381: Numerical analysis of convective heat transfer coefficient in building façades under the action of the wind

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ABSTRACT: The convective heat transfer coefficient (CHTC) of building surfaces is one of the most important parameters related to building energy losses, and therefore it is a crucial parameter when designing energy efficient buildings. In this work, 3D computational fluid dynamics calculations have been performed. The simulations have been validated with experimental values plublished in the literature. It has also been checked that the main turbulent structures around the building are reproduced in the computational model, and this information has also been used to discuss the validity of the previous experimental works.

Keywords: Convective heat transfer coefficient, computational fluid dinamics.

1. Introduction

This work focuses in the value distribution of the convective heat transfer coefficient (CHTC) on the façades of a building depending on wind conditions. Due to the importance of this parameter in the calculation of building energy losses many authors have already evaluated this coefficient. Unfortunatelly the divergences between the correlations proposed by the different authors are still higher than desiderable. This may have been caused by the experimental nature of most of these works. One of the main limitations of experimental full scale measurements in real buildings is the difficulty of taking into account all parameters that affect the the convective heat transfer. Additionally, the specificity derived from the building geometry and local wind conditions difficult the extrapolation of the results to other buildings typologies, and limit their application.

The possibility of controlling the boundary conditions in the computational simulations makes computational fluid dynamics (CFD) a valuable tool to evaluate the flow around buildings, because the main limitations of experimental set ups can be avoided. In this work computational fluid dynamics calculations (CFD) have been performed with the main objective of finding a model to predict convective heat transfer coefficient depending on the wind direction. The results of the simulations have been compared to experimental data published in the literature. The turbulent structures formed around the building have been analysed, and this has been used to discuss about some difficulties found in the previous experimental works.

Most of the authors that have worked on the evaluation of the convective coefficient in real buildings have performed similar experiments. Heat flux, surface temperature and air temperature have been measured in heated test panels inserted in the building façades at different heights. The resulting convective coefficient has been correlated to wind velocity measured at a distance of 1m from the test panel, with wind velocity measured in a station al 10 m, and with the velocity measured above the roof of the building.

Sturrock [1] performed “in-situ” measurements in a building 26 m high, and obtained correlations between the CHTC and V_r which is the wind velocity measured above the roof. The next year, Ito *et* al. [2] performed nocturnal measurements of the convective coefficient in a six storey building. The values of the convective coefficient were correlated to the wind velocity 8 m above the roof (V_{10}), and with the local velocity measured 0.3 m from the wall (V_s). Some years after, Sharples [3] reproduced a similar experiment, locating test panels at different heights (storeys 6, 14 and 18) in an 18 storey building. This author obtained a unique correlation between CHTC and local wind velocity measured at the distance of 1 m from the wall (V_s), which was valid for all façades, independent from their relative orientation. He also correlated HCTH and wind velocity measured in a meteorological station (V_{10}). Loveday and Taky [4] proceeded similarly inserting a test panel at the height of the 6th storey in a 28 m high building. Like the previous authors, they correlated HCTC with the wind 11 m above the roof and wind at a distance of 1 m from the panel (V_s). Recently, Liu and Harris [5] worked in an orientable, small size building (5.6 m height) partially sheltered from the wind. These authors obtained also expressions for the convective coefficient (HCTC) as function of local velocity measured at 1m distance from the wall (Vs), for different incidence angle intervals of the wind on the building façades (See fig.2.).

Emel and Abadie [7] have recently published new correlations for low rise buildings. Unlike the previous authors, this work was based on computational fluid dynamic simulations. They performed simulations for different incidence angles (0º, 45º, 90º) and wind velocities (1, 5, 10 m/s). They also studied the influence of temperature difference between façades and exterior air, and they concluded surface to air temperature difference plays an important role when wind velocity is 1 m/s or lower, and a secondary role for higher velocity magnitudes.

