INFLUENCE OF VENTILATION AND INFILTRATION FLOW RATES ON ENERGY DEMAND IN RESIDENTIAL BUILDINGS OF SPAIN

Alejandro Rincón-Casado[1], Francisco José Sánchez-de-la-Flor[2], Enrique Ángel Rodríguez-Jara[2], Pablo Pavón-Domínguez[1] y José Sánchez-Ramos[2]

UNIVERSIDAD DE CÁDIZ. Escuela Superior de Ingeniería. Dpto. Ingeniería Mecánica [1] y Diseño Industrial y Dpto. Máquina y Motores Térmicos[2]. Avda. Universidad de Cádiz, 10 - 11519 Puerto Real (Cádiz). Tfno: + 34 956 48 32 00.

Received: 02/Mar/2017 – Reviewed: 6/Mar/2017– Accepted: 12/May/2017 – DOI: http://dx.doi.org/10.6036/8332

INFLUENCIA DEL CAUDAL DE VENTILACIÓN E INFILTRACIÓN SOBRE LA DEMANDA ENERGÉTICA EN EDIFICIOS RESIDENCIALES EN ESPAÑA

ABSTRACT:

This work focuses on the study of the influence of ventilation flow rates on the energy demand of buildings with residential use. Currently, the Technical Building Code (CTE) is the Spanish regulation that fixes the criteria for design, calculation and execution of ventilation installations. The current criteria for the calculation of ventilation flow rates has been established with criteria of indoor air quality. However, these criteria influence the determinant form on the heating conditioning demands. In this work, a detailed method is applied for calculating hourly ventilation and infiltration flow rates. This method allows to study the influence of variables such as the permeability of the facade (fixed in EN 15242: 2007), and the external wind velocity on the ventilation and infiltration flows. In addition, we study the influence of these flows on the heating demands. This study is carried out in three Spanish climatic zones (Cádiz, Madrid and Zaragoza), where the external wind velocities and climatic severity change substantially. The result of this work illustrates the importance of these variables, especially in the heating demands, finding differences of up to 14% depending on the wind zone and the permeability of the building facade.

Key Words: Ventilation, Infiltration, Ventilation flows, Demand of ventilation, indoor air quality

RESUMEN

Este trabajo tiene como objetivo calcular de forma detallada los caudales de ventilación e infiltración y analizar su influencia sobre la demanda energética de edificios con uso residencial en España. Actualmente el Código Técnico de la Edificación (CTE) es la normativa española que regula los criterios de diseño, cálculo y la ejecución de las instalaciones de ventilación. Los actuales criterios para el cálculo de caudales de ventilación están condicionados por criterios de salubridad del aire interior. Sin embargo, no tienen en cuenta la infiltración por permeabilidad de la fachada o la zona geográfica de viento donde se encuentre el edificio. Estos criterios influyen de manera determinante sobre las demandas de acondicionamiento. La metodología empleada tiene en cuenta el cálculo de caudales de ventilación e infiltración hora a hora, permitiendo estudiar la influencia de variables como la permeabilidad de las fachadas (definidas en la EN 15242:2007), y la velocidad del viento exterior, sobre los caudales de ventilación. Además, se estudia de forma cuantitativa la influencia de estos caudales sobre las demandas de acondicionamiento. El estudio se realiza en tres zonas climáticas españolas (Cádiz, Madrid y Zaragoza), donde cambian sustancialmente las velocidades de viento exterior y la severidad climática. El resultado de este trabajo demuestra la importancia de estas variables sobre las demandas de acondicionamiento, sobre todo en calefacción, encontrando diferencias de hasta un 14% en función de la zona de viento y la permeabilidad de la fachada del edificio.

Palabras Clave: Ventilación, Infiltración, Caudal de ventilación, Demanda de ventilación, Calidad de aire interior.

1. INTRODUCTION

Adequate ventilation is essential for the health and comfort of the occupants inside of a residential building. The calculation of ventilation flow rates has been covered by the old technological Standards (NTE) until recent years. Designers of facilities were limited to follow the guidelines for the calculation of flow rates and the design of the facility. Currently, the rules related to ventilation installations in residential buildings are both the European standard EN 15251:2008[1] and the CTE HS-3:2013 [2] for a Spanish level. In both standards, it is required that the current residential buildings must have a ventilation system formed by air vents and extractors, and it should also ensure the operation of the system without user intervention, i.e., it does not depend on the opening of windows or doors. In the case of the CTE, there has been a considerable advance in the minimum flows required, however, they respond to criteria of indoor air quality. However, no account is taken of the facade permeability, which is collected in the EN 15251:2008[1]. Neither the outside wind velocity of the building is considered, is this a parameter that depends on the climatic zone where the building is located. In addition, the procedure for the calculation of flows is based on a simple balancing flow rates, without the possibility of taking into account the external agents such as wind velocity or facade permeability [3].

