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QUANTIFYING URBAN WIND EFFECT ON BUILDING ENERGY SIMULATION

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Abstract. *Urban spaces are characterized by specific microclimates that change wind speed, temperature and vapor pressure fields, which are essential parameters for building energy simulation (BES). However, these phenomena are reasonably simplified in most of BES tools. To take into account the impact of the urban environment on building energy demand, we propose to couple a Computational Fluid Dynamic (CFD) model to a BES tool. The CFD model is used to simulate airflow around the buildings and to calculate input parameters for the BES model. The proposed coupling method is investigated in two different urban morphologies, highlighting the impact of urban environment on the BES input parameters.*

Keywords: *urban climate, building energy simulation, CFD.*

1. INTRODUCTION

According to the International Energy Agency, buildings are the largest consumers of energy worldwide. Building Energy Simulation (BES) is a powerful computational tool to optimize building energy efficiency. Traditionally, BES tools use standard meteorological data from local airport. However, for buildings located in towns, these data are not representative of the local microclimate, because the urban morphology, the use of materials with high absorptance and heat capacity, the lack of vegetation and the anthropogenic heat sources modify the wind and temperature fields in the urban environment (Oke 1987).

The convective heat transfer coefficient (*CHTC*) can be strongly modified by the urban morphology (Merlier Lucie 2015), which also will impact the building energy demand. In the most BES tools, the *CHTC* is considered as constant for all building walls. Some recent studies (Emmel, Abadie, and Mendes 2007) show the importance of taking into account the direction and intensity of the wind to compute the *CHTC* for each wall. In the present work, we first propose a methodology to consider the urban environment in *CHTC* computation. Then, we present a case study with two different urban morphologies to highlight the impact of urban velocity fields on the results produced by a BES tool.

2. METHODOLOGY

2.1 Tools and models

The 3-D CFD ANSYS-CFX software (Ansys 2006) is coupled to the BES tool DOMUS, which is a hygrothermal building model developed to calculate energy and mass transfer, energy demand and thermal comfort in buildings (Mendes, Oliveira, and Santos 2005). Recent development have been introduced to improve solar radiative exchange simulation (Rocha, Oliveira, and Mendes 2017).

The coupling between ANSYS-CFX and DOMUS has been performed by a software developed in Python language. Buildings and grounds are created in DOMUS, and geometrical data are extracted to build the canopy in CFX, which is represented as a wind tunnel centered on the area where the buildings investigated are located, respecting urban CFD simulation practices (Franke et al. 2007). The boundary conditions are determined using a reference

temperature T_{ref} , a reference wind speed V_{ref} and wind direction D_{ref} . Buildings surface temperature and building indoor air temperature are simulated with DOMUS and are used as boundary conditions in the CFD simulation. CFX calculates the air speed field around the building(s). Then, CHTC are computed for each building wall to define the convective heat fluxes φ_c to be used in DOMUS. The coupling process is represented in **Erro! Fonte de referência não encontrada.**

