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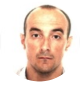

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Influence of the façades convective heat transfer coefficients on the thermal energy demand for an urban street canyon building

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Abstract

In an urban micro-climate environment, the convective heat transfer coefficient (CHTC) on the façades influences simulated building's energy demand and exterior wall surfaces temperatures. In this paper, it is analyzed how the CHTC values on the façades of a building located in an urban canyon influence the façades temperatures and how important is the choice of an accurate CHTC correlation on the space cooling and heating energy demand. CHTC correlations found in literature are based on some specific micro-climate parameters such as local wind speed, district construction density, temperature differences between façades and canyon air and wind direction. An accurate choice of the right correlation for the simulated urban environment is important to better represent the exterior walls heat removal due to outside wind climate. The effects of the use of different CHTC correlations have been evaluated by means of TRNSYS 17.0 simulation program. The study is performed for a building sited an urban street canyon with the aspect ratio H/W=1 and located in a Mediterranean climate, in Rome. The comparison performed between the results of the numerical simulations shows that some correlations lead to an underestimation of the space heating demand around 9.7% and to an overestimation of the space cooling demand around 17.5%.

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Keywords: Urban canyon; Microclimate; Building energy demand; CHTC;

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1. Introduction

The assessment of the building thermal energy demand requires an accurate modeling of the convective heat transfer coefficient on the interior and exterior surfaces of buildings' walls [1]. Moreover, the choice of parametric relations able to better define CHTC values on buildings' façades is a crucial issue for energy performances evaluations but also for the assessment of outdoor microclimate conditions [2].

For these reasons, many studies were carried out by researchers with the purpose of studying the physics of the heat transfer mechanism by convection on the buildings walls or roofs [3] and then to define the CHTC numerical correlations able to describe the phenomenon.

More specifically, the influence on thermal loads calculation of the interior convective heat transfer coefficient on building walls has been evaluated by means of experimental campaigns [4,5] and numerical simulation [6]. Some studies carried out in these last years on the evaluation of exterior CHTC values highlighted how different choices for the CHTC lead to sensible differences, from 20% up to 40 %, for what concerns the building thermal energy demand [7]. Several works are focused only on the study of stand-alone buildings [7], in forced convection [8] or in turbulent flows [9] while some other works consider two parallel buildings constituting an urban street canyon with fixed [10,11] or parametric geometry [12] in which mutual thermal interactions between buildings create the conditions that influence the values of CHTC.

In some studies, it is found that the choice of a CHTC correlation for summer season could not be effective for winter season [2]. Moreover, numerical simulation of building arrays immersed in a turbulent boundary layer were performed with the purpose of evaluating the influence of a specific urban fabric on CHTC value [13]. The impact of variation of buildings walls solar radiation absorption on the values of CHTC has been analyzed in [14] underlining its dependence on other construction thermos-physical parameters.

The importance of coupling CFD results with BES (Building Energy Simulation) tools is highlighted by [15,16] where evaluations on the thermal energy demands of buildings where performed for stand-alone and street canyon buildings respectively. BES software are used to evaluate the energy performances of buildings, modeling the heat/mass transfer with the outdoor environment in the most realistic conditions. As a matter of fact, BES tools have a great potential for what concerns the prediction of building thermal energy consumptions only if the model is as accurate as possible. This means that a high accuracy of the model, for what concerns boundary conditions, will help to better predict building consumption. The impact of exterior surface convective heat transfer coefficients on the building energy consumption in urban neighborhoods with different plan area densities is analyzed in [17].

In this paper, the impact of different CHTC correlations on the thermal energy demand for a street canyon building has been assessed by means of a BES tools as TRNSYS 17.0 [18]. The purpose of this study was to evaluate how CHTC correlations affect façades temperatures and building thermal energy demands by means of TRNSYS software adopting a "false" zone method [19]. In fact, by modelling the outdoor space of the canyon as an interior zone, TRNSYS applies the detailed radiation model that consider multiple reflections in the shortwave and longwave field. The main objective is an evaluation of the choices of different CHTC correlations to better represent the heat exchange phenomena between building envelope and surrounding environment using a validated radiative model.

2. Simulation model

As previously mentioned, in this paper, building energy simulations have been carried out adopting a TRNSYS model which consider the mutual inter-reflections in the shortwave and longwave radiative field. Hence, the boundary conditions used are those reported in a previous work [19]. All the simulations were performed for a building considered in an urban context, adjacent on both main long sides to street canyons. The BES software used to perform the numerical simulations in this work is TRNSYS 17.0, a transient 3D multi-zone building code able to simulate dynamically the energy behavior of a building with time steps of less than one hour.

