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Influence of street canyon's microclimate on the energy demand for space cooling and heating of buildings

A. Vallati[a]*, S. Grignaffini[a], M. Romagna[a], L. Mauri[b], C. Colucci[a]

[a]DIAEE Department of Sapienza University of Rome, Via Eudossiana 18, 00186 Rome, Italy
[b]Department of Mechanical Engineering, University of Roma Tre, Via Della Vasca Navale 79, 00146 Rome, Italy

Abstract

Since an important part of the world's energy is used for space cooling and heating of buildings, its minimization has great energy saving potential. Heat exchange between buildings and surrounding environment is due to convective and radiative heat flows. In this study a detailed building energy simulation (BES) has been carried out in order to analyze the effect of neighbouring buildings on these heat flows and in order to quantify mutual influence on the space cooling and heating demand of buildings. BESs were conducted for a stand-alone building and for a building situated in a typical street canyon. This study demonstrates the importance of considering the urban microclimate conditions for the prediction of the energy demand of buildings. With the implemented model most of the thermal effects of the urban microclimate can be modeled and quantified on a street canyon scale. Due to multiple reflections higher values of solar and thermal radiation are absorbed at the façades of buildings in street canyons than those that occur at stand-alone buildings façades. These effects cause higher surface temperatures in street canyons which means higher space cooling and lower space heating demands. Other reasons that cause this phenomenon are the lower convective heat transfer coefficients in street canyons that results in a reduction of the heat removal from street canyons and contribute to plump the urban heat island effect.

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* Corresponding author. Tel.: +39-06-44585664
E-mail address: andrea.vallati@uniroma1.it

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1. Introduction

Residential and commercial buildings are responsible, respectively, of approximately 25% and 15% of EU final energy consumption. Space heating accounts for almost 60% of residential energy consumption [1]. So there is a great potential to save energy by minimizing the energy demand for space cooling and heating of buildings. Today about 50% of the world population lives in urban areas and this proportion will grow to about 70% by 2050 [2]. The microclimate in urban areas differs significantly from the climate in rural areas thus influencing the energy consumptions of buildings [3]. Air temperatures are higher because of the urban heat island effect (UHI) [4] and the wind speed is lower because the buildings are protected from it. Measurements performed in the city of London showed night time air temperature up to 7 K higher than those measured outside the city [5]. In Athens, the average intensity of the heat island exceeds 10 K, which can double the energy demand for space cooling in buildings [6]. Global warming and summer heat waves [7,8] can further increase the temperature in urban areas and significantly reduce cooling potential due to passive night ventilation in temperate climates. The UHI effect not only influences the energy required for cooling and heating of buildings, but has also a great impact on thermal comfort and health of people living in urban areas [9]. Building energy simulation models (BES) are commonly used to forecast the cooling and heating demands of the buildings [10]. Nowadays the most used BES models were developed for stand-alone buildings. The question to ask is whether these BES models are suitable to predict the energy demand of buildings in urban areas. It is well known that the radiative exchange between neighbouring buildings has a sensible impact on energy demand [11,12]. Commonly only the shading is modeled in BES, while in order to properly solve the energy balance, even the multiple reflections of solar radiation and longwave radiation between buildings should be considered.

For the sake of simplicity, a canyon road geometry has been chosen as example of a typical urban configuration of a city. The budget of heat flows on the buildings facades is analyzed to evaluate the influence of short and longwave radiations on the surface temperature and their impact on energy demand in urban areas. It was considered a type of building constructed following the directions of the current Italian law. Radiative exchange of short and long wave radiation in the canyon is calculated by taking into account multiple reflections as implemented in BES model. Some data obtained by previous works have been used as inputs for the implemented model [13-16].

2. Mathematical model

In this work a BES code as Trnsys 17 was used for the calculation of the energy performance of the considered building. Trnsys 17 is a dynamic software that is able to model a 3D multi-zone building and through which it’s possible to perform simulations for the entire duration of a year with time discretization of 1 h. The heat conduction through the walls is modeled as transient thermal flow using transfer functions and the heat exchange related to convective effect between outdoor environment air and building envelope is modeled through the adoption of a surface CHTC equal to 17.8 W/m² K in this study (while it is equal to 3 W/m² K for indoor surfaces). For what concerns the radiative exchanges, in TRNSYS 17, here is a 3D radiation module that take into account multiple reflections but that is only used for internal zones.