For an energy demand approach, in the CTE, ventilation is treated as a thermal load, which is proportional to the flow rate of ventilation. Therefore, the precise estimation of the ventilation flow has a direct influence on the demands of heating and cooling of the building. Many authors have studied the ventilation and its effect on energy demand. In reference [4] a study in a residential building in different Italian cities is performed, in which, flow rates of the nodal method by a ventilation and cooling energy demand is calculated. It is demonstrated that the controlled ventilation causes average energy savings in cooling demand of 40%. Another study developed in reference [5] studied the potential for energy savings and indoor air quality caused by different ventilation strategies in residential buildings. The studied strategies are humidity control, control of presence, control of CO_2, and the control of all together. The energy savings achieved is a 25% in the control of each individual component. Combining all the strategies with the control of the ventilation system, a savings of 60%. Other work developed in reference [6] shows a study of both a residential building where a model using nodal methods for the calculation of the air flows and a thermal model for the calculation of energy demand. With both methods, authors developed a link for their joint simulation. Results obtained were compared with the measurements in an actual building for six days, validating the mathematical model. In reference [7] a review is made in different European countries, including Spain. In this work, the influence of the ventilation on human health is analyzed through measurements and surveys. In some countries, the air infiltration through the permeability of the facades and the opening of windows are the only ventilation systems, while in others, passive ventilation systems are frequently employed. In colder climates countries, mechanical systems have been installed, which are balanced or removal, with or without heat recovery units [8], [9]. Recently, a study has been made of the combination of flow rates of infiltration with mechanical ventilation for unbalanced ventilation systems. Studying the influence of the imbalances on the natural ventilation, applying the forward and the reverse method for millions of simulation time. However, it does not take into account the influence on the energy demand, only the methodology for calculating flow rates [10].

Three main types of calculation methods can be found in literature: the empirical methods; nodal methods; and the methods CFD (Computational Fluid Dynamics). The CFD methods, which solve the equations of motion of the fluid, are considered to be very precise and detailed, however, are not practical at the time of studying the annual demand. On the other hand, the empirical methods have less precision than the CFD, since they are based on the results of experimental trials, however, its computational cost is lower, and they are suitable for use in the calculation of the annual conditioning demands. Among the most popular empirical methods are the method of British Standard [11]; the method of the ASHRAE [12]; the method of Axley [13]; the method of Gidds and Phaff [14]; and the method of the IN 15242:2007 [15]. Finally, there are the nodal methods, which are based on the calculation of the node-to-node flow rates and calculate the flow rate in any area of the building. Among them, we find the pressure loop proposed by Axley [13] and the Mass Balance [11]. These methods are more accurate and easier for computing than the previous ones. The current programs in Spain, perform calculations under regulatory criteria, and do not allow flexibility to change the boundary conditions, or introduce new variables as the permeability of the facades or windows. Lastly, the HULC [16] method estimate the annual demand from the annual average flows, however, does not take into account the permeability of the building, nor has the flexibility to consider it as additional capacity.

In accordance with the current state of knowledge, it is noted that each country has its own rules and imposes its criteria of ventilation in residential buildings [7]. In the case of Spain, the rules to be applied is the CTE, which pays attention to the needs of air quality, without taking into account the infiltration. Therefore, the objective of this paper is to make a detailed calculation of the flow of ventilation and infiltration and to analyze the influence on the energy demand in residential buildings. To this end, it employs a single-area method where a nodal calculation method is used combining the pressure loop methodology [13] with the mass balance and the equations of 15242:2007 in [15]. A case study is conducted in order to analyze variables such as permeability of the building (infiltration) and wind velocity. These variables have a direct effect on the energy demand, depending on the geographic location and the constructive characteristics of the building. Three Spanish geographical areas have been analyzed, considering an identical building in three different locations, for comparing the energy demand in function of the ventilation flow.

2. METHODOLOGY

The calculation method used in this work for the estimation of the ventilation flow can be classified as a nodal method. Nodal methods exhibit greater advantages for calculating of annual energy demands due to its low computational cost. Specifically, it has been employed a combination of the three nodal calculation methods: Loop pressures, Mass Balance and the method of the IN 15242:2007 [15]. The pressure loop consists of the application of the Bernoulli equation Ec. (1) between two points of a line that goes from the outer to the inner building, and at all points must meet the continuity equation. It is a systematic method in which ties of pressures from outside to inside are taken in order to relate internal and external pressures. Developing and grouping the Bernoulli equation is obtained Ec (2), in which the pressure difference causing the driving forces of the air movement (wind and temperature) is equal to the pressure drop that occurs in each of the components of ventilation that crosses the line. The nodal Mass Balance method [11], serves to meet the conditions of mass balance in each campus building. The balance is achieved when the flow of air entering an enclosure is the same as when it comes out, so it complies with the Ec. (3). By applying the Boussinesq approximation is despised the variation of density of the air, simplifying the Ec.(3) to the Ec.(4). The formulation proposed by the EN 15242:2007 [15] provides the pressure drop in the different components of the ventilation system Eq.(5)-(10).

