THERMODYNAMIC ANALYSIS OF BUILDINGS WITH NATURAL VENTILATION AND INDOOR AIR QUALITY

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ABSTRACT

The aim of this study is to analyse the behaviour of natural ventilation techniques in low-rise commercial buildings in terms of Indoor Air Quality (IAQ). Verifying how the outside air flow can enter a building using natural ventilation techniques to check if they are suitable to be bound by the regulations, thus validating passive techniques for ventilating buildings.

With the emergence of the regulation of thermal installations in buildings (RITE) in Spain, the basic regulatory framework that regulates the requirements in energy efficiency and security is set up, thermal installations in buildings need to meet the demand of welfare. It is compulsory to vent all conditioned spaces of a building using fans, which involves installing ducts and equipment. With the RITE approval is compulsory to install them in buildings that do not have cooling demand. This implies an increase in the cost of ventilation and operation.

An analysis of different foreign regulations related to natural ventilation is performed, the UK regulations Building Bulletin 101 - Ventilation of School Buildings and the ASHRAE Standard 62.1-2007 - Ventilation for acceptable indoor air quality. The design requirements that these regulations prescribe are collected. In these guidelines, it is possible to introduce the necessary outside air in buildings using natural ventilation techniques, in order to maintain IAQ, healthy environments and avoid potential pathologies related to comfort inside buildings.

A case study is carried out, designing a low-rise commercial building prototype with natural ventilation systems. It is calculated the size, distances and orientations of the openings necessary in each occupied zone. Subsequently it is checked the design made by computational thermodynamics simulation. The thermodynamic simulation tool used to test the feasibility of natural ventilation techniques is Energy Plus, which by Airflow Network module enables the modelling of natural ventilation in buildings. Additionally, it is also used Computational Fluid Dynamics (CFD) simulations to properly design natural ventilation systems and to validate inside thermal comfort of the proposed building.

The study work scheme has the following parts:

1. Calculation of the intake outside air needs in the model building, according to the Spanish regulation.
2. Design of Natural Ventilation systems to implement into the model building.
3. Thermodynamic simulations are performed to verify the compliance with the requirements of the Spanish normative.
4. Analysis of results.

Finally, it is verified that in normal weather conditions and proper design of natural ventilation systems, indoor air quality meets the requirements of regulations. In conclusion, thanks to the implementation of this technology we can achieve considerable savings in the implementation and operation, along with a decrease in CO_2 emissions to the atmosphere.

KEYWORDS

NATURAL VENTILATION, INDOOR AIR QUALITY, CFD, ENERGY SAVINGS, THERMODINAMIC MODELING

1 INTRODUCTION

The reason of this study is the need to know the advantages of implementing natural ventilation methodologies in commercial buildings. The system will be analyzed to find out if the regulatory requirements in terms of Welfare and Health inside buildings are met, compared to other ventilation systems in buildings and analyze its energy, economic and environmental impact. The ultimate goal is to show that the IAQ analyzed and CO_2 concentration inside buildings are within the ranges established by law using natural ventilation systems as well as using mechanical ventilation.

To verify that the regulations are met using natural ventilation techniques, a commercial building prototype is modeled using a thermodynamic simulator. Several viable options for the implementation of natural ventilation systems are studied, the necessary outdoor openings are sized and thermodynamic and CFD simulations are performed, the results give us the amount of external air introduced in each internal area of the building, evaluating whether the airflows meet the requirements of the regulations. The energy simulation tools used for the calculation of natural ventilation and internal comfort is Energy Plus[1].

A building prototype is developed without incorporating the design measures necessary for natural ventilation. This building will have heating system and mechanical ventilation system and will serve as a reference when comparing the results obtained in the proposed building using natural ventilation systems.

Energy consumption and outside air flows supplied to each zone are compared, verifying the feasibility of using natural ventilation systems for ventilating commercial buildings.