Therefore, in this study, the street canyon was modeled as an internal zone with an open-air ceiling that is an atrium. In this way, the shading of the adjacent buildings and the long-wave radiation exchange between the buildings can be modeled accurately. In the following pages we analyze heating and cooling demands for a residential building with three floors. The energy simulation is performed for a stand-alone building in an open field, with no obstacles around it, and for the same building situated in a virtual urban environment, between two street canyons. We considered a street canyon with an aspect ratio H/W = 1 (with H building height and W width of canyon).

Fig. 1 illustrates the studied building surrounded by two street canyons with H/W = 1. Here it is also possible to see the orientation chosen for the construction unit.

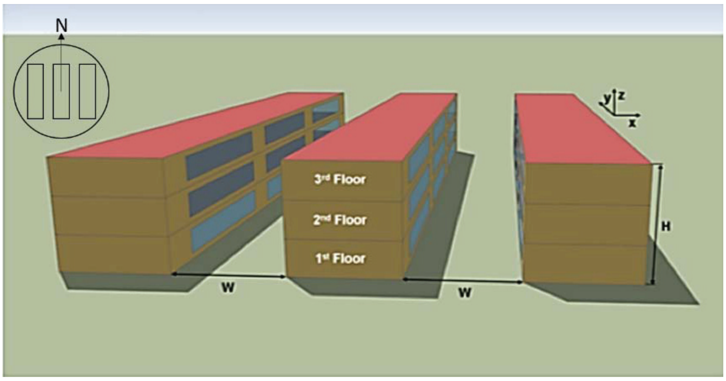

Fig. 1. Studied building surrounded by street canyon with aspect ratio (H/W) of 1.

The building is assumed to be very long (110.5m), corresponding in fact to a row of buildings. The height H (three floors) and the width W of the building are of 13.5 m each. The border walls of the buildings are modeled as adiabatic assuming that they are connected to other buildings. The building under consideration is flanked by two more rows of buildings, as it's clear observing Fig. 1, which have the same features of the studied building. Even in their case, the boundary surfaces of the model are considered adiabatic. The energy requirements of these two buildings are not evaluated.

We analyzed a building whose thermophysical characteristics are listed in Table 1.

Table 1. Values of transmittance of the building envelope elements

Description	**U (W/m^{2}K)**
Top Roof	0.31
External Wall	0.35
Ground Floor	0.34
Window	1.40

The solar absorbance of the surfaces facing the street canyon environment are $\alpha_{walls} = 0.6$ for external building walls and $\alpha_{asph} = 0.9$ for the streets pavement (asphalt). All the surfaces have emissivity value $\varepsilon = 0.9$.

3. Results

The results we are going to evaluate were calculated for two consecutive years using the weather files of the city of Rome. For viewing convenience two days of winter (January 1-2) and two days for the summer period (July 1-2) were chosen.

In Fig. 2 the heating and cooling demands for the stand-alone building (SAB) and for the building inside the canyon (SBC) with H/W=1 were analyzed. As it is possible to see in the figure, the building inside the canyon provides a heating energy requirement greater than the one of the stand-alone building, while the cooling load is lower for the building between the canyons. The reason is due to the fact that the building surrounded by the canyons is shaded compared to the isolated building, above all because the fraction of glazed surface is large (50%). This effect produces an increase in energy demand in winter and a decrease in summer demand.

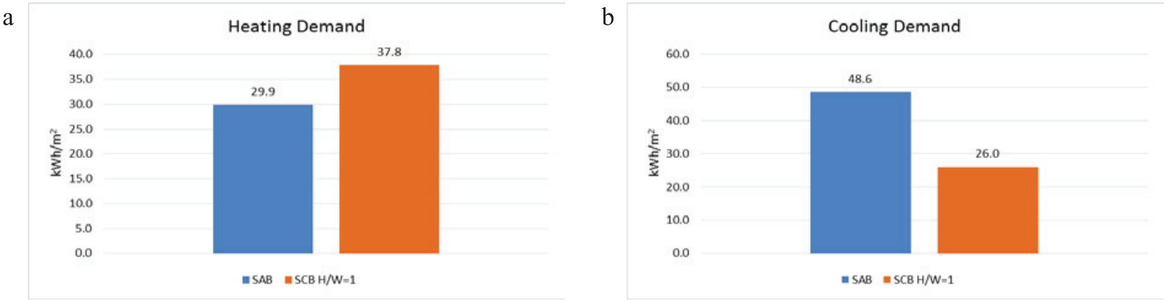

Fig. 2. (a) Heating load of the SAB and SCB buildings; (b) Cooling load of the SAB and SCB buildings.

