Cross Ventilation CFD Modeling: Characterization and Study of Different Façade Openings Configurations at the Refurbishment of a Residential Building in Málaga (Spain)

Abstract: *The opening of new windows on the façade is proposed as a refurbishment strategy in an existing building in Málaga to facilitate cross ventilation of dwellings. The building is a residential block of 140 public housing units for rent for people with low income in Málaga (Spain), property of the City Council. By modeling with Computational Fluid Dynamics (CFD), eleven configurations of openings are studied in two different areas of the main housing type of the building.*

The quantity of introduced/extracted air into/from the room and the generated airflow patterns are obtained. The modeling allows comparing the different openings configurations to determine the most appropriate ventilation option for every room.

Cross Ventilation, Sustainable Refurbishment, Computational Fluid Dynamics (CFD)

1. Introduction

The European Directive 2010/31/UE announces that Member States should draw up national plans for increasing the number of nearly-zero energy buildings. Namely, the Directive highlights the problems created at peak load times because of the rise in the number of air-conditioning systems in European countries. Natural cross ventilation has great potential as an alternative to conventional air conditioning systems in climates such as Málaga. Therefore, it is proposed as a strategy for the refurbishment of the building under study, a residential block of 140 apartments.

The capacity to predict the behaviour of a fluid such as air was a major advance in the control of this phenomenon and, consequently, also in the product or technology that use it. Since the 90s, the use of numerical simulation programs or Computational Fluid Dynamics (CFD) has increased. These tools are highly developed in some fields of engineering, but its use is very recent in enclosed spaces such as apartments, where there is still some degree of uncertainty about its characterization and modeling. The need to improve energy efficiency in buildings with passive systems such as cross ventilation requires the application of CFD models, finite element models, which allow the evaluation and analysis of these systems at low cost and time, compared to other alternative models. The protocol used in this research defines how to generate the CFD model for enclosed rooms. The application of this protocol in the building under study has enabled to calculate the air exchange that is achieved with each of the openings configurations that were proposed.

2. Background

There are different methods to determine the location and the necessary surface of openings in cross ventilation. They can be classified into two categories [Allard 1998]. Empirical simplified methods use simple mathematical formulas to calculate the inlet and outlet that are required for cross ventilation. Other methods are the iterative computerized methods which are based on computer model simulations.

2.1. Natural ventilation in national regulations and in tools or guidelines of sustainability assessment of buildings

In general, these methods consider only the effects of wind and not those of temperature. They are useful in pre-design stage. Almost all of them are intended for new buildings rather than for existing ones. Most determines minimum surfaces required to illuminate and ventilate the indoor spaces at homes as a measure to ensure their salubrity. They established a ratio of floor space-glazing surface-openings surface.

This is the case of the *Design Standards for Social Housing in Andalucía*, the *Provisional Ordinances for Social Housing (1981)*, various municipal ordinances derived from the *General Urban Plan* of each locality, the *Technology Building Standards* or the Spanish *Technical Building Code* (CTE) in its *Core Document HS3 Salubrity. Indoor Air Quality.* All derived from the *Minimum Hygienic Conditions Act of 29 February 1944*.

The cross ventilation has greater cooling potential than the simple ventilation, up to 3 times higher with the same openable surface [Velasco 2011]. To find specific requirements for cross ventilation is necessary to go to tools or guidelines for evaluating sustainable buildings such as the *Guide to Sustainable Building of the Basque Country,* GREEN, LEED, RESET, PASSIVHAUS or BREEAM.

2.2 Computational Fluid Dynamics (CFD)

These methods combine the effects of wind and temperature, so they do not have the limitations of the previous ones. They are methods for predicting the behavior of air in rooms using a computer. Currently, CFD tools are the most used methods for calculating ventilation flow rates compared to other analytical, empirical or scale models methods [Chen 2009].

The computational fluid dynamics model solves the Navier-Stokes equations using numerical methods. The CFD methods are based on a geometrical model introduced by the user through a graphical interface. From the graph model, the software obtains the boundary conditions which are restrictions to the equations of the fluid in motion. The envelope is the most important element when introducing the model, because it is in contact with the fluid. Once the geometry data is introduced, other data about the fluid such as density, viscosity, pressure, velocity, temperature, etc. are provided. With all these data, the program calculates the fluid variables at all points, and represents them in the graphical.model. Thus, it is able to give values of parameters such as pressure and gas velocity, temperature, etc. Due to the nature of natural ventilation physical phenomenon, there is always going to be a high degree of uncertainty. However, these methodologies can be used as tools for dimensioning air inlets and outlets approximately.

The results can be displayed in countless ways, for example, isolines, maps, directions of flows, etc. It all depends on the power of the program that is used. In this paper, FLUENT software is used which belongs to ANSYS group.