2. Methodology

Simulations have been performed for a low-rise building with the dimensions of Liu and Harris´s orientable house, with an 8.5 m x 8.5 m square plant and a total height of 5.6 m. To analyze the flow around the building, a fluid volume of 160 m x 80 m plant dimensions, and 40 m of height has been simulated. The building has been positioned at a distance from the inlet and outlet boundary conditions of 8 and 20 times the height of the building respectively. The front distance has been calculated to ensure fully developed turbulent flow when reaching the building, and to avoid the influence of the obstacle in the inlet boundary conditions. The back distance permits the fully develop of the turbulent wake.

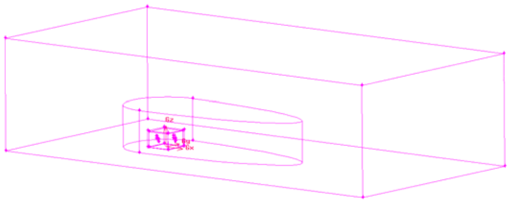

Fig. 1. Simulated geometry

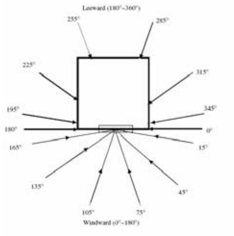

Fig.2. Liu and Harris [5] angular segmentation

A small area has been defined in the centre part of each façade, (0.8 m wide per 0.5 m height), which corresponds to the measurement panel setup of Liu and Harris [5], and will therefore enable the full comparison of results. With a panel in the centre of each façade it is possible to obtain octagonal symmetry, which reduces the number of total simulations by 16. The relative orientation between wind direction and building has been obtained by means of a turnable cylindrical volume created around the building. The flow around the building has been simulated for inlet velocities from 1 to 10 m/s. The cylindrical volume and the building inside have been turned in intervals of 5º (from 0º to 45º).

Simulations have been made with different available models [10]: Sparlat-Almaras, standard *k-ε*, reliable *k-ε*, standard *k-w*, and SST *k-w* models. *k*- ε standard model has been selected because it demanded 5 times less iterations than the other models to reach convergence, and because it showed better agreement with the experimental results from Liu and Harris [5].

3. Results

3.1 Comparison of simulation results with previous works

The following figure shows the relation between far field velocity (V_{10}) and local velocity (V_s) measured 1m distance from the façade obtained by the different authors, including the present work results which have been represented by dots:

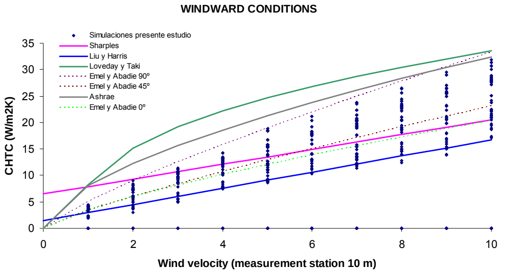

Fig.3. Wind velocity at 1 m distance of the wall as a function of far fiel velocity V_{10}. Windward conditions

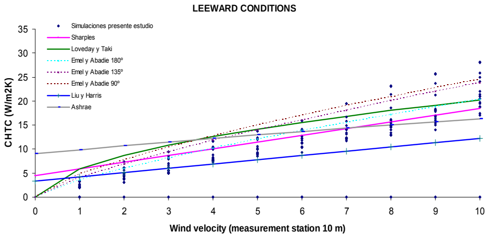

Fig.4. Wind velocity at 1 m distance of the wall as a function of far fiel velocity V_{10}. Leeward conditions

In windward conditions, Sharples [3] and Loveday and Taky [4] over predict the local velocities, the reason could be because the measurements were done in high buildings of 78 and 28 m of total height. On the other hand, the values obtained by Liu and Harris [5], are lower than our simulations, even though the building shape is exactly the same. This could be explained by the particular conditions of sheltering of the experimental set up. Finally, it can be concluded than the comparison with the simulations performed by Emmel and Abadie [7] show very good agreement. In leeward conditions, Loveday and Taky [4] obtain values for the CHTC very low, in comparison with the rest of the authors.

The following figures show a comparison between the correlations obtained by the different authors between the convective coefficient and local velocity (V_s), and the convective coefficient and far field velocity (V_{10}).