$$p_1 + \frac{1}{2}\rho_1 v_1 + \rho_1 g z_1 = p_2 + \frac{1}{2}\rho_2 v_2 + \rho_2 g z_2 \tag{1}$$

$$\sum \Delta P_{Driving\ forces} = \sum \Delta P_{Ventilation\ Elements} \tag{2}$$

$$\sum_{n}^{1} \rho_i Q_i = 0 \tag{3}$$

$$\sum_{n}^{1} Q_i = 0 \tag{4}$$

According to the CTE-HS3:2013 [2], the air for the ventilation of the spaces for residential ventilation system must move from dry rooms (bedroom and lounge) to wet enclosures (bathrooms and kitchen), to prevent the transmission of odors and pollutants. In addition, required ventilation flows at each room must be ensured regardless of the performance of the user. Therefore, in dry rooms, ventilation vents must be installed to ensure the minimum flow of entry, and in the wet rooms, mechanical extractors must be installed to ensure a minimum extraction flow. However, the CTE does not take into account the flow of air infiltration, that is to say, the air that enters through the permeability of the windows and the permeability of the enclosures of a facade. In addition, nor does it take into account the effect of the wind outside, or the float caused by the temperature difference between the exterior and the interior of the building. This information is available in the European standard EN 15242:2007[15]. Therefore, in order to carry out a detailed calculation, these variables must be taken into account in the calculation of the ventilation flow and infiltration, since they have a direct influence on the energy demand of the building.

One of the most relevant driving forces in ventilation is the wind, which causes a difference in pressure between the outside and the inside of the building (Eq. 5). This pressure difference depends on the pressure coefficient in the façade (Cp), the density of the air (ρext), the wind speed (Vref) and of the internal pressure (PREF). Another cause of air movement is due to the floating phenomenon (or chimney effect), caused by the temperature difference of the air, which leads to a difference of densities, influenced by the altitude? (Eq. 6). The pressure difference originated by the wind is combined with the caused by the temperature to obtain the total pressure difference in the façades (Eq. 7). Another driving force is the one made by the mechanical extractors, which ensure a pressure difference and a continuing flow removal. On the other hand, the ventilation vents or louvres are installed, usually at the top of the windows, and work by a pressure difference, that is, the flow passing through this element, is based on the difference in pressure between the outside and the inside of the building. In the Ec. (8) shows the equation of standard behavior for an air vent, where n and C depend on the characteristics of the air vent. These air vents should provide the design flow when working to a difference in pressure of 20Pa. Finally, although there are elements of ventilation, there is no entry or exit of air infiltration or exfiltration) through the windows and the facade, due to its permeability, these flows are considered as leakage, but directly involved in the flow of ventilation of the building. In Eq.(9) And Eq.(10), show the equations to calculate the leakage flow by windows and facade, respectively. Like the rest of elements of the ventilation system, the flow of leakage depends on the difference in pressure between the outside and the inside, and the coefficients of permeability defined in the

EN 15242:2007[15]. Finally, in order to comply with the mass balance equation, all input flows must be equal to the output flows, Ec.(11).

$$\Delta P_v = C_P \rho_{ext} \frac{V_{ref}^2}{2} - p_{ref} \qquad (5)$$

$$\Delta P_T = (\rho_{ext} - \rho_{int}) g \Delta z \qquad (6)$$

$$\Delta P = \Delta P_v + \Delta P_T \qquad (7)$$

$$Q_{rej} = C \Delta P^n \qquad (8)$$

$$Q_{fvent\cdot i} = Q_{100} A_i sing(\Delta P) \left(\frac{|\Delta P|}{100}\right)^{0.667} \qquad (9)$$

$$Q_{ffac\cdot i} = Q_{4Pa} A_{exp} \left(\frac{1}{4}\right)^{0.667} sing(\Delta P)(|\Delta P|)^{0.667} \qquad (10)$$

$$\sum Q_{vent\cdot i} + \sum Q_{fvent\cdot i} + \sum Q_{ffac\cdot i} + Q_{ext} = 0 \qquad (11)$$

Building thermal demand can be calculated by applying a single-area or multi-zone procedure. The single-area method considers the building as a single area, where they enter and leave the ventilation flow rates through its components. On the contrary, in the multi-zone model, the building is divided into zones, such as homes, and flows are exchanged among each zone. The model selected in this work is the single-area, since the goal is to characterize the influence of the exchange ventilation flow between the building and the outside, and its influence on the demand.

To analyze the effect of the ventilation flow on energy demand, it is used the dynamic simulation software TRNSYS 17 [17], where users can create the model of the building from its geometry, materials, and thermal loads according to the location of the building. On the basis of the variation of wind velocities, outside temperature and permeability of facades and windows, values of energy demand schedules are obtained. By using this tool, it is possible to compare the annual energy demands among different study cases and to observe the influence of the variables on the thermal demand.

3. RESULTS AND DISCUSSION

With the aim of simplifying the calculations and easily detect the influence of the flow rates on the demand, the case study will be a single family house consists of three bedrooms, bathroom, living room, kitchen and corridor distributor (Figure 1). The living area of the house is 90 m^2 distributed on one floor and a height of 4 m. Except for the bathroom, all rooms have a window. The windows of the bedrooms and the living room have air vents for ventilation, and in the bathroom and the kitchen, there is an extractor fan that runs continuously. With this configuration ensures that the air is directed from the dry to the wet spaces, where it is expelled to the outside through mechanical extractors.