BESs are implemented to simulate a street canyon building (SCB) model with H/W=1. The geometrical parameter H/W, named "canyon aspect ratio", is referred to the canyon between the buildings: H is the height of the canyon and W is its width. In the set of simulation only one orientation for the street canyon axes was adopted: E-W. This means that building glazed façades face the North and the South thus interacting with the street canyon environment. The following Fig. 1 shows the street canyon geometrical parameters and its configuration.

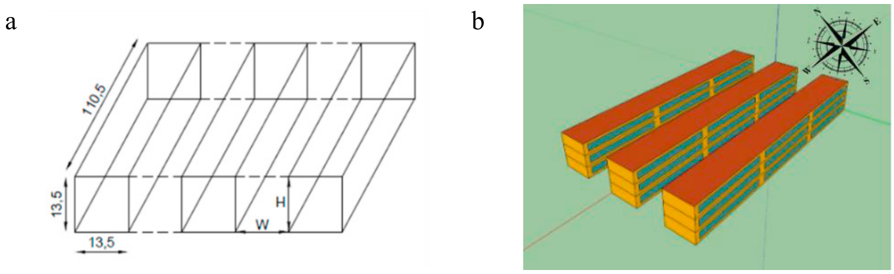

Fig. 1 – (a) Geometrical features of building and canyons; (b) 3D overview of SCB configuration.

Thermophysical and optical features of the opaque and transparent elements of the building envelope are reported in Table 1, below.

Table 1 – Main features of construction envelope elements.

Envelope element	Materials	Thickness *(m)*	U *(W/m² K)*	g	α	ε
Walls	Plaster, brick, insulation	0.44	0.36		0.6	0.9
Roof	Plaster, concrete, screed, insulation	0.37	0.32		0.6	0.9
Pavement	Ceramics, concrete, isolation, plaster	0.54	0.34		0.6	0.9
Windows	Glass, wood	-	1.40	0.6		0.84

Persons and other devices sensible gains values (and occurrences profiles) are reported in the following Table 2, as recommended in the national standard UNI/TS 11300-1.

Table 2. Internal gains values and their occurrences.

Internal gain	W/m^2	Weekday time slots	
		On	Off
Persons	4.52	0-24	-
Lights	5	17-24	0-17
Other devices	1.41	8-24	0-8

The space cooling and space heating demands are determined considering the room air temperatures controlled to remain at 20 °C during the winter (the statutory heating period in Rome from 1st November to 15th April) and 26 °C during summer (considering as cooling period the days in which the internal temperature exceeds 26 °C). As a matter of fact, climatic data for the Italy city of Rome are used as input for the BES. For these reasons 4 different CHTC correlations have been chosen reported in the following Table 3.

Table 3 – CHTC correlations used for the numerical simulations.

Code	Correlation	Reference
A	$CHTC = 18$ [W/ m^2 K]	TRNSYS 17.0 default value
B	$CHTC = 4+4*u_o$ [W/ m^2 K]	UNI EN ISO 6946 corrected
C	$CHTC = 4+4*u_{loc.}$ [W/ m^2 K]	UNI EN ISO 6946
D	$CHTC=\sqrt{[(3.39-5.03\lambda_p)U_{loc}^{0.94}]^2+[1.52\vert\Delta T\vert^{0.36}]^2}$ [W/ m^2 K] (windward) $CHTC=\sqrt{[(1.15+0.82\lambda_p)U_{loc}^{0.94}]^2+[1.52\vert\Delta T\vert^{0.36}]^2}$ [W/ m^2 K] (leeward)	J. Liu et al. [20]

In Table 3, u_0 is the undisturbed wind speed (values from weather data file of TRNSYS), u_{loc} is the local wind speed calculated with Type 2260 (function of shear exponent at weather station, shear exponent at site location, weather station data collection height and building height), λ_p is plan area density and here is taken equal to 0.25 and ΔT is the difference between weather data air and façade temperatures. Case A is considered as the reference since it is the default value of CHTC in TRNSYS and the main purpose is evaluation of the goodness of adopting a constant CHTC value to represent the heat exchange phenomena between building envelope and surrounding environment.

3. Results

Fig. 2 shows North and South façade temperatures on 1st and 2nd of January chosen as representative of winter while Fig. 3 shows North and South façade temperatures on 1st and 2nd of July chosen as representative of summer.