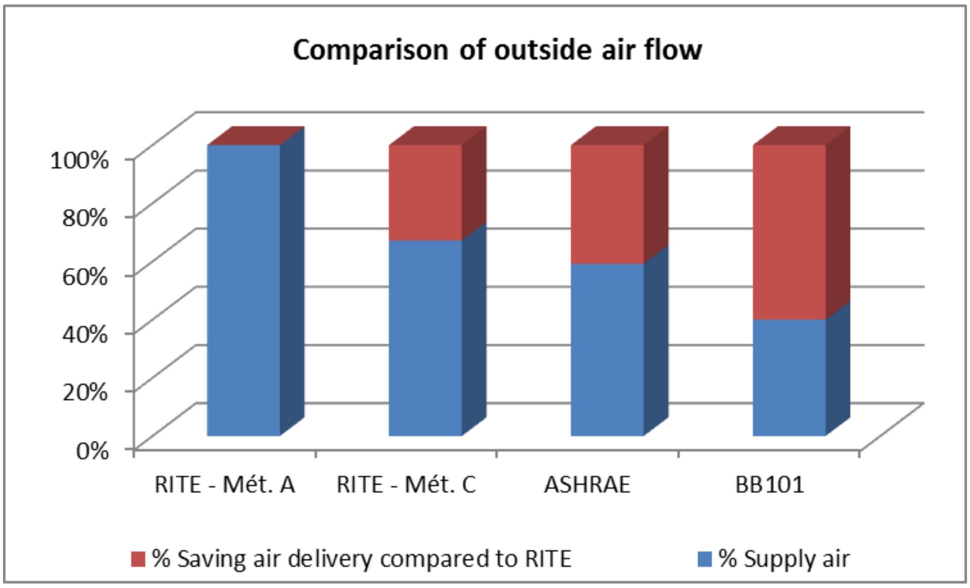
2 REGULATIONS

The Regulation of Thermal Installations in Buildings (RITE) in Spain establishes the conditions that ventilation, heating, cooling and domestic hot water installations must met to facilitate the demand for thermal and health wellness through a rational use of energy. RITE does not prescribe the implementation of natural ventilation systems in the design, in comparison to regulations in others developed countries where these systems are allowed. But RITE allows the possibility of alternative solutions using a simplified procedure, allowing building ventilation techniques using natural techniques, as long as its technical feasibility is justified. The requirements to be viable as required by RITE by designs using natural ventilation systems in this study are explained. Other foreign policies as the ASHRAE Standard 60.1 or UK regulations allow natural ventilation as a viable strategy to maintain a good IAQ in buildings.

If we compare outdoor air requirements necessary to enter in commercial buildings to maintain good IAQ, we can see how the Spanish regulations (RITE) requires a greater supply flow of outside air against regulations in USA and UK. According to the method of calculating the flow of outside air that enables RITE, ventilation flows vary, even more if we rely on the regulations that RITE referred to, as for example the UNE-EN 13779.

[1] EnergyPlus - U.S. Department of Energy. http://apps1.eere.energy.gov/buildings/energyplus/

Using Method C. RITE direct method for CO_2 concentration and the different calculation methods described in the regulations: *UNE-EN 13779 - Ventilation for non-residential buildings, NTP 742 - General ventilation of buildings and NTP 549 - Carbon dioxide in assessing of indoor air quality*; a value of 8.4 l/s·person as exterior air flow is specified as necessary to introduce in the occupied areas of the building assessed, since RITE specifies the maximum values of the ranges of comfort described in the regulations specified above, specifying a outside air flow using Method A. RITE indirect method of outside air flow which is 12.5 l/s·person.



2.1 REQUIREMENTS FOR INDOOR AIR QUALITY (RITE) IN A TERTIARY BUILDING PROTOTYPE

The first point of the analysis is the calculations of the outside air flows required to enter in each area of the prototype building for tertiary use at low altitudes to ensure that IAQ is suitable as required by regulations. For this reason, the tertiary building prototype is designed and requirements are analyzed. According to the table surfaces of the building prototype we calculate the occupation of each area using the designated occupancy rates. In this way, we can calculate the requirements for the admission of outside air for each zone of the Prototype. The most significant areas of the building to be naturally ventilated are the office areas, because these areas have the greatest occupation in terms of number of people and hours of use per year. The building has three types of offices easily distinguishable by their size and location in the building. The calculations required by the regulations specified above are performed, obtaining the following needs of air changes per hour (ACH) depending on the type of office analyzed

- Offices type 1: 5.0 ACH
- Offices type 2: 5.0 ACH
- Offices type 3: 3.3 ACH

3 APPLIED SOLUTIONS TO THE TERTIARY PROTOTYPE TO BUILDING AND ITS TECHNICAL DEVELOPMENT

Natural ventilation is produced mainly by two mechanisms: the chimney effect and wind pressure ("wind effect"). The chimney effect arises from the decrease in air density when its temperature rises. Wind pressure also influences the ventilation of a building by creating pressure variations around the outside of the building. The pressure variations are highly dependent on the shape of the building, speed and wind direction.