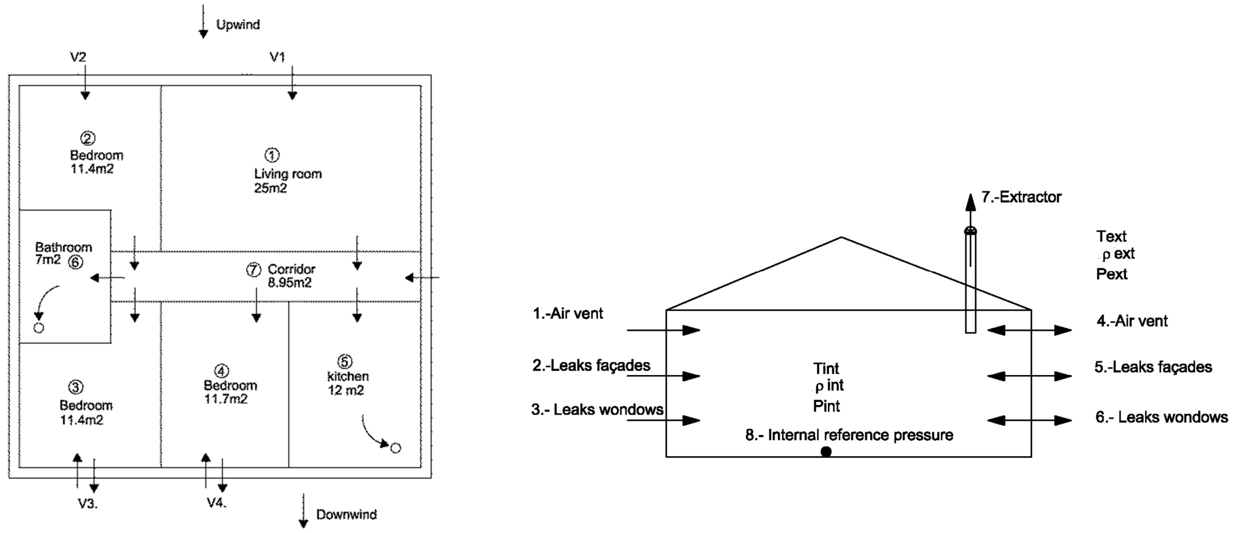

Figure 1: Schematic case study. Panta (left), lump sums (right).

The minimum flows required by the criteria of safety, are fixed by the CTE-HS3:2013 [2], for example, in the bedrooms requires an input flow rate of 15 l/s/pers., and in the living room of 3 l/s/pers. However, in the bathroom requires a minimal extraction of 15 l/s, and in the kitchen 2 l/s/m2. From these minimum values, a balance of flow is performed with the aim of balance admission and extraction flows. In this case, it is necessary to increase the air extraction through the bathroom of 15 to 24 l/s to balance the system (see Table 1). Therefore, the resulting extraction flow is 48 l/s, which is in compliance with the minimum requirements in the regulations [2]. According to them, the design of the installation is justified by selecting the vents and extractors that meet with the aforementioned minimum flow. However, this procedure does not calculate hour by hour the ventilation flow in detail and does not take into account the outdoor wind velocity and the difference of temperature. In addition, nor does it take into account the flow of infiltration or exfiltration by the permeability of the façade and windows.

Unit		**Bedroom1**	**Bedroom 2**	**Bedroom 3**	**Living Room**	**Bathroom**	**Kitchen**
Number of occupants (N)		2	2	2	6	-	-
Area (m2)		11.4	11.7	11.4	25	7	12
Flow rates (l/s)	**Unitary qi**	5	5	5	3	-15	-2
	Minimum (qiN)	10	10	10	18	-15	-24
	Balanced	**10**	**10**	**10**	**18**	**-24**	**-24**

Table 1: minimum flows and balanced flow rates according to CTE-HS3:2013[2].

By applying the methodology of section 2, you can calculate the actual flow rate of the air vents, the flow by infiltration of facade and windows, and the difference in pressure caused by the wind outside. For the air vents, the model S13 4000 Manufacturer Titon [18], which complies with the tests required by EN-13141-1:2004 [19] with a coefficient C=2,226 and a n=0.5113 for the EC. (8) have been selected. For the leaks by facade (EC 10), it has been considered a low leakage of 0.5m3/h·m2 4Pa according to EN 15242:2007[15]. And for the leaks by windows (Ec 9) has been selected a window class 3, with a permeability of 9m3/h·m2 to 100Pa according to EN 12207:2000[20]. With regard to the driving forces (wind, temperature and extractors), to calculate the difference in pressure caused by the wind (Eq. 5), the pressure coefficient in the façades is obtained according to the EN 15242:2007[15], where 0.25 is to windward and -0.5 is to leeward. The difference of pressure caused by the float [21] deduced by the difference of temperature (Eq. 6), is not a determining factor given the low height of the housing (4 m). Finally, with regard to the extraction flow is used as input 48 l/s in Eq.(11).