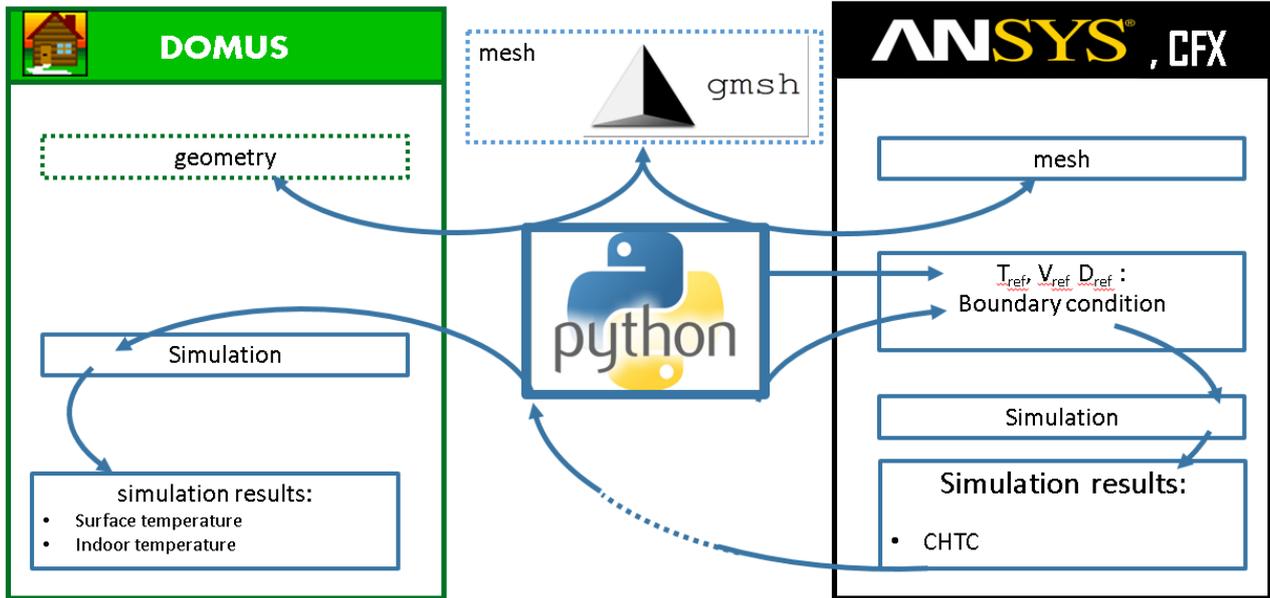


Figure 1. Coupling methodology between DOMUS and ANSYS CFX

The coefficients $CHTC_i$ and the convective heat flux $\varphi_{c,i}$ for the wall i can be determined by Equations (1) and (2) (Jayamaha, Wijeyesundera, and Chou 1996), respectively:

$$CHTC_1 = 8.85 + 1.7v_1, \quad (1)$$

$$\varphi_{c,i} = CHTC_1(T_{ref} - T_{s1}), \quad (2)$$

Where T_{s1} the surface temperature [°C] of the surface i and v_1 the local wind speeds near the wall i [$m \cdot s^{-1}$].

2.2 Study Case

The study case relies on, two geometry inspired from the cases A1-1 and B1-1 from the Compilation of Experimental Data for Validation of Microscale Dispersion Models (CEDVAL) (Environmental Wind Tunnel Laboratory, Meteorological Institute, Hamburg University n.d.). A1-1 represents an isolated rectangular building and B1-1, a finite array of buildings. Geometric parameters of the two geometries are presented in Fig. 2.