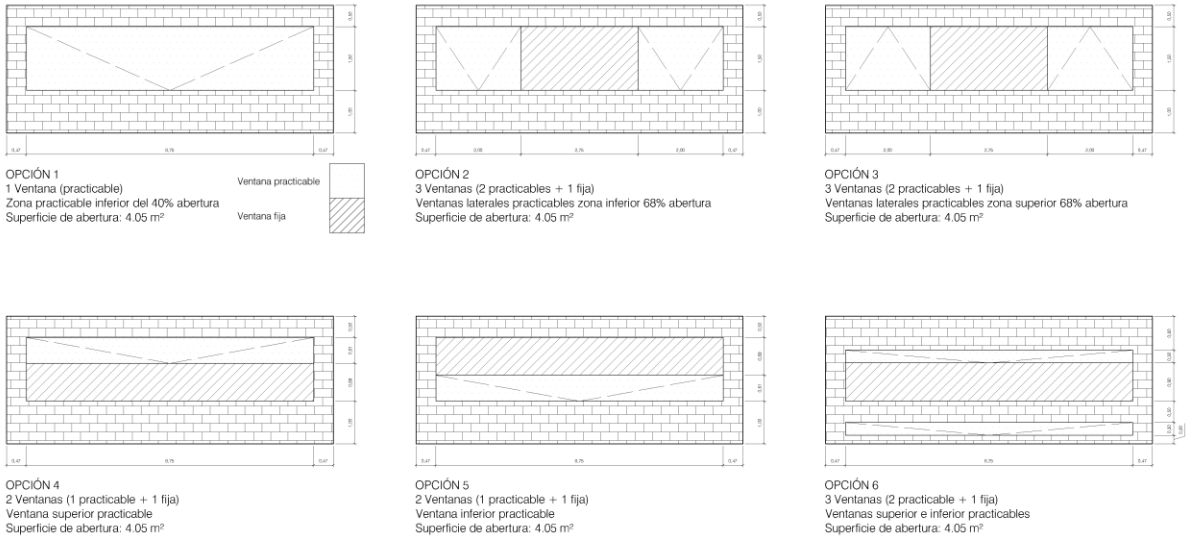
The design of the openings and their arrangement in the façade is a key factor, besides the opening surface, to ensure that the external air flow entering each zone is adequate. To be able to analyze the impact that has the arrangement of the openings in the exterior walls on the ventilation in zones, different simulations were performed using CFD techniques. CFD simulations are used, because the thermodynamic simulations are not feasible for analyzing openings design. This is because the thermodynamic and energy simulation programs are able to model and give results of the air flows coming into the building, the flows leaving the building and internal paths that perform the air flows between different areas inside the building. But do not discriminate between the situation of openings in the façade, neither inside air movements by natural convection effects. For this reason, CFD techniques are used.

Firstly, a pre-dimensioning of the openings to the outside surface is performed to achieve introduce the external air quantity specified in regulations. This analysis is performed using different methods of empirical calculation as *AM10CalcToolv5 (CIBSE), Florida Solar Energy Method I and II, ASHRAE, Aynsley and British Standard*. Later we validate the sizing of the openings to the outside via thermodynamic simulation using Energy Plus, specifically using its *AirFlowNetwork* module that allows the simulation of multi-nodal natural ventilation models, considering differences in internal pressures and external air flows between zones.