According to the mass balance of the Ec.(11), when a single-area case is considered, the inner pressure is similar in each room (Pref), therefore, the flow which enters or leaves through the openings (air vents or leaks) depend on the difference in pressure between the outside and the inside (ΔP). All the equations defined in Section 2, have been computed in the EES Solver program [22], thereby, ventilation flow rates through each component, for example, the wind speed or the relative permeabilities of façade or windows, can be calculated.

To analyze the influence of the wind velocity over the ventilation flow, the equations are solved by varying the speed of 0 to 10m/s, for 0.25m/s increments. Wind direction is considered blowing to windward to leeward, and parameters of permeability of windows and facade are kept constant in all the cases studied. It is shown is Fig.2 the flow rates in air vents (Qrej), Qffach facade (leakage), leaks by Qfvent (Windows) and the extraction flow (Qext), differentiating between facade on the windward side (B) and facades to leeward (S). When wind velocity is close to 7m/s, the flow of entry through the facade in leeward regime is canceled due to the suction effect of the wind. Indeed, for outdoor wind velocities greater than 7 m/s, a reversal of the ventilation flow of air vents, leaks by facade and windows to leeward occurs.

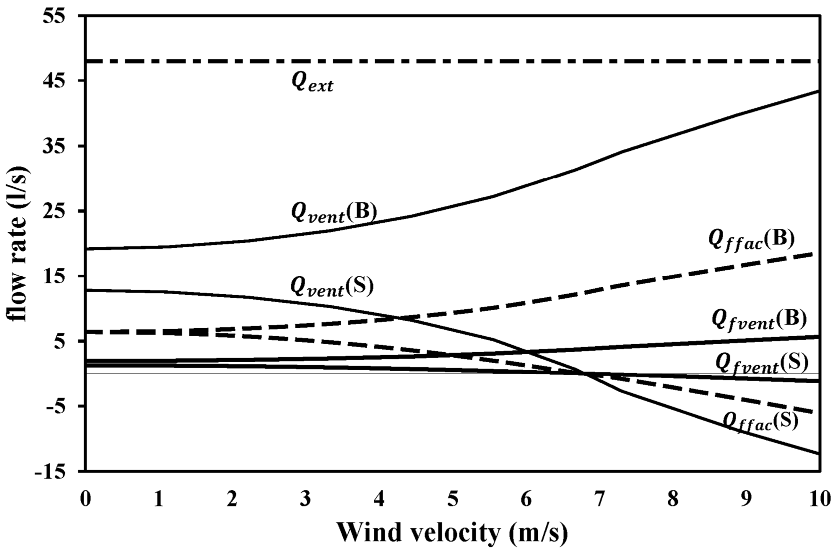

Figure 2- A variation of the flow of ventilation air vents (Qrej), extractors (Qext), Qffach facades (leak) and leak by windows (Qfvent), depending on the speed of wind outside, for facade to windward leeward (B) and (S).

The influence of the parameters of permeability of facade and windows on ventilation flow can be analyzed similarly to the wind. The parameters of permeability are determined by the architectural design; the constructive system; and the materials used. For the level of permeability of the building has been considered the joint permeability of windows and doors of a facade. Considering three levels of permeability (high, medium and low). According to the IN 12207:2000[20], windows are considered to take values of 50, 27 and 9 m3/h·m2, for permeabilities high, medium and low, respectively. And in the case of facades, according to the in 15242:2007[15] are considered the values of 2, 1 and 0.5 m3/h·m2, for permeabilities high, medium and low, respectively. Solving the equations for each level of permeability and by varying wind velocity between 0 and 14 m/s, the total ventilation flow rates (Qin) for each level of permeability can be known. Fig.3 shows the input ventilation flow rates for the three levels of leakage studied. As observed, the investment ventilation flow occurs for lower wind velocities, when a high permeability level is considered.

Alejandro Rincón Casado, Francisco José Sánchez de la Flor,
Enrique Ángel Rodríguez Jara, Pablo Pavón Domínguez
José Sánchez Ramos

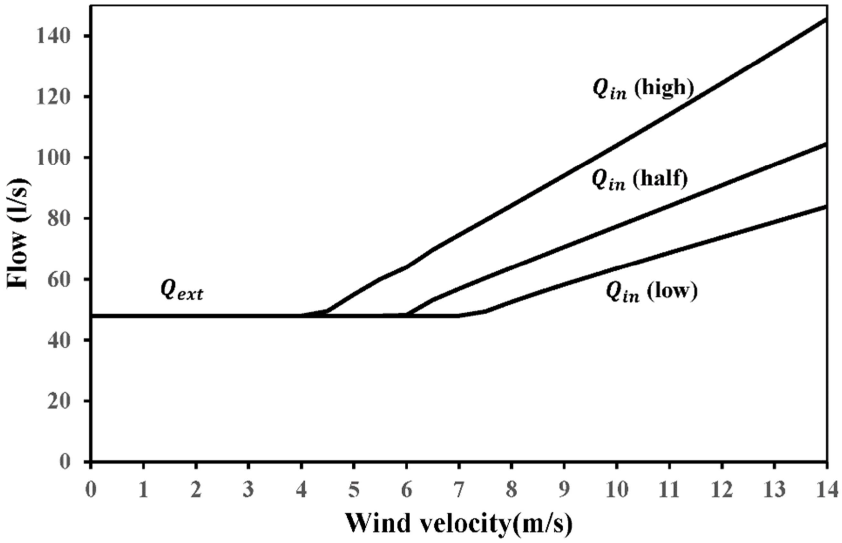

Figure 3: Flow inlet vents (Qin) for permeability of the building high, medium and low, depending on the speed of wind outside.