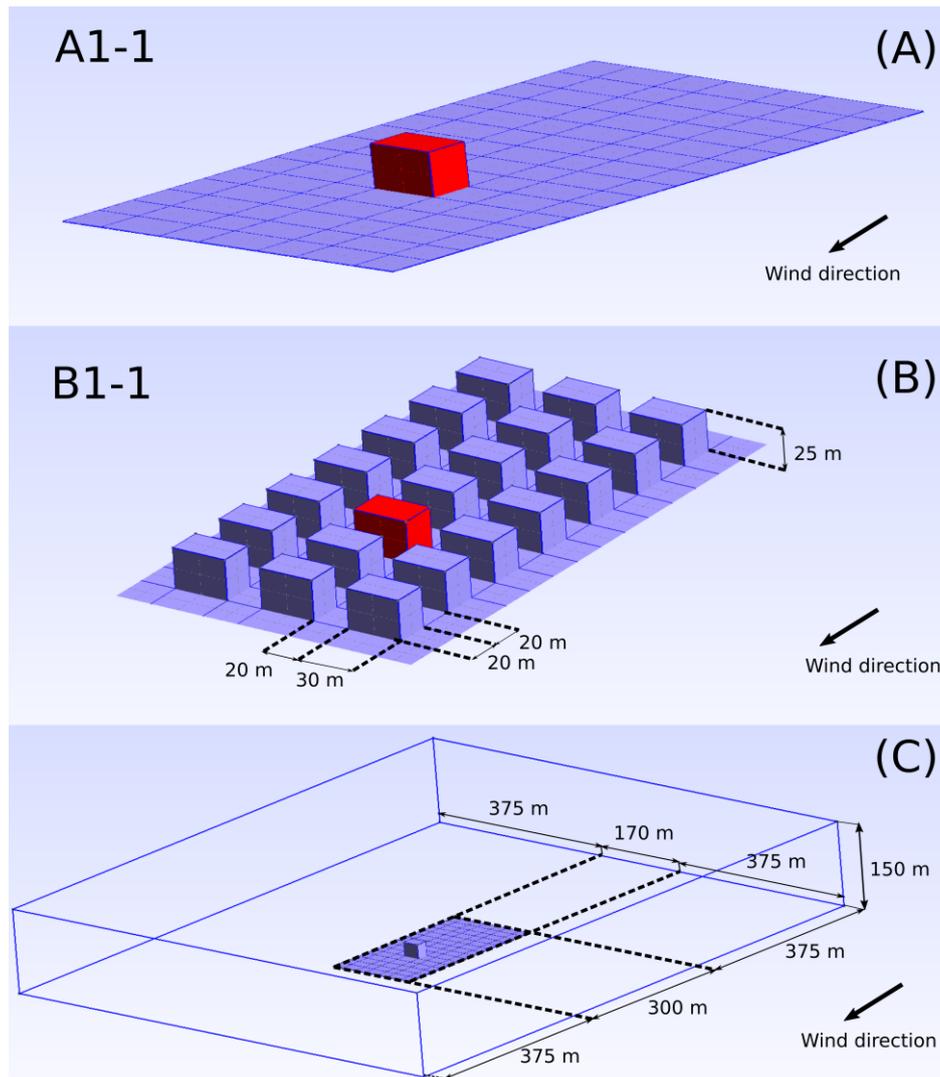


Figure 2. Geometric representation of A1-1(A) and B1-1(B) cases and the wind tunnel dimension (C)

The aim of this work is to investigate the impact of taking into account the urban environment on convective heat transfer in a BES tools. To accomplish this task, two type of simulations are performed and compared. The first one is a traditional BES where the urban environment is considered by computing solar radiative effect (shadow effect, reflected solar irradiance). However, urban environment impact on velocity fields and $CHTC$ is not estimated. In the second one, both solar and wind effects are taken into account by the BES tool. The comparison of the results of both simulations shows the effect of considering the urban environment on convective heat transfer in BES tools.

The methodology to realize to comparison is the following:

In a first step, CFD simulations are carried out with height reference wind speed ($V_{ref} = 1, 2, 3, 4, 5, 6, 7$ and 8 m/s) at the altitude $Z_{ref} = 10$ m, under isothermal conditions (20°C) for a direction corresponding to the East for the case A1 and B1. A steady RANS with a k-Epsilon turbulence model is used to model the airflow around the building. These eight simulation results are used to compute the mean $CHTC_i$ value for the referential buildings walls (red one in Fig. 2) for an isolated building (A1) and enclosed building (B1).

In second step, two different BES for the month of December with the climate of the city of Curitiba in Brazil are performed:

- In the category BES-A1, a traditional BES is performed for the geometry B1. To compute the convective heat fluxes, the referential building is considered as isolated. The $CHTC$ values used to compute convective heat fluxes in DOMUS correspond to the A1 geometry. In this way, urban environment effects are taking account in solar radiative exchange, but not in convective heat exchange.
- In the category BES-B1, the BES is performed for the geometry B1 but considering the urban environment to compute convective heat fluxes. The $CHTC$ values used to calculate convective heat fluxes in DOMUS correspond to the B1 geometry. In this way, urban environment effects are taking account in solar radiative exchange and convective heat exchange.

For both BES-A1 and BES-A2, eight references of wind speed are considered in the CFD simulation and a constant wind from the East during all the month is assumed in both cases. The different parameters of each simulation case are summarized in *Table 1*.

Table 1. Simulation parameters for each case.

Simulation name	CFD geometry & CHTC	BES geometry	Solar radiative transfer impacted by urban environment?	Convective heat transfer impacted by urban environment?
BES-A1	A1	B1	Yes	No
BES-B1	B1	B1	Yes	Yes

Both simulations are initialized with results obtained with a simulation performed during the period of January 1 to November 30, and the thermal regime is considered free. All walls and roofs are composed of plaster and brick (see *Table 2*) which thermal properties are resumed in the *Table 3*.

Table 2. Composition of buildings walls.

Composition	plaster / brick / plaster
Thickness [cm]	2/15/2
Solar absorptivity	0.5
Emissivity	0.6

Table 3. Thermophysical properties of buildings walls composition.