Once the outside necessary openings are specified, different design options in the openings in the façade are analyzed, distributing the opening surface and its height in the façade to take advantage of natural convection inside the areas to be ventilated naturally. Creating cross ventilation, and designing ventilation shunts with expulsion of air through chimneys favoring the chimney effect of the inside air flow, helping to evacuate the inside air and improving ventilation of the area. 6 different distribution openings (glazing) designs were developed on the facade, keeping the opening area constant, because this value of opening area ensures the required air flow. The design options analyzed are described as follows:

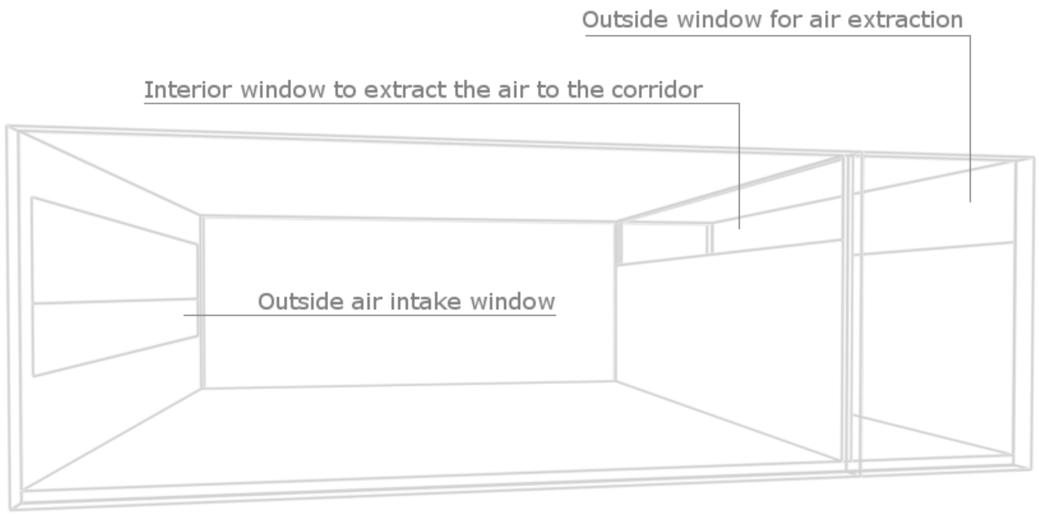
- <u>1 openable window</u>: The air intake is performed by opening the bottom of the window (openable windows).
- <u>3 windows (2 opening + 1 fixed)</u>: The air intake is performed by opening the bottom of the 2 opening windows (openable windows).
- <u>3 windows (2 opening + 1 fixed)</u>: The air intake is performed by opening the top of the 2 opening windows (openable windows).
- <u>2 windows (one practicable + 1 fixed)</u>: The air intake is performed by opening the upper window (longitudinal window).
- <u>2 windows (one practicable + 1 fixed)</u>: The air intake is performed by opening the lower window (longitudinal window).

- <u>3 windows (2 practicable + 1 fixed)</u>: The ventilation of the area is done by opening the lower longitudinal windows (air intake) and upper (exhaust air)