Once the influence of the wind and the permeability of the ventilation flow rates have been described, it is interesting to study the influence of these variables on the energy demand, specifically in the heating regime. For this purpose, it must be taken into account the climate where the building is located. Three locations are studied: Barcelona, Madrid and Zaragoza, which differences among them are found both in the climate severity and in the category of wind area. The reference standard CTE-Actions: 2006 [23] is considered for the wind effect. As shown in Fig.4, the selected localities correspond to the zones of wind A, B, and C. The wind velocity data and frequencies are obtained from the Meteonorm program[24] for each location. In Fig. 4 (right) the three studied locations are depicted.

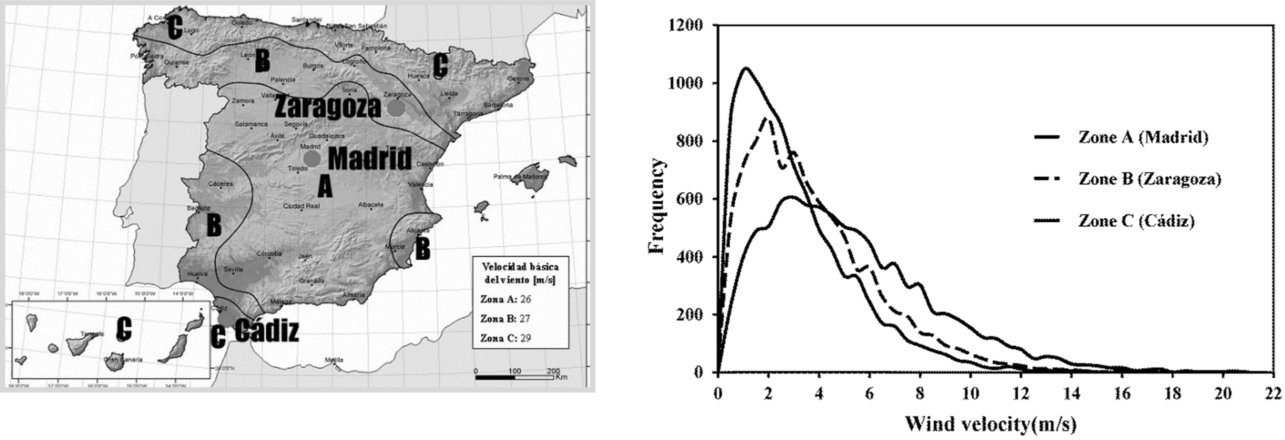

Figure 4: Map of wind speed according to CTE-Actions (left). Frequency distribution of wind speeds of locations studied (right).

Element	***Thickness(m)***	***U* (W/K·m2)**
Ceiling	*0.5*	*0,495*
Walls	*0.2*	*0,669*
Floor	*0.5*	*0,578*
Windows	*-*	*2.48*

Table 2: values of thermal transmittance of the shroud of the building.

With the aim of characterizing the influence of the ventilation flow on demand, there annual dynamic simulations have been conducted by using the software TRNSYS 17[17], where the input variables are: hourly ventilation flow; meteorological data of each locality; temperature of 24ºC; and the thermal transmittance shroud (Table 2) [25]. To comparing, each locality is simulated for three degrees of permeability (high, medium and low), and the annual demand for heating is estimated. As an example, Fig.5 shows a dynamic simulation of one of the cases studied. The comparison among cases is shown in Fig. 6, which represents the annual demand for heating of the building for three levels of permeability and in three different locations. According to results, significant differences in the demands of heating is stated. Fig.6 represents the energy demand in the heating mode of the building by varying the permeability of the facade and the area where is located (Zone A, B and C). As outstanding results, it is observed that the C zone requires a 5% higher demand in the area for a low permeability, however, in the case of high permeability, this difference increases to 14%. Therefore, in view of these results, it is expected that using these consumption values for the energy classification the drive letter of classification of the building might be changed.