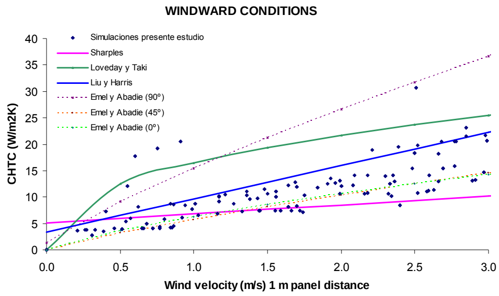

Fig.5. Correlations between CHTC and the local velocity Vs measured at 1m from the façades. Windward conditions.

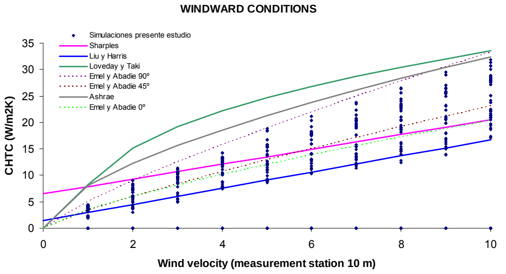

Fig.6. Correlations between CHTC and the local velocity Vs measured at 1m from the façades. Windward conditions.

The results of the present work show good agreement with Liu and Harris [5], and the 3D simulations performed by Emmel and Abadie [7]. This good agreement was expectable because the three studies focused on similar low rise buildings, taking into account that Liu and Harris´s [5] building was in conditions of low sheltering, which could explain, as exposed above, the lower values. In relation to the other authors, not much can be concluded. If convective coefficient is a positive function of the wind velocity measured next to the wall (1 m) as shown in section 1, it would have been expected that the values of convective coefficient in the case of Sharples [3] had been higher than the values of Loveday and Taky [4], but the fact is that Loveday and Taky [4] correlations determine a very high convective coefficient as a function of the wind velocity, in comparison to other authors.

The following figure shows a comparison of simulation results with Liu and Harris [5] for windward conditions:

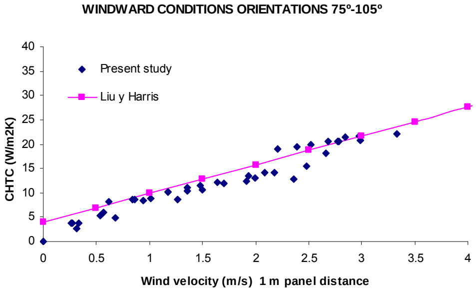

Fig. 7. Correlations between CHTC and the local velocity Vs measured at 1m from the façades. Orientation segment [0-15º]

The simulations of the present work show good agreement for all intervals, except in the orientation angles between [0-15º] and [180-195º]. In these orientation intervals, simulations do not determine any tendencies, but when analyzing Liu and Harris [5] results, these intervals show very low regression coefficients. This divergence could be caused by the vortex structures formed in the lateral façades: such as fluid detachment in the incidence corner, which produces a recirculation of wind air around the façade, most concretely in the area of the panel. These divergences observed in 3D simulations and also in “in-situ” measurements suggest that velocity at 1 m from the wall may not be a characteristical parameter in all situations. This is discussed in the following section, when analysing fluid structures.

For leeward conditions:

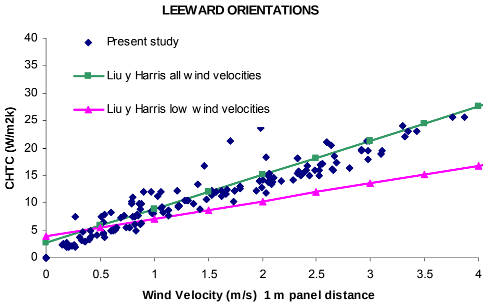

Fig. 8. Correlations between CHTC and the local velocity Vs measured at 1m from the façades. All leeward orientations

For Leeward conditions, the results of the simulations are higher than Liu and Harris [5] experimental results. These experimental correlations were obtained with a relative low number of points, and showed low regression coefficients. This could have been caused by the nature of the winds, which show low probabilities in these orientations (non-prevailing winds). Taking this into account, the authors presented another expression valid also for all leeward orientations, but useful in cases of highest wind velocities. The comparison of this new expression with the simulations of the present work showed very good agreement. This results show the importance of correct knowledge and treatment of the winds in a determined location (wind roses), because otherwise it can lead to incorrect results.