Material name	plaster	brick
Density [kg/m ³]	2050	1900
Thermal conductivity [W/m ² K]	0.720	0.749
Thermal mass [J/kg K]	932	920

3. RESULTS AND DISCUSSION

3.1 CHTC results

The CFD simulation results are used to compute the mean $CHTC_i$ value for the roof, the wall1 and wall2 (cf. Fig. 3) for the cases A1 and B1.

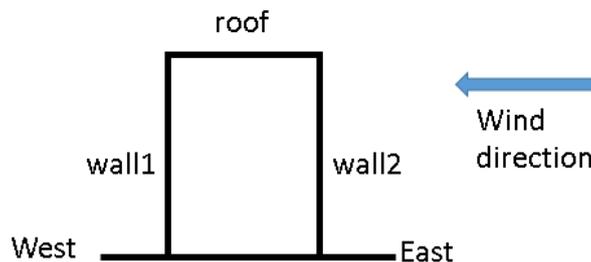


Figure 3. Representation of the different walls in the presentation of the results.

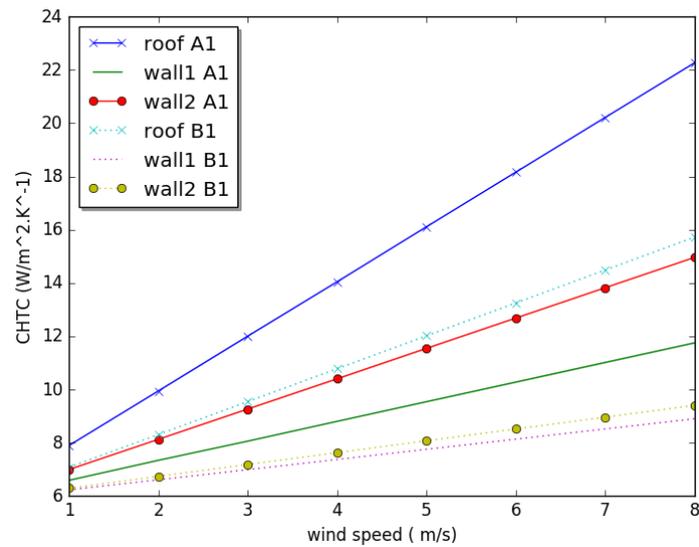


Figure 4. Representation of CHTC values as a function of the reference wind speed for the cases A1 and B1.

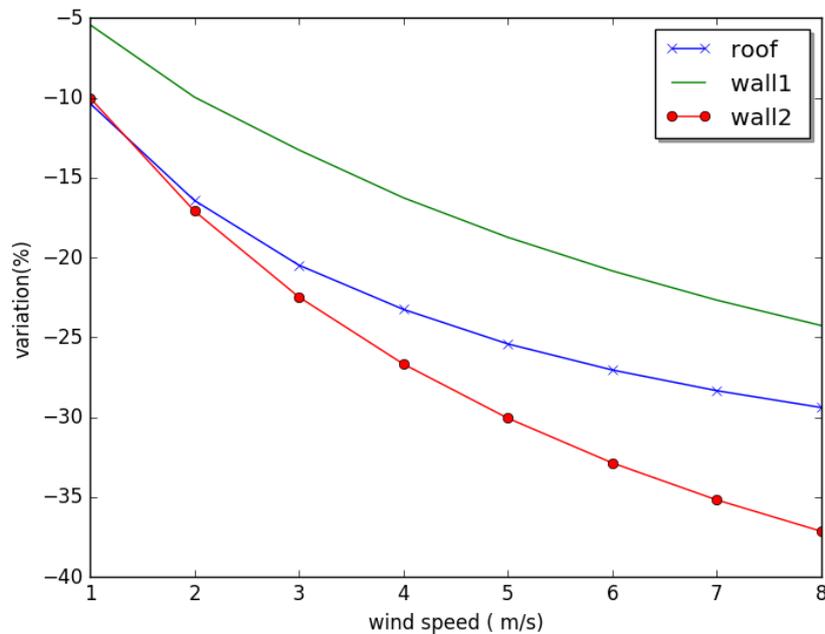


Figure 5. Representation of CHTC variation between the cases A1 and B1 as a function of the reference wind speed.