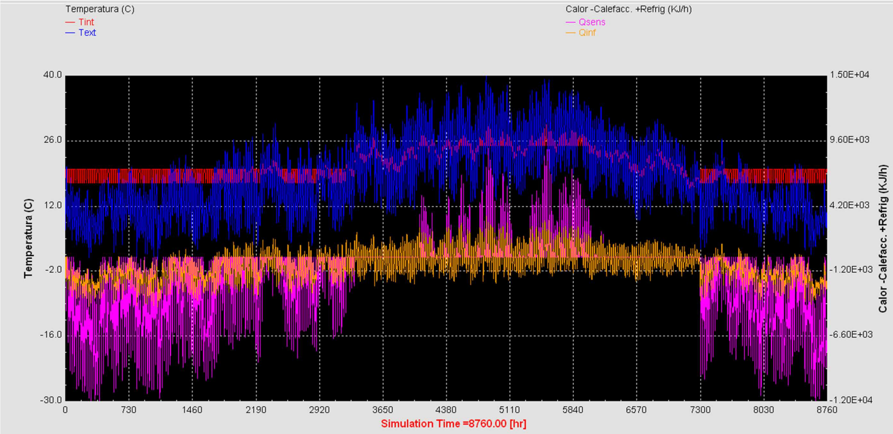

Figure 5: Dynamic Simulation Case Example TRNSYS 17[18],

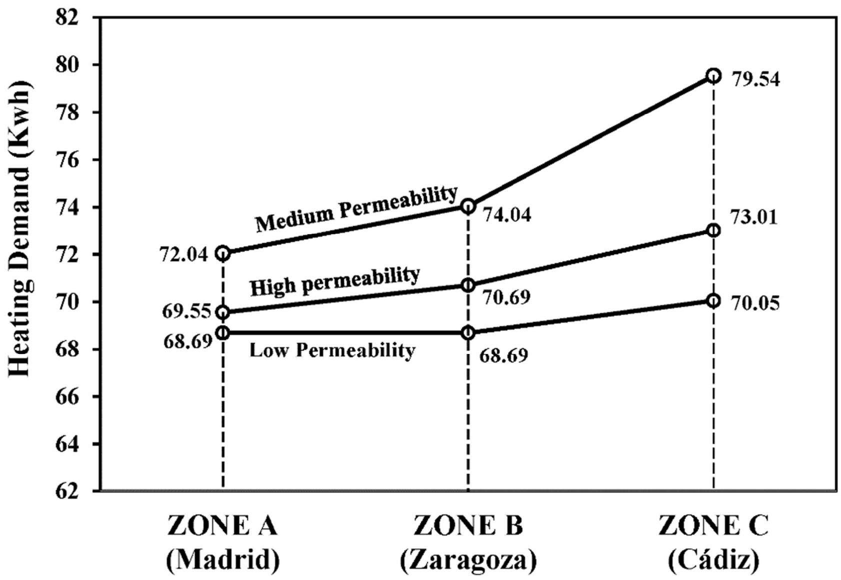

Figure 6: Influence of the wind and the permeability of the building on the demand for heating.

4. CONCLUSIONS.

This work presents a detailed method for the calculation of ventilation and infiltration flows of a residential building. For the calculation of both the regulatory minimum flows and flow rates of infiltration through facades and windows the CTE-HS3:2013[2] and equations of 15242:2007 [15] are employed. Once flow rates are calculated on an annual basis, the influence on the energy demands of heating is estimated. for different permeability of facade and localities.

With regard to the detailed calculation method of ventilation flow rates, the procedure for the calculation of the ventilation time to time depending on the speed of the wind outside and the permeability of the façade is shown. Within the current methods, we used a method of calculation that brings simplicity and savings in computational cost in large buildings. In this method, actions causing the air movement in the building: wind, temperature difference and the extractors are taken into account. This method of calculation is useful for designers of new buildings or existing buildings, getting more accurately than methods proposed by the CTE-HS3:2013[2].

Results show that the ventilation flow rates are influenced by wind speed, as well as the wind direction, given that in the facades to leeward there is a wind speed from which reverses the flow of ventilation. This phenomenon causes an excess of ventilation, resulting in an increase of the thermal load and, consequently, a loss of comfort. To avoid this excess load, it is necessary to increase the energy demand in heating mode, which is an inevitable phenomenon for users. Indeed, according to the CTE, ventilation must occur without user action. However, to avoid reflux in air vents, air vent should be installed a dumper, where the user can act in cases of excess wind outside. Moreover, the influence of the permeability of facade and windows on ventilation flow have been also analyzed. Therefore, it is concluded that the greater permeability of the building, the greater ventilation flow, and as a result, the inversion flow occurs at a lower outside wind velocity.

To quantify the impact on the demand of the permeability and in the area of the wind where it is placed in the building, dynamic simulations have been carried out by the hour in three different cities, by varying the flow of ventilation depending on the wind and three levels of permeability studied. Simulations for the three geographical areas show that the influence on the demands vary from 5% to 14% in the most unfavorable cases. Thus, the influence of the ventilation flow on the energy demand is demonstrated and quantified.

Finally, it is concluded that the influence of both ventilation and infiltration on the energy demand is significant. For reducing the its impact on the demand is compulsory mitigate the causes, i.e., the excess of ventilation. Therefore, as a result of this study, the following suggestions for design and use are derived. Wind actions are inevitable phenomena, however, its effect can be minimized by installing aerators with gates, so the user can manipulate them in case of strong wind. Another way to minimize the ventilation flow would be shutting down the pumps thorough the signal from an anemometer installed on the vent cover (hybrid). With respect to the permeability of new buildings, care should be taken to the tightness of the façade, by the design of the constructive system and the monitoring of their implementation; and in the case of existing buildings, through waterproofing. With regard to the sealing of the windows, recourse must be had to windows with better classification, specifically in areas exposed to the wind.