We now analyze the radiative fluxes and the surface temperatures on the external walls. The analysis is carried out for a period of time of 48h during the summer and winter periods. It is considered the SA and SBC configuration of a street canyon having N/S orientation. Fig. 3 shows the solar radiation, the sum of direct, diffuse and reflected radiation on the facade of the building overlooking the street canyon.

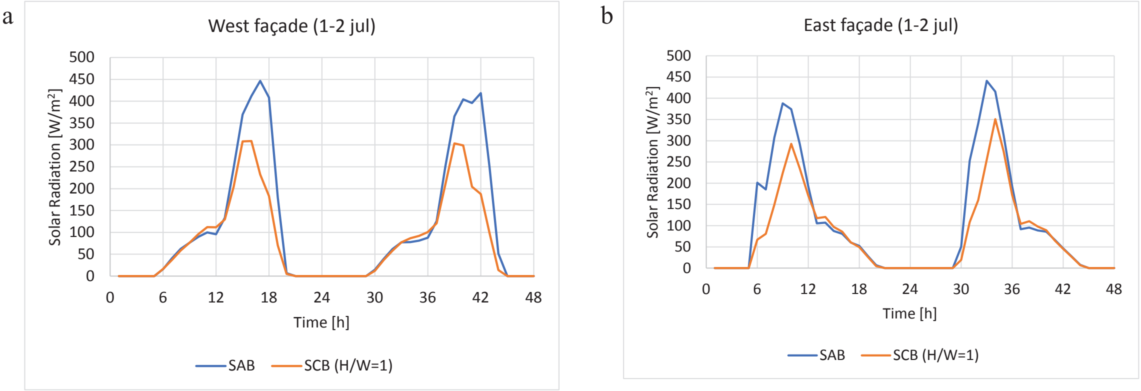

Fig. 3. (a) Solar radiation absorbed at west façade on summer period; (b) Solar radiation absorbed at the east façade on summer period.

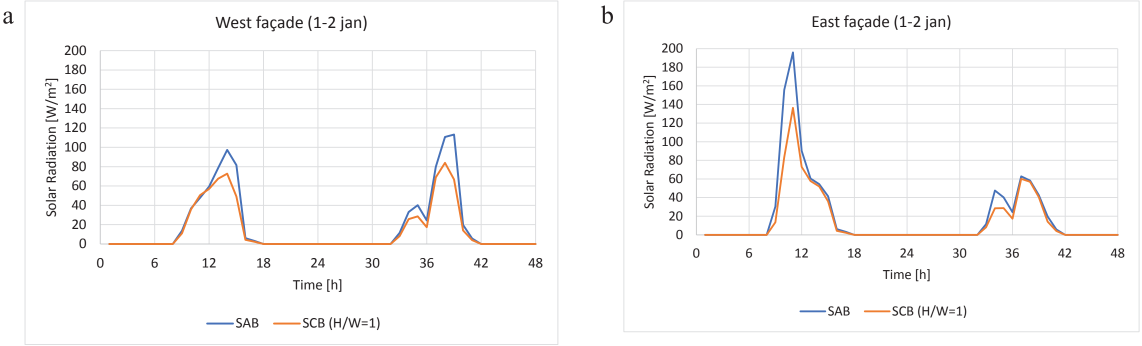

Fig. 4. (a) Absorbed radiation at the west façade on winter period; (b) Longwave radiation for the East façade on winter period.

As shown in the figures above, on both façades occurs the typical classical trend of solar radiation, which provides a peak during the day. For the west façade, the peak occurs in the afternoon and is mainly due to the diffuse solar radiation while the east façade peak occurs during the morning and is due to direct solar radiation. For the SBC configuration, the solar radiation decreases for both east and west facade and this effect is exclusively due to shading. It is also possible to notice, in Fig. 4, a decrease in the differences between SAB and SCB solar fluxes in winter period.

In Fig. 5 and 6, below, are shown the trends of the radiative heat fluxes (solar plus longwave thermal radiation) for two east and west façades, for a duration period of 48 h during the summer (July 1-2) and during winter period (January 1-2). Of course, also in this case, the comparison is made for two configurations: stand-alone building (SAB) and street canyon building (SCB), with aspect ratio H/W=1.