Figure 4 presents the *CHTC* values computed with CFD simulation for the roof, the wall1 and the wall2 for eight velocity references for geometries A1 and B1. The comparison between the cases A1 and B1 (cf. Fig. 5), shows the impact of the urban environment on *CHTC* distribution. The urban environment reduces the *CHTC* between 5% and 35%. The less impacted value is associated to the wall2 (decreasing between 5 and 25%). In the A1 case, the wall1 *CHTC* value is already the lowest (between 6 and 12 $W/m^2 C^\circ$) because it is a downwind wall where the velocity fields are weak. It is possible to observe that the roof and the wall2 are more sensitive to the urban environment. For low reference wind speed (1 and 2 m/s), the *CHTC* decrease for the wall2 and the roof is very close. However, for highest wind speed reference, the decrease is higher for the wall1 (-37%) than for the roof (-29%).

3.2 Surface temperature results

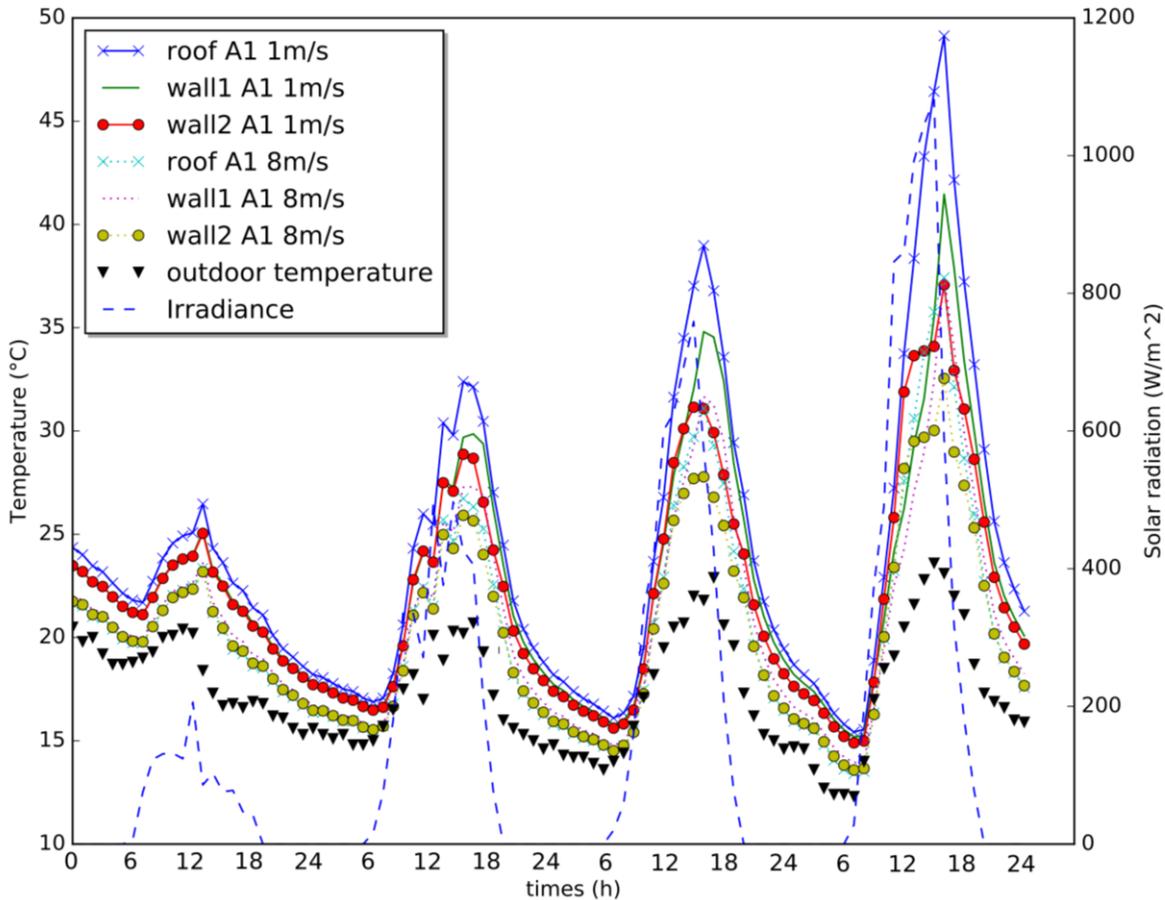


Figure 6. Temporal evolution of surface temperature for the roof, the wall1 and the wall2 for the case BES-A1 for two reference wind speed ($V_{ref} = 1\text{m/s}$ and 8m/s).