During the winter season (Fig. 2a and Fig. 2b), A, B and C correlations provide similar values for what concerns façades temperatures while D correlation overestimate façades temperatures especially in the central hours of the days. In summer (Fig. 3a and Fig. 3b), in the middle of the days, all the correlations provide distinct values of exterior wall surface temperatures. D correlation continue to overrate façade temperatures even during night time for what concerns North façade (Fig. 3a) while B correlation provides the lowest values. In this summer case, the default values used in TRNSYS (case A), are similar to normative values. More in details, the overestimation between D correlation façades temperatures and the others is around 4 °C in winter at noon. As previously mentioned, B relation provide lowest values of façades temperatures, compared to the others while D provides highest values of surface temperatures and there is a temperature difference up to 10 °C at noon in summer. This fact highlighted that some correlation is more suitable for describing the convective phenomenon in winter than in summer season [2].

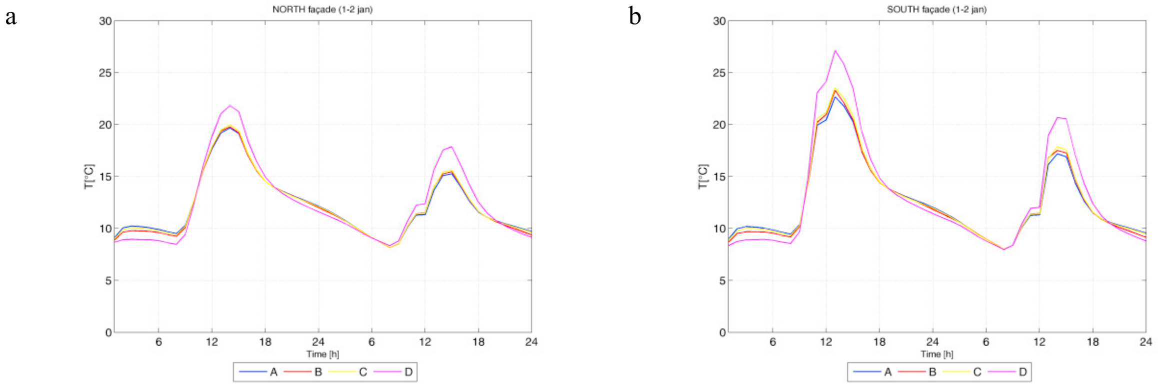

Fig. 2. (a) Temperature of the North façade in the winter; (b) Temperature of the South façade in the winter.

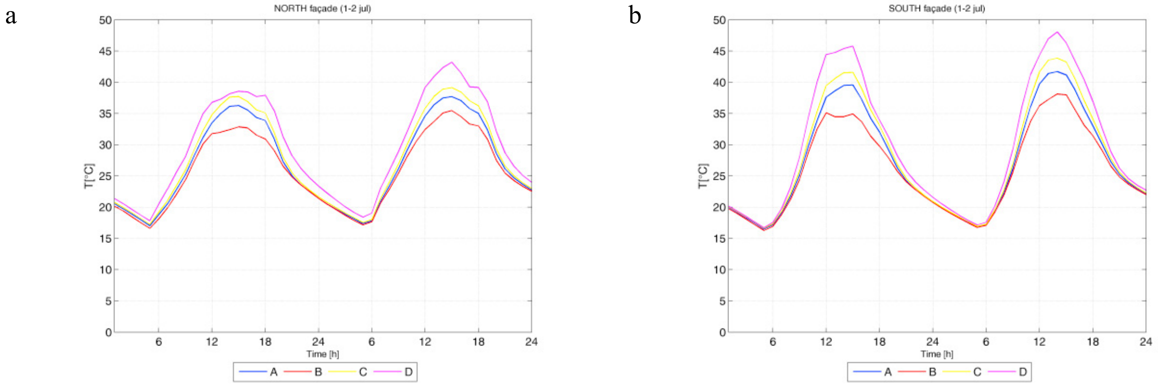

Fig. 3. (a) Temperature of the North façade in the summer; (b) Temperature of the South façade in the summer.

For what concerns the trends of thermal dispersion, strictly related to the values of CHTC correlations, Fig. 4a and Fig. 4b show the longwave radiation on North and South façades during winter (1-2 January), while Fig. 5a and Fig. 5b show the longwave radiation values during summer (1-2 July).

The trends of longwave radiation in winter season, in Fig. 4a and Fig. 4b, are consistent with façades temperatures: there is a higher thermal dispersion towards the sky for D relations, due to surfaces higher temperatures, both for north (Fig. 4a) and for South façades (Fig. 4b). In general, in winter, the thermal dispersion on South façade double the thermal dispersion on North façade. This fact is certainly related with the higher presence of direct solar radiation hitting the South exterior walls which raises their temperatures while the sky fictive temperature remains the same. It is also possible to notice the reversal in the thermal dispersions of D correlations compared to the others, consistent with the same reversal in temperatures (Fig. 2a and Fig. 2b).