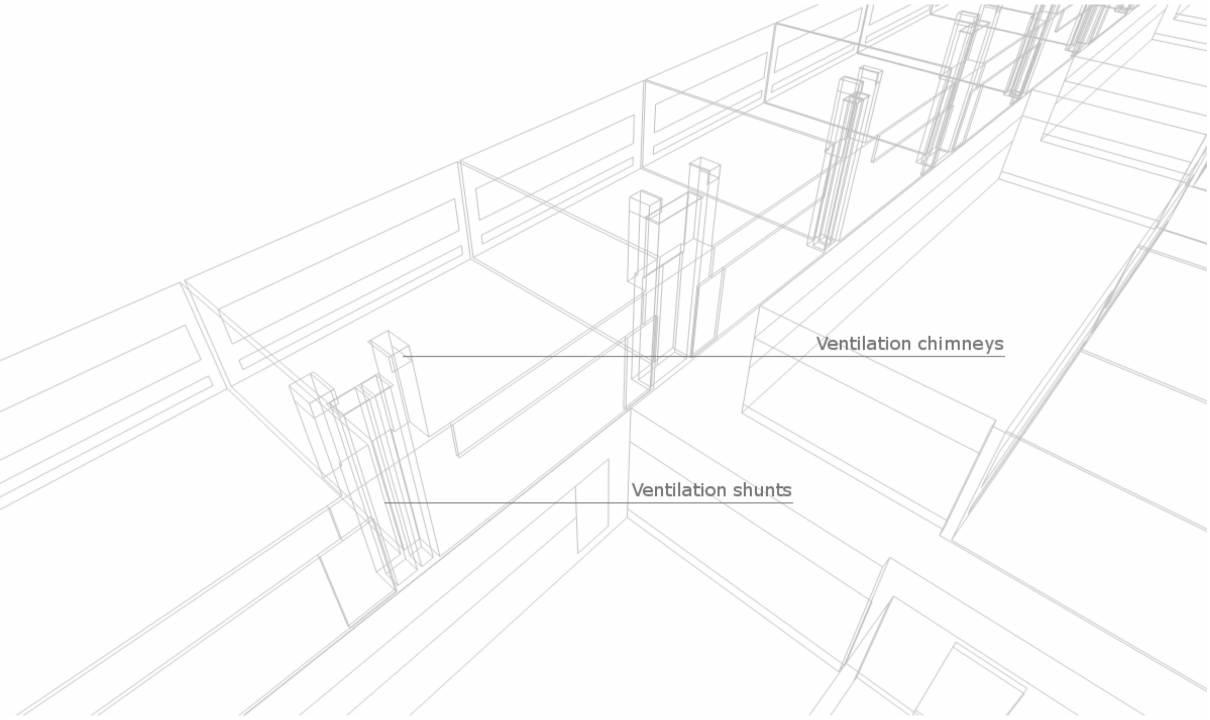
In addition to the different situations of the openings in the façade, two techniques for cross ventilation are evaluated. The first is achieved by arranging an opening in the top of the inner partition which separates each office with the corridor. And the second creating shunts and ventilation chimneys.

- <u>3 windows (1 practicable + 1 Fixed + interior to corridor)</u>: The ventilation of the area is performed by opening the lower longitudinal window (air intake) and the inner window (air discharge), which extracts the air into the corridor area which is ventilated with outside air.



- <u>2 windows (one practicable + 1 fixed + ventilation shunts)</u>: The ventilation of the area is performed by opening the lower longitudinal window (air intake) and opening the vents of the shunts (exhaust air), which extract the air from the zone to the outside area by the ventilation chimneys on deck. The admission of outside air can be introduced by a strip as specified in the following illustration, or through openings to the outside with motorized vents, the important to validate the solution is to measure the surface of opening to the outside according to the results obtained in the present study.

To allow cross ventilation in the zones in the floors below the top floor, ventilation shunts are designed which lead the exhaust air to ventilation chimneys on deck.