3.2. 3D simulation results: analysis of aerodynamic phenomena

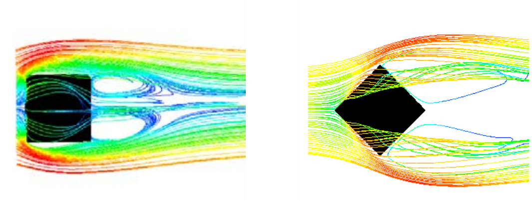

Fig. 9. Flow around the building for different wind orientations: 0º and 45º

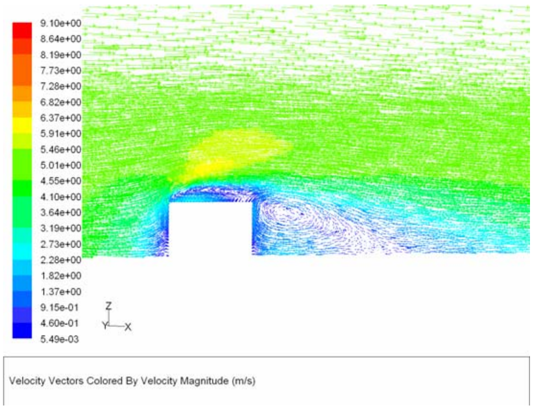

Fig.10. Flow around building in a vertical plane

Previous figures show the flow around the building. When the wind flows perpendicular to the front façade, it is possible to identificate the main turbulent structures as published in [8] and [9]: horseshoe vortex upstream the obstacle that surrounds the whole building. In the back side inside the horseshoe vortex the structures are separation line in the back part of the building, a low pressure region producing vortexes with axes in Z and a stagnation region which produces the return of the fluid close to the back wall of the building, aspirated from the upper part.

Additionally the vortexes formed in the lateral façades of the building with their regions of fluid detachment and reattachment can be observed. As shown in figures 9 and 10 the effects of detachment and reattachment decrease with the angle. For angles superior to 20º the detachment and reattachment effects disappear and it can be seen how the flow attaches to the wall.

The theory of heat transmission for forced convection [11] expresses the convective heat transfer coefficient (h) as a function of the Nusselt number, which is itself a function of Reynolds and Prandt numbers. Reynolds number characterizes the fluid that circulates parallel to a surface, at a distance bigger than the dynamic boundary layer. The velocity of the flow measured at the distance of 1 m from the wall is a characteristical parameter of the flow when the flow is parallel to the wall. When vortexes and complex fluid structures are formed around the studied wall, the velocity measured at the distance of 1 m form the wall is not the characteristical parameter of the interaction between flow and wall. These turbulent structures could affect the results obtained experimentally or numerically.

3.3. Distribution of the convective coefficient in the building walls.

The following figures show 3D views of the variation of the convective coefficient along the façades and roof of the simulated building.

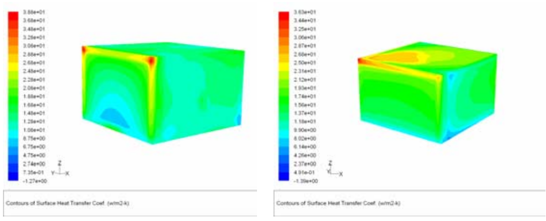

Fig.11. Variation of convective coefficient in the façades of the building for orientations 0º and 45º

In the figures above, the one related to orientation 0º shows how the values vary with the height, and how maximum values are reached at the incidence corners. This data confirm some conclusions published by Sharples [3]. Lateral façades show lower variation in the convection coefficient, which definitely decreases in the back façade where there is a stagnation region.