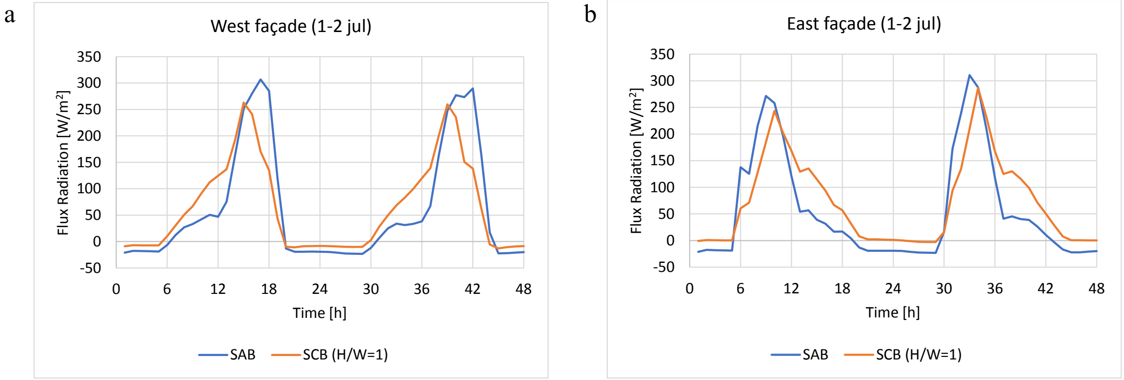

Fig. 5. (a) Absorbed total radiation at the west façade on summer period; (b) Absorbed total radiation for the East façade on summer period.

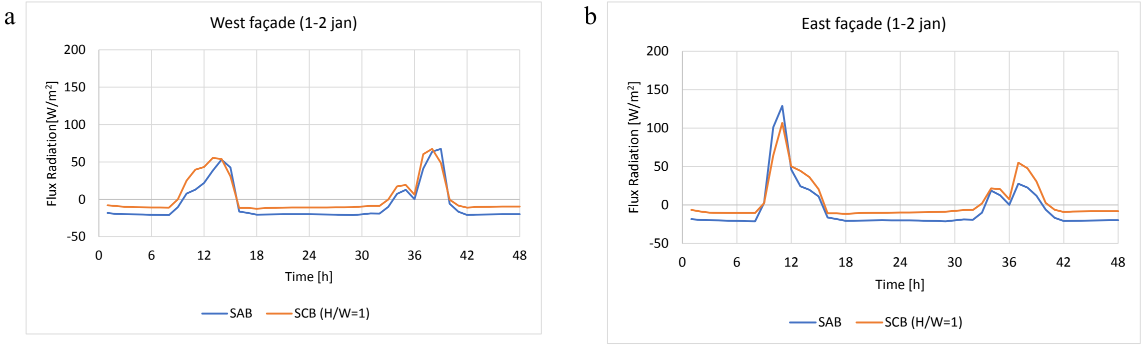

Fig. 6. (a) Absorbed total radiation at the west façade on winter period; (b) Absorbed total radiation for the East façade on winter period.

As can be seen from the previous figures the trend of the total longwave radiation is similar to that of the solar radiation. The comparison of figures 5 and 6 shows that, for both façades, the total radiation decreases compared to the solar radiation absorbed by the walls. In fact, the facades heat up because of the absorption of solar radiation but then emit long-wave radiation to the cold sky and to the facades of nearby buildings, leading to a (net) lower total value of radiation. Overnight it is possible to observe negative values of total radiation; this can be explained by the long-wave thermal radiation to the cold sky. This decreasing of the total radiation is lower for the SCB building because of the shelter of neighbouring buildings.

The following Fig. 7 and 8 shows the analysis carried out for what concerns the temperature of the east and west walls by comparing it with the corresponding values regarding the stand-alone building and highlighting also the air temperature. The plots reported concern cooling and heating periods.

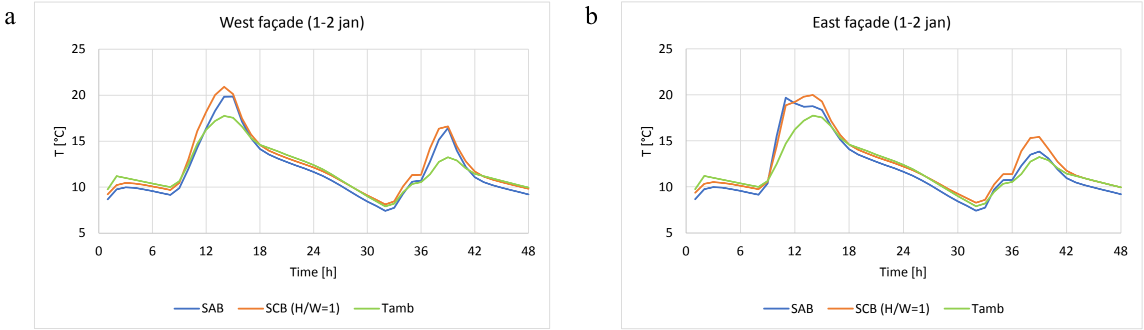

Fig. 7. (a) Temperature of the west façade on the winter period; (b) Temperature of the east façade on the winter period.