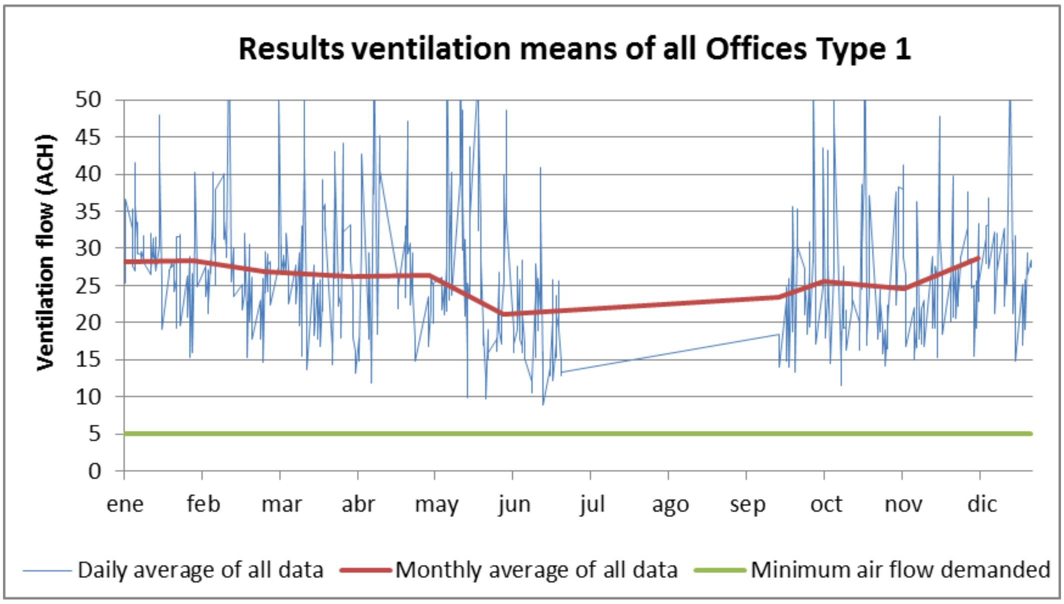


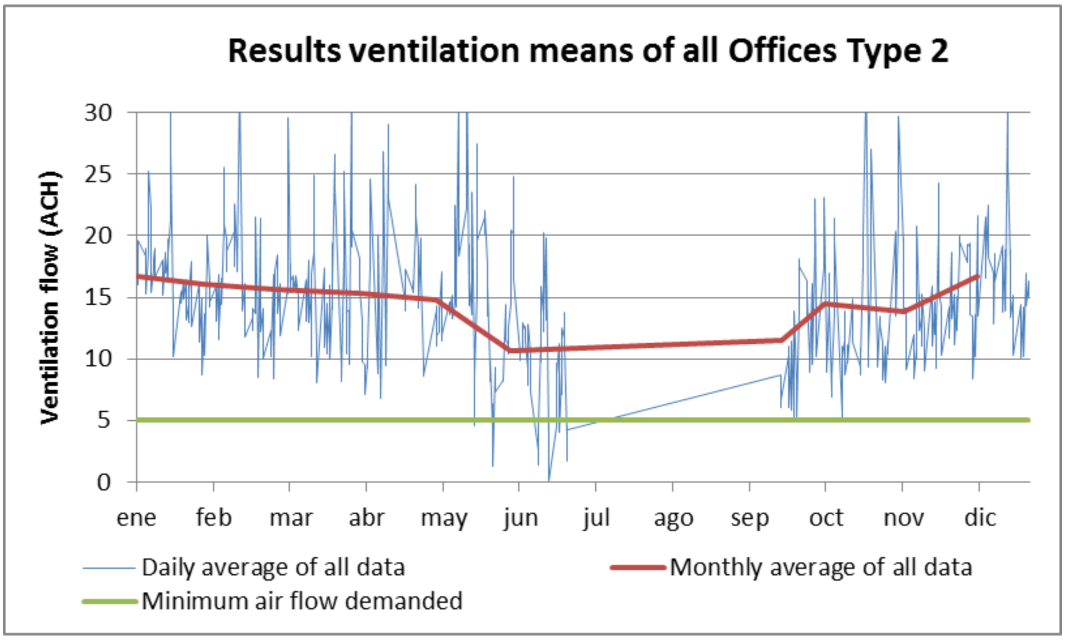
To perform the comparison between the 8 design options, different factors of natural ventilation that help us to make decisions in the most favourable option are analyzed, using design option of the natural ventilation system.

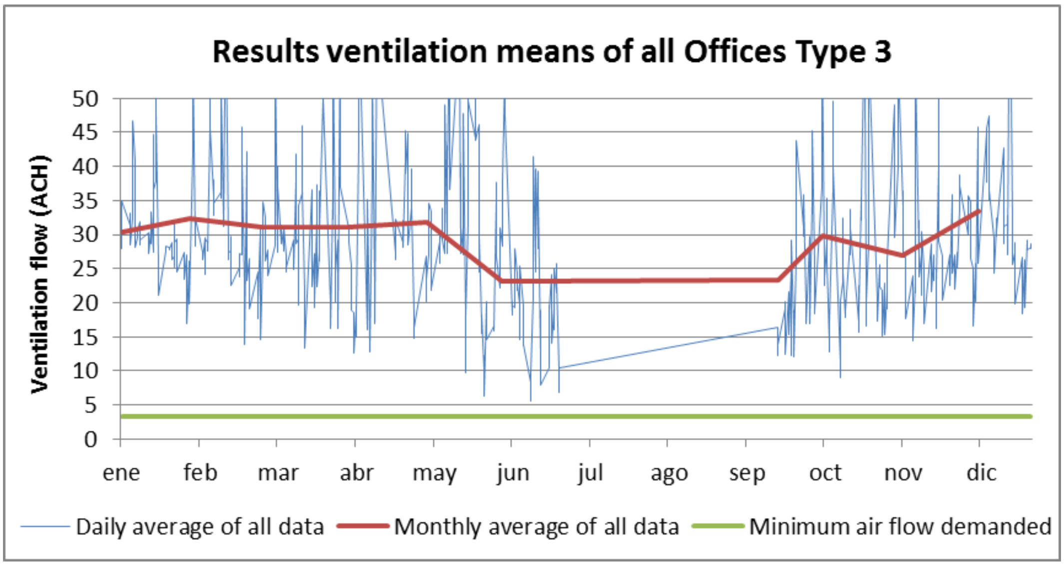
Finally, the design option that offers better results is based on the construction of different shunts in each area to be ventilated, with expulsion of air to deck through chimneys favoring the pressure difference between inside and outside, improving the stack effect of various shunts and ventilation in each area.