BIBLIOGRAPHY

[1] UNE-EN 15251:2008 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.
[2] The Technical Building Code (CTE) HS-3 Indoor Air Quality, 2013. The Law 38/1999 of 5 November. Spain.
[3] Rodríguez-Soria, B., Perez-Bella, J., Domínguez-Hernández, J., Cano-Sunen, E., Coz-Díaz, J.. (2012). Indoor air quality and energy efficiency. DYNA, 87(1). 74-79. DOI: http://dx.doi.org/10.6036/4140
[4] N Cardinale, M Micucci, F Ruggiero, Analysis of energy saving using natural ventilation in a traditional Italian building, Energy and Buildings, Volume 35, Issue 2, February 2003, Pages 153-159, ISSN 0378-7788, http://doi.org/10.1016/S0378-7788(02)00024-5..
[5] J. Laverge, N. Van Den Bossche, N. Heijmans, A. Janssens, Energy saving potential and repercussions on indoor air quality of demand controlled residential ventilation strategies, Building and Environment, Volume 46, Issue 7, July 2011, Pages 1497-1503, ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2011.01.023..
[6] Chris J. Koinakis, combined thermal and natural ventilation modeling for long-term energy assessment: validation with experimental measurements, Energy and Buildings, Volume 37, Issue 4, April 2005, Pages 311-323, ISSN 0378-7788, DOI: http://doi.org/10.1016/j.enbuild.2004.06.022.
[7] C. Dimitroulopoulou, Ventilation in European dwellings: A review, Building and Environment, Volume 47, June 2012, Pages 109-125, ISSN 0360-1323, DOI: Https://doi.org/10.1016/j.buildenv.2011.07.016.
[8] P. Concannon Residential ventilation Technical Note 57 Aivc Air Infiltration and Ventilation Center (2002) 29600035518
[9] P.G. Schild State-of-the-art of low-energy residential ventilation Contributed Report 07 Air Infiltration and Ventilation Center (2007)
[10] Nolwenn Hurel, Max H. Sherman, Iain S. Walker, Sub-additivity in combining infiltration with mechanical ventilation for single zone buildings, Building and Environment, Volume 98, March 2016, Pages 89-97, ISSN 0360-1323, DOI: Https://doi.org/10.1016/j.buildenv.2015.12.020
[11] BS 5925-1991 "Code for practice for Design of Buildings: Ventilation principles and designing for natural ventilation"
[12] ASHRAE Handbook:2005 Chapter 27 - Fundamentals - If Units. American Society of Heating, Refrigerating and Air-Conditioning Engineers / 2005 / ISBN: 1931862710.
[13] James W. Axley, Multi-zone dispersal analysis by element assembly, Building and Environment, Volume 24, Issue 2, 1989, Pages 113-130, ISSN 0360-1323, http://dx.doi.org/10.1016/0360-1323(89)90001-2.
[14] Gids, W. and Phaff, H. 1982. Ventilation Rates and Energy Consumption due to open Windows. A Brief Overview of Research in the Netherlands, Proc. of the Third IEA Air Infiltration Center Conference, Vol. 1, pp. 4-5.

[15] UNE-EN 15242: 2007_Ventilation for buildings. Calculation methods for the determination of air flow rates in buildings including infiltration.

[16] HULC CALENER leading Unified Tool (version 1.0.1528.1109 of 12 July 2016).

[17] 17 Transys. 2008. Solar Energy Laboratory, University of Wisconsin-Madison 1500 Engineering Drive, 1303 Engineering Research Building Madison, WI 53706 - U.S.A.

[18] Titon UK. S13. Http://www.titon.co.uk/pages/window-door-hardware/ventilators/slot-vents/trimvent-select-s13.php

[19] In 13141-1:2004. Ventilation for buildings. Performance testing of components/ products for residential ventilation.

[20] In 12207:2000. Windows and doors. Air permeability. Classification.

[21] A. Rincon-Casado, F.J. Sanchez of the flower, E. Chacon Vera & J. Sánchez Ramos (2017) New natural convection heat transfer correlations in enclosures for building performance simulation, Engineering Applications of Computational Fluid Mechanics, 11:1, 340-356, doi: https://doi.org/10.1080/19942060.2017.1300107

[22] EES 2003. Engineering Equation Solver. University of Wisconsin-Madison.

[23] The Technical Building Code is-AE. Security structural. Actions. 2006. Spain

[24] Meteonorm 6.1 Jan Remund and Stefan Kunz. Meteotest. Fabrikstrasse, 14, CH-3012 Bern. Switzerland.

[25] Domínguez-Hernández, J., Perez-Bella, J., Cano-Sunen, E., Coz-Díaz, J., Rodríguez-Soria, B.. (2017). Adjusting the design thermal conductivity considered by the spanish building technical code for façade materials . *DYNA*, 92(2). 195-201. DOI: http://dx.doi.org/10.6036/8005