3. Methodology

3.1. Analysis of possible solutions to improve natural ventilation via windows

First, the natural cross ventilation options that is possible to apply in the existing building are evaluated, considering the following aspects:

1. Building typology and morphology: isolated multifamily residential block with semi-open courtyard. The most numerous housing type has opposing façades, but it just has windows on the exterior façade not on the interior one, except the front door to the apartment (Figure 1).

2. Climatic zone: warm humid climate (A3, according CTE classification). It is favourable for night cooling and, also, for natural ventilation during the day in warm periods, depending on outdoor temperature. It can be useful also for hygienic reasons throughout the year.

3. Dominant wind direction: velocity, frequency and wind direction obtained from the compass rose of Málaga (Figure 2). Pressure zones (windward) and suction (leeward) in building are determined, considering also the obstacles to the arrival of the wind. The East and West façades receive wind from SE (120°-150° to the North) with different speeds and frequencies. The interior walls (courtyard) are sheltered from the wind.

4. Distribution, size of openable windows, opening systems and complementary elements (sun protection, etc.): façade openings are analyzed and it is verified that housing type A fulfills geometrical requirements of the VERDE tool criterion *D11 Ventilation efficiency in areas with natural ventilation* [GBCe 2011].

3.2. Geometrical definition of the different façade openings configurations

To enhance natural ventilation, it is proposed to open new openings in the interior façade, facing those of exterior façade. The size of the new openings fulfills the minimum openable surface required in CTE DB HS3, 1/20 of floor area, adapted to the structure and geometry of the space. The different cases presented in location and sizes aim to analyze different possible circulation of air flow inside the apartment to select those that meet best the needs of the user.

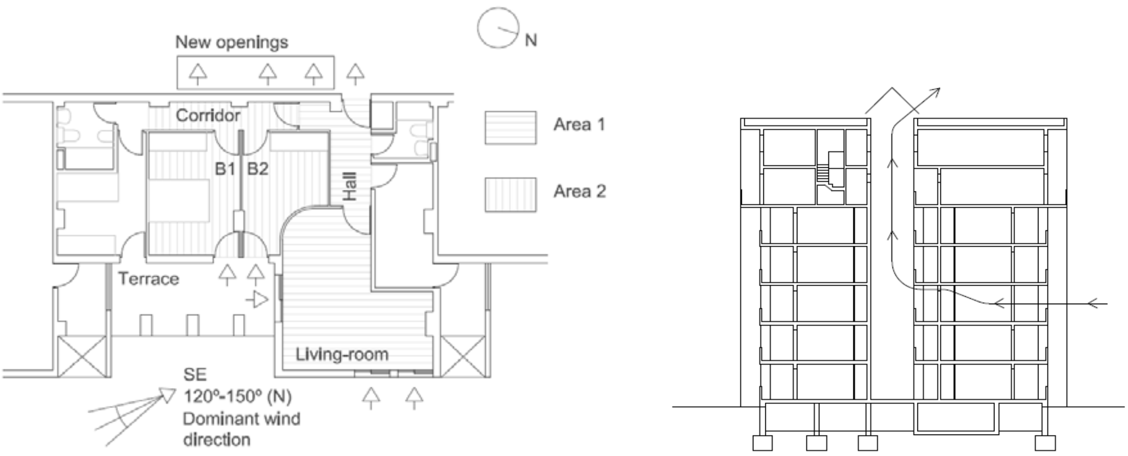


Figure 1. Floor plan of housing type A with Areas 1 and 2. Cross section of the building.

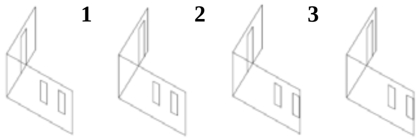
	Inlets											Outlets	
Area 1	**Living-room** A=18.91m^2 A/20=0.95m^2	**1**	**2**	**3**	**4**							**Hall** A=4.14m^2 A/20=0.21m^2	**1-4**
													
Area 2	**Bedrooms** B1: A=11.14 m^2; A/20=0.56 m^2 B2: A=8.34 m^2; A/20=0.42 m^2	**5**	**6**	**7**	**8**	**9**	**10**	**11**				**Corridor** A=1.17m^2 A/20=0.21m^2	**5-11**
													

Table 1. Possible openings configurations on façades of Area 1 (living room-hall) and Area 2 (bedrooms-corridor).