In the first place, outside air inlet opening surfaces through external façades for each office ventilated naturally are analyzed. It is remarked, that these surfaces are needed to provide the outside air flow in the most restrictive periods, summer times, since the effect of the thermal gradient is nonexistent. Thermal gradient is increasing and favoring the functioning of natural ventilation in winter times. The opening modulation of these ventilators should go from fully closed, when the rooms are empty or no ventilation is needed, to the desired and calculated opening surfaces.

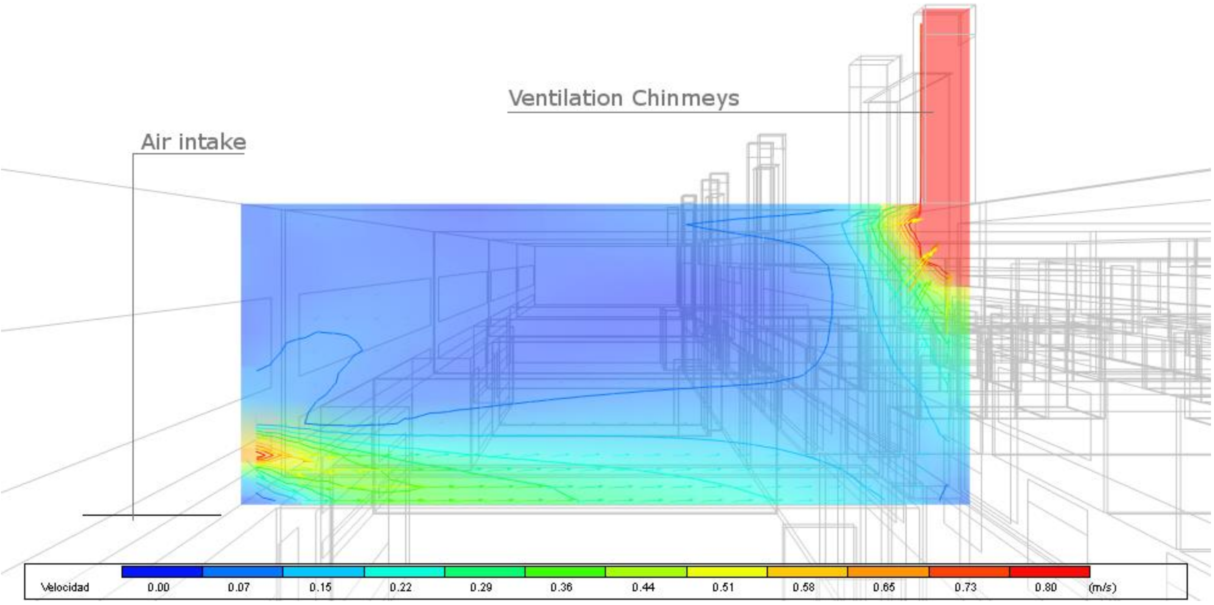
Air changes per hour and monthly averages results in the hours that the center is ventilated are presented:


Results ventilation means of all Offices Type 1
Ventilation flow (ACH)
50
45
40
35
30
25
20
15
10
5
0
ene
feb
mar
abr
may
jun
jul
ago
sep
oct
nov
dic
Daily average of all data
Monthly average of all data
Minimum air flow demanded