Figure 6 presents the temporal evolution of surface temperature for 4 days (11 to 14th December) for the roof, the wall1 and the wall2 for two reference wind speedz ($V_{ref} = 1$ and 8m/s) in the BES-A1 case .

Firstly, the surface temperature is mainly influenced by the solar irradiance. During the four days,, direct solar irradiance increases from 200 to 1100W/m^2 . For the roof (the most sunny surface) and for any kind of reference wind speed, the direct solar irradiance increases surface temperature between 23°C (for $V_{ref} = 1\text{m/s}$) and 15°C (for $V_{ref} = 8\text{m/s}$).

The impact of convective heat transfer, is lower than solar radiation. An increase of the reference wind speed from 1m/s to 8m/s lead to a decrease of 10°C in sunny condition, and 2°C in non-sunny condition. It is leading to the conclusion that surface temperature are more sensitive to convective heat transfer in sunny condition than in non-sunny condition. In this coupling approach, convective heat transfer are proportional to the difference between the outdoor temperature T_{ref} and the surface temperature T_{si} . Higher is this difference; more convective heat transfer is sensitive to the $CHTC$. Indeed, in the 11th of December the direct solar irradiance is very low. Then, surface temperatures are very close to the outdoor temperature (5°C), and the potential of surface temperature decrease by convection is weak. In 14th of December, the direct solar irradiance is very high. The gap between, surface temperatures and outdoor temperature exceed 10°C and the potential of surface temperature decreased by convection are stronger.

As the roof is the most exposed surface to the direct solar radiation, its surface temperature seems to be more sensitive to reference wind speed variation. Then the surface temperature decrease due to reference wind speed increase is always superior for the roof than for the wall 1 and wall2. As the wall1 is a downwind wall, its $CHTC$ is less sensitive to the reference wind speed variation than the wall2.

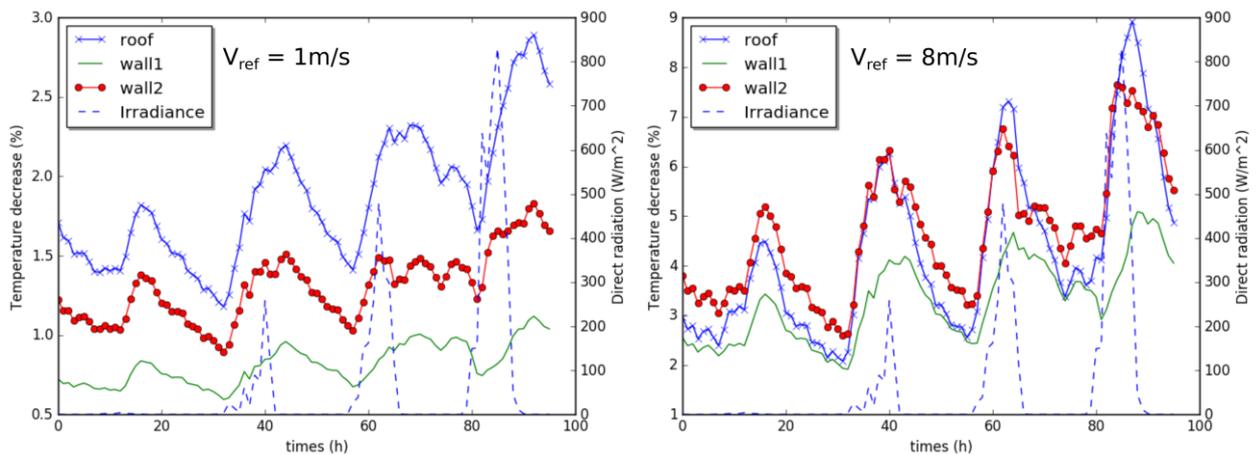


Figure 7. Temporal variation from the 11th to 14th of December of surface temperature decrease due to the difference between A1 and B1 for two reference wind speed.