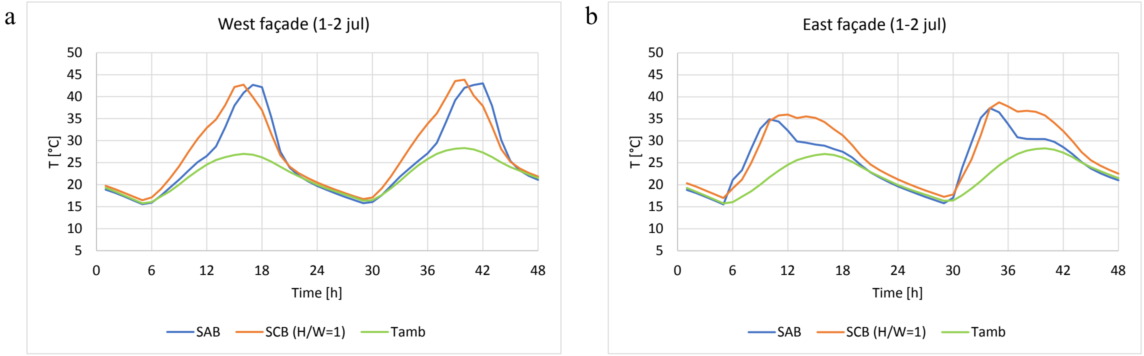

Fig. 8. (a) Temperature of the west façade on the summer period; (b) Temperature of the east façade on the summer period.

Looking at the graphs it is clear that, in winter, both walls assume the same trends with the SCB temperatures similar to those of the SA building. During the summer, east façade assumes, for a longer period of time, higher values than those of the SA building, while the west façade shows similar results for the two considered configurations.

4. Conclusion

In this work, cooling and heating loads for a stand-alone building and for a building in a street canyon, in the city of Rome, have been determined, by means of a BES software. The parameters which influence these energy demands have been analyzed and compared. The most important phenomena affecting the microclimate within an urban street canyon were modeled such as multiple inter-reflections in the field of solar and thermal radiative exchange between neighboring buildings and reduced convection heat transfer due to the shelter from the wind. This study was conducted on a building with envelope transmittance values in accordance with current laws.

It was found that, for how is set the model, and considering the climate of the case study city, the cooling demand is less for buildings in a canyon configuration compared to the stand-alone building while for heating demand occurs the opposite. Inside the street canyon, the net radiation on the façades of the building, being the sum of solar radiation, the long-wave thermal radiation and inter-multiple reflection, is higher than that on the facades of stand-alone building, except when direct solar radiation prevails (from 14.00 to 16.00 for the west façade and from 9 to 11 for the east façade). This phenomenon appears to be amplified in the summer season, when the external surfaces of the SA building receive, in highest insolation hours, a net radiation appreciably higher than in the SCB case, for a more extended time window (from 15 to 20 for the west façade and from 5 to 11 for the east façade). Moreover, for buildings in the canyons, the longwave radiative exchange towards the sky and the subsequent cooling of the facades, is partially blocked. As a result, the surface temperatures of facades of buildings in urban areas show to be higher, for a greater number of hours, compared to those of the buildings in rural areas. In the canyon, the entrance of direct radiation is partially hindered during the daytime because of shading, while overnight the long-wave radiation trapping phenomenon prevails. For this reason, the cooling potential for night ventilation is significantly reduced in urban areas especially in temperate climates.

As future study, we expect to carry out the following kind of deepening: (i) a more massive envelope building, representative of construction types of the city center of Rome, should be considered; (ii) it should be analyzed the effect of the introduction, in our simulation model, of a more accurate wind direction-dependent CHTC correlation, in order to consider the wind sheltering effects due to the urban canyon orientation; (iii) in order to achieve a sort of intensity index of the UHI phenomenon, a more extended model representing a larger urban fabric should be simulated, for taking into account of the influence of the surrounding building features on the microclimate of a single street canyon.

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