Results ventilation means of all Offices Type 2
Ventilation flow (ACH)
30
25
20
15
10
5
0
ene
feb
mar
abr
may
jun
jul
ago
sep
oct
nov
dic
Daily average of all data
Monthly average of all data
Minimum air flow demanded


Results ventilation means of all Offices Type 3
Ventilation flow (ACH)
50
45
40
35
30
25
20
15
10
5
0
ene
feb
mar
abr
may
jun
jul
ago
sep
oct
nov
dic
Daily average of all data
Monthly average of all data
Minimum air flow demanded

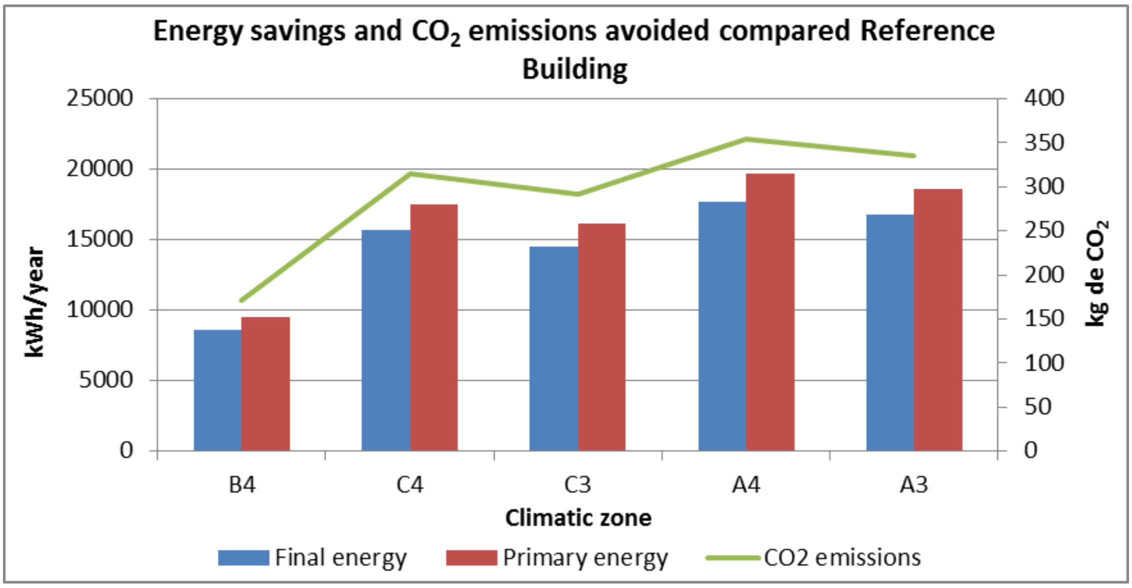
Air changes per hour are always above the minimum required, justifying the requirements of RITE. Thanks to the installation of motorized louvers in the openings to the outside, we can modulate the amount of air entering each zone, providing only the amount of the required air depending on the CO_2 concentration that exists in every area at every moment. The air flow pattern can be seen in the following image:



One of the objective of this study is to check the consumption of energy, besides the CO_2 emissions to the atmosphere, and these are lower in the Proposed Building using natural ventilation than in the Reference Building with mechanical ventilation and heat recovery, according to requirements of RITE.

This fact is justified by the consumption of the fans in the Reference building, which does not existent in a building with natural ventilation system, however there is the disadvantage that there is not the possibility to install an energy recovery system.

Energy simulations in both models were performed, in the Reference and Proposed Building in the warmest climatic zones in Spain, the climatic zones are A3, A4, B4, C3, C4 from the technical building code in Spain (CTE). The results of energy consumption obtained demonstrate that the energy consumption of the fans to condition the analyzed building is greater than the energy that can recover the energy recovery system. Thus, it has been demonstrated the energy savings needed by RITE in reference to ventilation systems.



4 CONCLUSIONS

The viability of the system has been demonstrated, even with the energy disadvantage due to the lack of heat recovery, since the energy savings produced by the absence of the energy consumption of the fans is bigger than the savings caused by the heat recovery in a building with the same characteristics using a mechanical ventilation system.

If we analyze the results of the air changes per hour of the outside air flow for the entire building, we checked that during all hours that the building is occupied, the outside air flow rates are suited to those required by the rules of obligatory fulfillment.

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