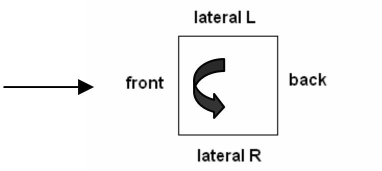

Fig.12. Representation of building façades and orientation of turns

In the case of building turned 45º respect to the normal incidence of the wind, the detachment effects disappear and this produces a homogenization of the values of the convective coefficients in the windward walls, except at the incidence corners where higher values are reached.

The following table shows the percentage that the convective coefficient measured in the test panel represents with respect to the mean value of the whole façade. The values are represented for the different façades and for different orientation angles:

Turn	Front	Back	Lateral Right	Lateral Left
0º	0.74	1.13	1.24	1.12
5º	0.78	1.16	1.64	1.42
10º	0.78	1.09	1.15	1.34
15º	0.74	0.96	1.04	0.93
20º	0.77	0.98	1.04	1.00
25º	0.82	0.94	1.03	0.93
30º	0.85	0.96	1.06	1.12
35º	0.87	0.95	1.06	1.12
40º	0.90	0.93	1.04	1.11
45º	0.93	0.93	1.20	1.20

Table 1. Percentage that the convective coefficient measured in the test panel represents with respect to the whole façade

As it would have been expected, the panel in the centre of the front façade becomes more representative of the whole façade as the building turns, and the wind attaches to the wall, so that the distribution of the HCTC becomes more homogeneous in that façade. On the other hand, the results obtained for the lateral façades, especially in the first turning angles, show a great variability, due to the turbulent structures formed in that area.

3.4. Heat loss calculations

The following figures show a percentage comparison ($\%_1$) of the heat loss coefficient of the façades (ΣUA) for the case study building, using average coefficients from the literature (previous discussed authors) and with the new ones derived from this CFD study.

Figure 13 shows the values in case of heavyweight external walls and figure 14 shows the values for the case of a glass façade building.

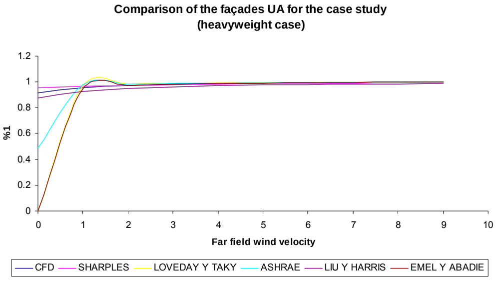

Fig.13. Comparison (%1) of the heat loss coefficient of the façades (ΣUA) for the case study building. (Heavyweight case)

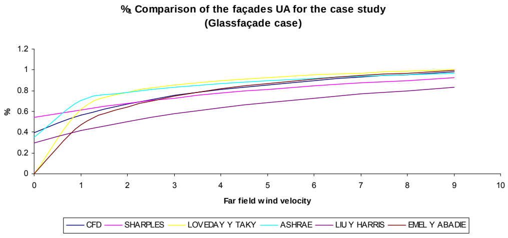

Fig.14. Comparison (%1) of the heat loss coefficient of the façades (ΣUA) for the case study building. (Glass façade case)

In glass façades, the influence of the external convective term on the overall façade heat transfer coefficient is higher than in heavyweight façades.

In the case of heavyweight façades, the different expressions for the convective coefficient produce big dispersion on the UA values for low wind velocities (0-1.5 m/s) and an asymptotical convergence for high velocities. In the case of glass façades, there is dispersion in the UA values in all the velocity range. These dispersions can lead to divergences in the overall heat loss calculations that can be up to 30% in the case of glass façades, and 10% in heavyweight façades.

4. Conclusion

This work shows the need of more detailed studies of the heat transfer convective coefficient in building façades, with the objective of establishing valid patrons of its variability that may be used in a high number of buildings typologies. To this respect, CFD tools appear as a valuable alternative that can provide good results for different building, avoiding at the same time experimental set ups in real buildings, which have a higher cost and whose results are of difficult extrapolation. This work provides a methodology, computationally economical and robust for the analysis of wind flow around a building.

5. Acknowledgements

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6. References

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