Figure 7 presents the temporal evolution of surface temperature decrease due to urban environment (difference between the BES-A1 and BES-B1) for two references wind speeds. The impact of urban morphology on surface temperature is higher with high reference wind speed (maximum decrease: 9%) than with low reference wind speed (maximum decrease: 3%)

According to results presented in previous sections, for low reference wind speed, the roof surface temperature is the most sensitive to the urban geometry variation. Indeed, its CHTC decrease due to urban geometry variation is the higher and the roof is the most exposed to solar radiation.

For high reference wind speed, during non-sunny condition, the wall2 surface temperature is the most sensitive to the urban geometry variation. During sunny condition, the roof surface temperature is the most sensitive to the urban geometry variation. Indeed, the convective heat transfer is more influenced by the gap between outdoor temperature and surface temperature.

3.3 Indoor temperature results

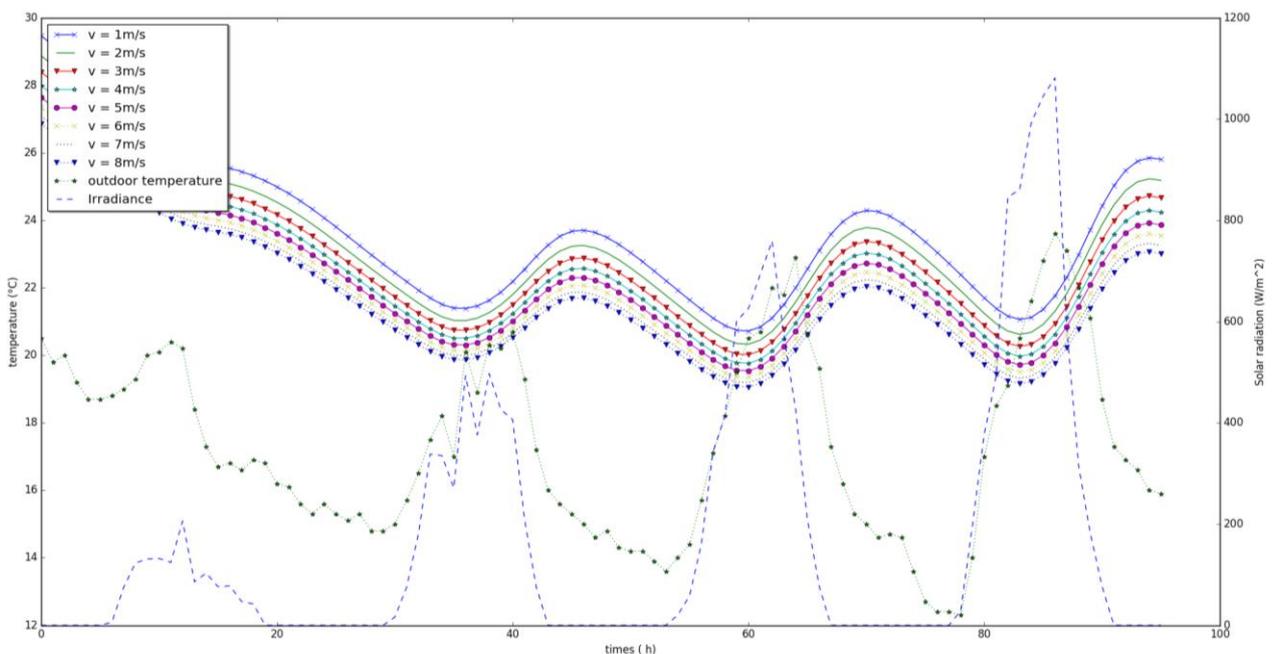


Figure 8. Evolution of indoor temperature for the BES-A1 case from the 11th to the 14th of December .

Figure 8 presents the indoor temperature evolution for the case BES-A1. As expected, more the reference wind speed is high more the walls convective transfer are high. As the convective heat transfers are higher, the indoor

temperature decreases to get closer of the outdoor temperature. There is a difference of 2°C between a reference wind speed equal to 1m/s and equal to 8m/s.

