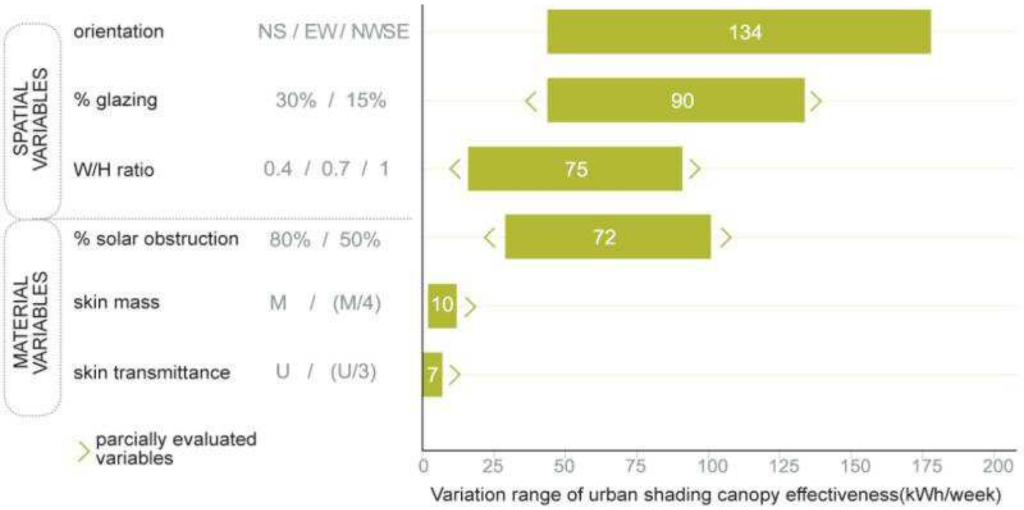

Fig.6 "Scale of relative importance between the study variables ". Source: The author

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