3.3. Definition of operational conditions for CFD modeling

First, the orientation of the building with respect to the dominant wind direction is checked. Then, the direction and characteristic intensity of the wind is determined from the compass rose. Finally, the pressure coefficient applied to the opening is calculated in vector form with the following formula (Table 2):

$$\Delta P_{wind} = \frac{1}{2} C_p \rho v^2$$

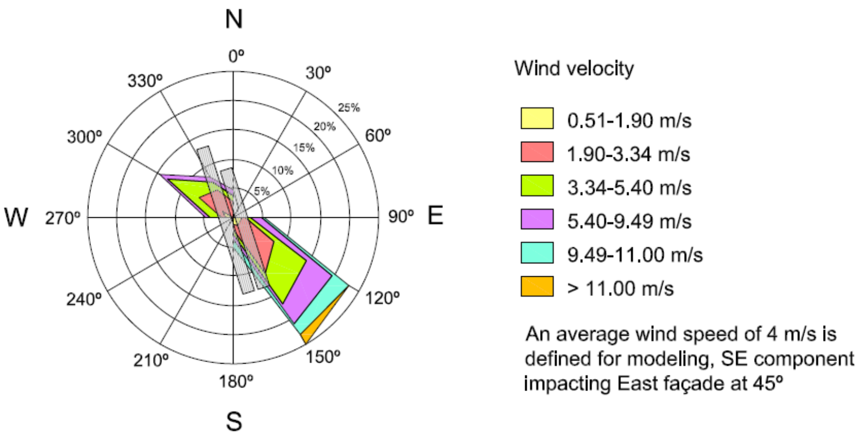


Figure 2. Boundary conditions. Building orientation with respect to the annual compass rose of Málaga [Source: Mapa estratégico de ruido Ciudad de Málaga, Ayuntamiento de Málaga]

	Pressure coefficient (Cp)	Wind velocity (v)	Pressure (ρ)
Windward	0.3	2.828 m/s	0.9487
Tangent	0.1	2.828 m/s	0.3162
$\lvert\rho\rvert$			1.549 Pa

Table 2. Vector components of the boundary condition imposed by the incident wind on the exterior East façade.

The suction effects are not considered at leeward, on the outlets, because they are sheltered from the wind. So, ambient pressure is considered, without wind effects.

3.4. CFD modeling

ANSYS Fluent software is used for the implementation and development of the CFD models. Geometry of Zones 1 and 2 is generated by modeling all possible inlet and outlet openings (Figure 3). In Zone 2, the furniture (a double bed and two wardrobes) is modeled so that the predicted flow is more realistic. The details about the selection of the turbulent model, the near-wall treatment, the type of mesh used and the resolution can be found in the Final Project "Calculation CFD protocol for coefficients of heat transfer by convection in enclosed rooms" (Solleiro 2013).

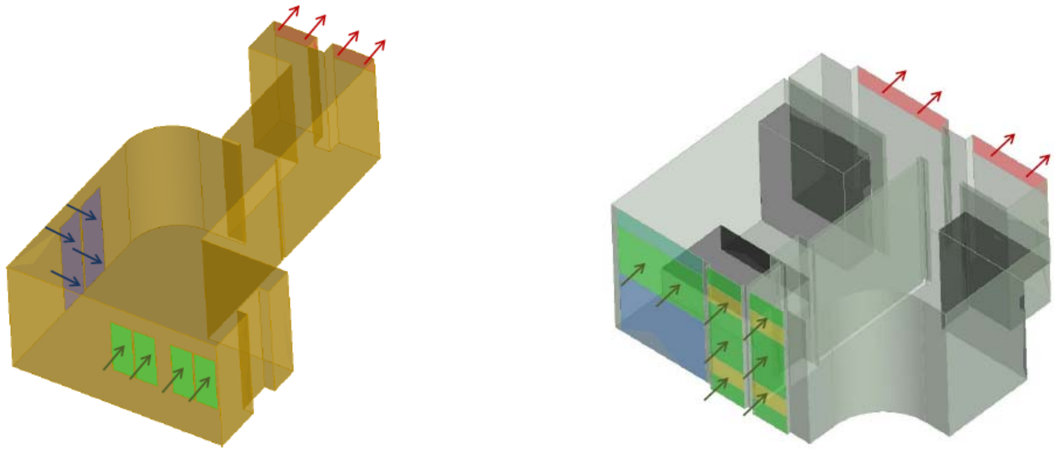


Figure 3. Geometry generated with ANSYS Fluent for Area (left) and Area 2 (right) with inlets (green, blue and yellow) and outlets (red).

4. Results

The air flows obtained by CFD modeling are summarized in Table 3.