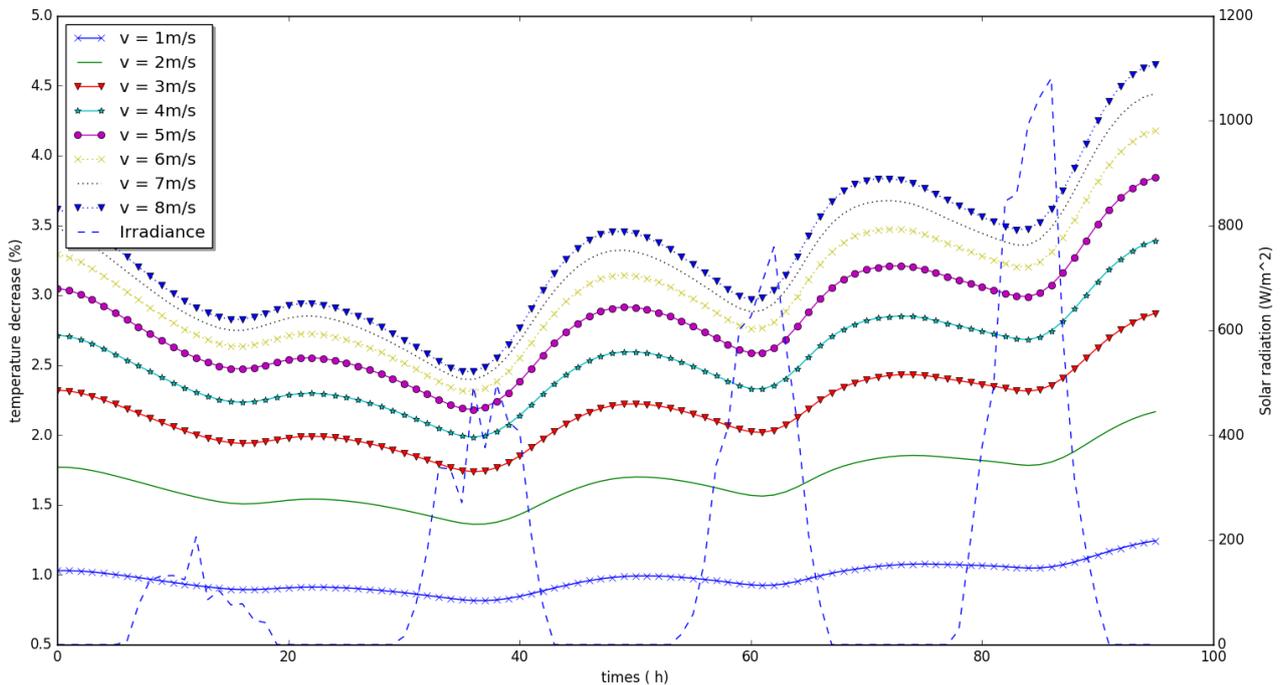


Figure 9. Evolution of indoor temperature decrease due to the difference between A1 case and B1 case from the 11th to the 14th of December.

Figure 9 presents the indoor temperature variation due to urban environment (difference between BES-A1 case and BES-B1 case). The minimum value is 1% with a reference wind speed equal to 1m/s and the maximum value is 4.5% with a reference wind speed equal to 8m/s. According to the previous results, *CHTC* variation has more impact on indoor temperature during days with high solar radiation.

4. CONCLUSIONS

We presented BES-CFD coupled simulations run thanks a code developed in Python language. This model was used to compute *CHTC* and convective heat fluxes for two different urban morphologies, enabling to highlight the impact of the urban environment on BES parameters that currently cannot be done by existing BES tools (working independently).

This parametric study highlighted the impact of reference wind speed and urban environment on convective heat transfer. We show that considering the urban environment can decrease the surface temperature up to 9%, and the indoor air temperature up to 4.5%.

The study case was performed considering only the same wind direction during one month to quantify the impact of wind velocity on BES. The next step is to perform a coupled simulation considering direction and intensity of wind speed corresponding to the local meteorological data for each time step.

In this study, only wind velocity is considered to compute the *CHTC* and only the outdoor temperature from meteorological data is used as reference temperature to compute convective heat transfer. Further research will be also conducted for a complete non-isothermal coupling, by computing different ambient air temperature for each wall with CFX and using them to perform DOMUS simulation.

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6. RESPONSIBILITY NOTICE

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