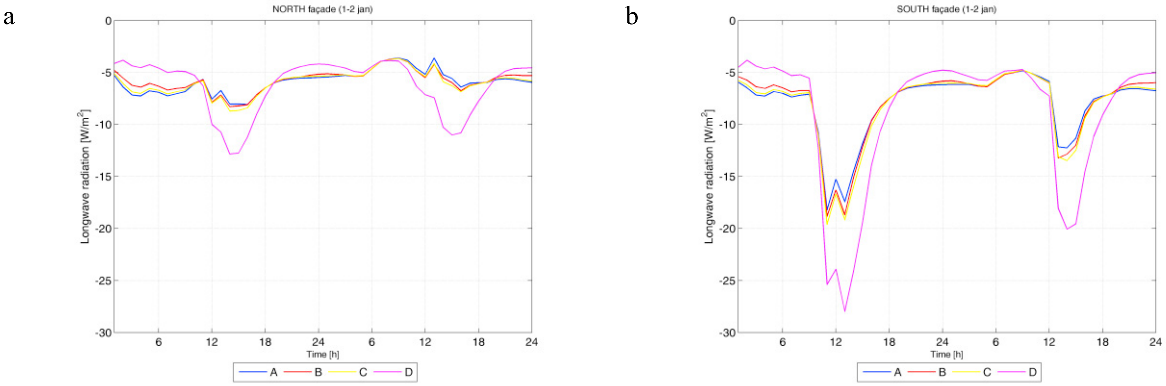

Fig. 4. (a) Longwave radiation on the North façade in winter; (b) Longwave radiation on the South façade in winter.

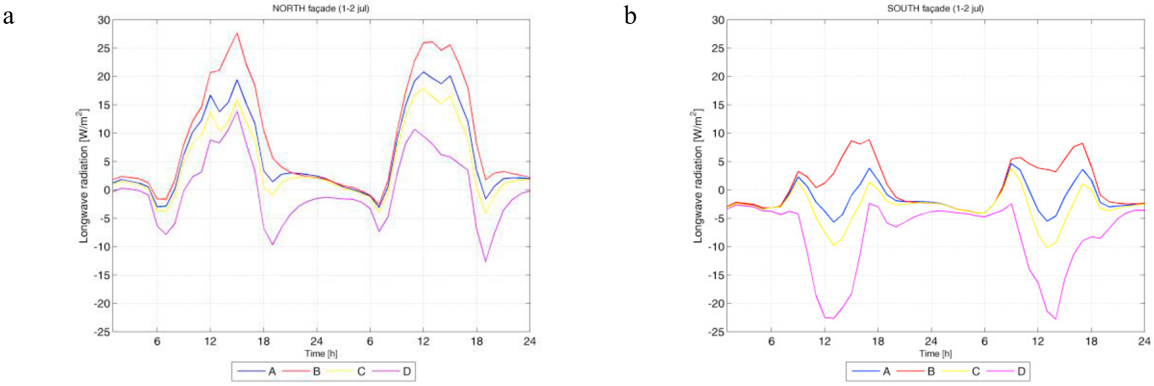

Fig. 5. (a) Longwave radiation on the North façade in summer; (b) Longwave radiation on the South façade in summer.

The trends of thermal dispersion for summer season, in Fig. 5a and in Fig. 5b, shows a behavior in accordance with façades/air difference temperatures. In fact, depending on these temperature difference, there are thermal dispersions or gains.

Hence, B correlations provides that façades have the highest thermal gains during day time; for North façades (Fig. 5a), since air temperature is lower during the dawn hours, thermal dispersions occur in these time slots (higher thermal gains occur during day time). D correlation, providing the highest façades temperatures as shown in the previous figures, has lowest thermal gains and more intensive thermal dispersion, mostly during night time. A and C correlations provide similar trends of thermal exchange values, always as a function of exterior air temperature.

At last, building thermal energy demands have been evaluated for heating and cooling seasons. While A, B and C correlations provide similar values for what concerns thermal energy demands, both in summer and in winter, D relation involves an underrate of heating demand as well as an overrate of cooling demand. These season energy demands values are totally in agree with the trends of façades temperatures.