		Area 1					Area 2						
		1	**2**	**3**	**4**		**5**	**6**	**7**	**8**	**9**	**10**	**11**
Q	kg/s	0.934	0.945	0.937	0.933		1.578	0.747	1.167	0.759	1.179	1.177	1.647
	1/h	46.11	46.65	46.26	46.06		87.20	41.28	64.56	41.94	65.15	65.04	91.03
So (m2)	Inlet	2.82				D1	2.02	0.29	0.58	0.29	0.58	0.58	3.73
						D2							2.02
	Outlet	0.66					1.17						
So/A (%)	Inlet	15				D1	18	3	5	3	5	5	34
						D2	24	4	7	4	7	7	24
	Outlet	16					28						
V (m³)		59.528					53.180						

Table 3. Airflow introduced/extracted into/from the room (Q), openable surface (So), ratio openable-area-to-floor-area (So/A) and volume (V)

In the living room area, the same air change is observed in all cases. This is due to the assumption that the vector components of the wind affect the same way in the South and East orientations. So, the higher the inlet surface, the higher the level of ventilation. In Cases 1 and 4, it is noteworthy that a better air sweep occurs without producing recirculation (Figure 4).

Case 4 is the most favorable for nocturnal ventilation because the air flow is projected on two walls of the apartment with thermal inertia. Additionally, the sliding windows could be replaced by folding ones to increase the ventilation of the room in order to get more cooling capacity.

In the bedroom area, it happens something similar. The air changes increase as the inlets surface increases. However, when adding one more opening in bedroom 1, Case 11 shows that it is not achieved a significant increasement in air changes with respect to Case 5. This is because the level of ventilation by the action of wind has already saturated the room. So, this solution is rejected. Case 5 is the one that gets more air changes. The openings in Cases 6 and 8 are sufficient to achieve a similar level of ventilation to the one of the living room area, with better air flow pattern in Case 6 than in 8 (Figure 5). Cases 7, 9 and 10 reach an intermediate level of ventilation. Case 10 shows more appropriate flow distribution for night ventilation.

The velocity of air is limited to an average value of 1m/s except in walls in front of inlets where the velocity is around 1.5 m/s and near the outlets where the maximum value is 2.5 m/s because the inlet size is much bigger than the outlet one, up to 4 times bigger in the living room-hall area and up to 3 times larger in some of the cases of the bedrooms-corridor area (Case 11).

Figure 4. Flow lines for Area 1 generated with ANSYS Fluent. Cases 1 (left) and 4 (right).

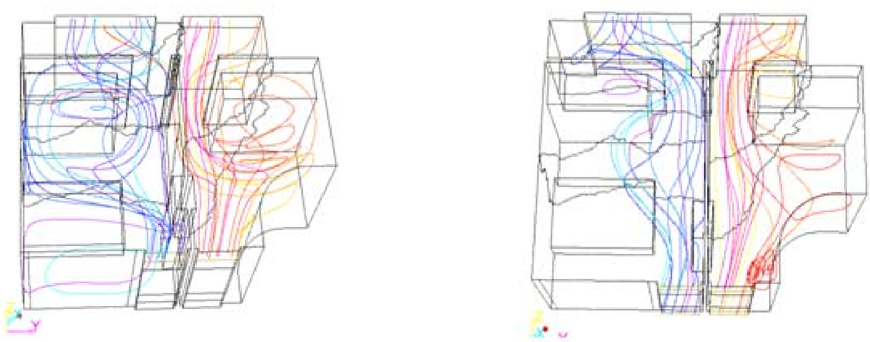


Figure 5. Flow lines for Area 2 generated with ANSYS Fluent. Cases 6 (left) and 10 (right).

5. Conclusion

The opening of new windows in the housing type A, on the inner façade of the semi-open courtyard, provides adequate levels of ventilation in living room and bedrooms. Even with inlets size smaller than A/20 (CTE DB HS3 Salubrity), a good ventilation level is generated under the wind conditions of this case study. The air changes achieved with cross ventilation exceed by far the minimum air changes required by the CTE DB HS3 Salubrity (around 1/h).

In Area 1 (living room-hall), with 100% of the inlets opened, air changes around 46/h are achieved (Cases 1-4). This is a similar value to Cases 6 and 8 which have much smaller inlets in bedrooms. The smaller oultlet size of Area 1 than in Area 2 may be the reason of this similar value. The ratio openable-surface-to-floor-area is 16% in Area1 and 28 % in Area 2.

In Area 2 (bedroom-corridor), with 100% of the inlets opened, air changes around 90/h are achieved (Cases 5 and 11). If the inlets are reduced to 30%, the air renewal decreases to 65/h, 75% lower (Cases 7, 9 and 10). When the inlets are reduced to 15%, the air renewal decreases to 40/h, around 50% less (Cases 6 and 8). Openable-surface-to-floor-area ratios are between 15-25% for higher air changes (Cases 5 and 11), 5-7% for intermediate (Cases 7, 9 and 10) and 2-4% for the lowest. As you reach the 25-35% range of openable-surface-to-floor-area ratio the increasement of air changes due to the bigger size of openable surface is less significant (Case 11).

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