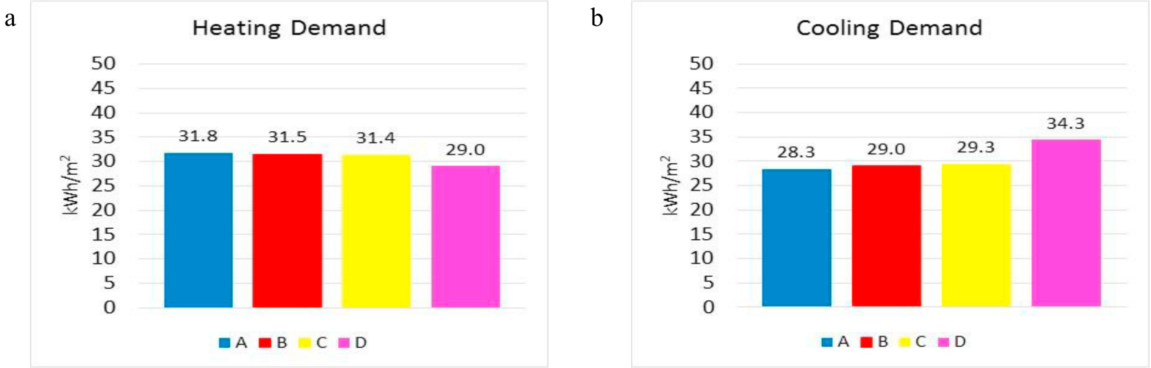

Fig. 6. (a) Heating demand and (b) cooling demand as a function of CHTC correlations.

The comparison performed between the results of the numerical simulations shows that D correlation lead to an underestimation of the space heating demand around 9.7% and to an overestimation of the space cooling demand around 17.5 % compared to A correlation. The percentage variation of the energy demands results between A, B and C correlations remains in a range of values between 1.3% for what concerns heating demands and between 3.4% for cooling demands as shown in the following Table 4.

Table 4 – Percentage variation of energy demands between each correlation.

	Heating demands	Cooling demands
A → B	-1.0 %	+2.4%
A → C	-1.3%	+3.4%
A → D	-9.7%	+17.5%
B → C	-0.3%	+1.0%
B → D	-8.6%	+15.5%
C → D	-8.3%	+14.6%

Since B and C are based on the same correlations (UNI EN ISO 6946) in which the wind speed is taken at different conditions, they provide similar results for what concerns façades temperatures and thermal exchange intensity; hence, they have quite corresponding values of thermal energy demands (variation of -0.3% for heating demands and of +1.0% for cooling demands). Case A constitute a good compromise to reproduce the convection phenomenon on the building façades since provides low differences regarding thermal energy demand with B (-1.0% for heating demands and +2.4% for cooling demands) and C (-1.3% for heating demands and +3.4% for cooling demnads) cases, which are the normative correlations.

Correlations D is not representative of the convective phenomena simulated in our model since the difference shown with all the others cases, both for what concerns temperatures/thermal exchange and for thermal energy demands, are very important: -9.7% with A, -8.6% with B and -8.3 with C for heating demands, +17.5% with A, +15,5% with B and + 14.6% with C for cooling demands. It is demonstrated even on the thermal energy demands that D correlations overrate thermal dispersion in winter and underrate it in summer.

4. Conclusions

The results of this study showed that the choice of the right CHTCs correlation becomes more important considering that the energy simulation model must be calibrated in accordance with the stringent requirements of ASHRAE Guideline 14-2002. Wind directions, shape of the district, height of buildings and distance between them in the urban fabric are important parameters which could influence the results of this study. This study underlined the importance of carefully choosing the façades CHTC correlations to simulate building energy behavior, especially if the objective is a prediction of heating and cooling energy consumption for a building in an urban context.

More specifically, building façades temperatures and their relations with longwave radiation have been evaluated as well as space heating and space cooling energy demand. Four different correlations named A, B, C and D were considered as functions of local wind speed, district density and temperature differences between façades and canyon air and wind direction. While A, B and C correlations provide similar values for what concerns thermal energy demands, both in summer and in winter, D relation involves an underrate of heating demand as well as an overrate of cooling demand. A comparison performed between the results of the numerical simulations shows that D correlation lead to an underestimation of the space heating demand around 9.7% and to an overestimation of the space cooling demand around 17.5 % compared to A correlation. The percentage variation of the energy demands results between A, B and C correlations remains in a range of values between 1.3% for what concerns heating demands and between 3.4% for cooling demands.

This study demonstrates that in our TRNSYS detailed radiative model, the constant default value for CHTC on building envelope exterior surfaces can approximate relatively well the convective phenomena, since there is a good correspondence with the normative correlations results, B and C. A deeper study might be performed for what concerns D correlations that constitutes a more refined correlation. Based on these considerations, as possible future research, it could be interesting performing a sensitivity analysis on the thermal energy demands changing the city, the district construction density and shape and the surfaces albedo also to verify if correlations D works better for some specific case.

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