PAPER • **OPEN ACCESS**

Energy saving due to natural ventilation in housing blocks in Madrid

To cite this article: RA González-Lezcano and S Hormigos-Jiménez 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **138** 012002

Energy saving due to natural ventilation in housing blocks in Madrid

RA González-Lezcano[1] and S Hormigos-Jiménez[1]

[1]Department of Architecture and Design, Escuela Politécnica Superior, Universidad CEU San Pablo, Urbanización Montepríncipe, 28668 Boadilla del Monte, Madrid, Spain.

Corresponding author's e-mail: rgonzalezcano@ceu.es

Abstract. Getting a healthy and comfortable indoor environment in homes in southern Europe is a complicated task. In continental climates, with very cold temperatures in winter and very hot in summer, energy consumption greatly increases with air conditioning significant spending. To propose action guidelines for use of natural ventilation and to develop effective design strategies is essential. Therefore, and given a specific building type block of flats in Madrid, this article focuses on establishing what periods of the year natural ventilation is required to reduce energy consumption in air conditioning, also considering the quality of the outdoor environment and the design of the building. To develop this, a statistical study of the chosen type, that allows studying the direction and the wind speed in the area, is performed. Analysis of wind pressures in holes in the facade is performed by means of numerical simulations of fluid flow (CFD) inside to later infer in the natural ventilation rate required within policy parameters. With the data obtained, a study of energy saving is made as a function of natural ventilation rate established for the building type.

1. Introduction

1.1. Natural ventilation and its influence on energy saving

Natural ventilation is the process through which indoor air is replaced by fresh outdoor air. This happens through openings in façade in order to achieve users' thermal comfort and good levels of indoor air quality without consuming energy. Natural ventilation is widely used to improve Indoor Air Quality (IAQ) as it affects occupants' health. Good Indoor Air Quality is defined as air free of pollutants although, if it is not good enough, it can cause users irritation in eyes, nose and throat; discomfort; or even health problems such as respiratory or cardiovascular diseases [1]. In this context, air exchange rate is as an extremely important factor to take into account to avoid pollutants concentrations indoors. Air exchange is achieved through ventilation in order to ensure a healthy indoor environment [2-5]. However, the use of insulation and tighter buildings are more which have reduced heating and cooling energy demands. This is to the detrimental of ventilation as air exchange decreases and pollutant concentration indoors increases [6]. Ventilation is included within Heating, Ventilation and Air-Conditioning systems (HVAC), which suppose most of the energy consumption in a building; on the one hand, Orme [7] established in 1991 a percentage of 26.48% of the total annual energy delivered in service and residential buildings; on the other hand, The International Energy Agency ensures that the European HVAC consumption has increased meaningfully, it supposes approximately 50% of the total energy consumption in European buildings [8-9]. In addition, inappropriate ventilation supposes up to 70% in heat losses [5, 10].

Renewable energy is intended to satisfy the energy demand in housing blocks but, in most cases, this is not satisfactory enough. Energy consumption must been avoided wherever it is possible. Therefore, the use of natural ventilation becomes essential to achieve this goal.

1.2. European research on ventilation and regulations regarding Indoor Air Quality in Spain

Although there are regulations available on air quality, there is still a lack of experience and know-how regarding this field, especially within the main stakeholders such as engineers, architects, housing corporations, product producers [11]. This lack of knowledge was identified by several European projects such as the NatVent Project [12] or the HealthyAir Project [13]. Considering the outcomes of the European Project HealthyAir, improvements regarding Indoor Air Quality and ventilation must be developed in three fields [13]: education and awareness; regulation and policies; and research and development. This Project has demonstrated that people in charge of building design are generally not aware of ventilation issues and they declare that they do not have simple tools for creating a proper design regarding ventilation. It is therefore necessary further research and transfer of knowledge.

HealthyAir Project also shows that the regulations need to be updated [13]. Most of building codes consider CO_2 the predominant pollutant in indoor spaces, but new construction methods and technologies have increased the concentration of other pollutants or have crerated new ones.

There are several regulations which can be applied in residential buildings in Spain: the European standard UNE EN 12207:2000 [14]; and the national standards CTE-HS3 [15] and RITE [16]. The national standard CTE-HS3 is a section of the Spanish Technical Building Code which covers the aspects related to Indoor Air Quality in buildings and it has applicability in residential buildings and their different areas. This standard shows the minimum ventilation flows per area (table 1).

Table 1. Minimum ventilation flows required. CTE-HS3

Residential building area	Minimum ventilation flow (L/s)		
	Per occupant	Per usable m^2	Considering other parameters
Bedrooms	5		
Living rooms	3		
Bathrooms and toilets			15 per room
Kitchens		2	
Storerooms		0.7	
Garages			120 per parking space

The other national standard, RITE (Regulation for Thermal Installations in Buildings) establishes which must be the thermal conditions regarding indoor design in buildings in Spain (table 2).

Table 2. Indoor thermal conditions. RITE.

Season	Temperature (ºC)	Relative humidity (%)
Summer	23-25	40-60
Winter	21-23	40-50

1.3. Environmental conditions affecting ventilation in Madrid

Natural ventilation must be an important factor to be taken into account for the building designers. Location, position and design of the building, as well as the environmental conditions, must be studied to reach energy saving through optimum natural ventilation. Natural ventilation of a building occurs because of the ambient condition around it; wind direction and temperature vary along the day thus, a good design focused on natural ventilation must study those changes [17]. The design which takes climate into account is the bioclimatic design and it has the purpose of reducing energy demands for heating and cooling [18]. In this type of design, natural ventilation is included next to passive climate control strategies and renewable energy in bioclimatic design.

The city of Madrid is included within the Community of Madrid, in Spain, in Southern Europe. There are several types of climate in the Community of Madrid [19] as the result of various Atlantic storms with stable air of subtropical origin. Stable air predominates during 60 per cent of the days of the year. Most of the territory is under the Mediterranean climate (temperate climate), which is characterized by dry and hot summers, with an average of temperature above 22ºC, and wet and cold winters. In the urban area of Madrid, the climate is modified by the heat island effect. Heat generated from the constant urban activity causes an increase in average temperature values in both day and night temperatures. Additionally, absolute humidity is lower because of the scarce vegetation and little evaporation. In the city of Madrid, the following climate values, provided by the State Meteorology Agency [20] (AEMET), can be found (table 3), from May to September.

Table 3. Normal climate values in Madrid.

Period: 1981-2010										
Area: Retiro; Latitude: 40º 24’ 43’’ N; Longitude: 3º 40’ 41’’ O; Height (m): 667										
Month	T	TM	Tm	R	H	DR	DN	DF	DH	I
May	16.7	22.2	11.3	50	53	7.3	0.0	0.1	0.0	268
June	22.2	28.2	16.1	21	44	3.4	0.0	0.0	0.0	315
July	25.6	32.1	19..0	12	38	1.7	0.0	0.0	0.0	355
August	25.1	31.3	18.8	10	41	1.7	0.0	0.0	0.0	332
September	20.9	26.4	15.4	22	50	3.3	0.0	0.2	0.0	259

T, average monthly/annual temperature (ºC)
TM, average monthly/annual temperature during the day (ºC)
Tm, average monthly/annual temperature during the night (ºC)
R, average monthly/annual precipitation (mm)
H, average relative humidity (%)
DR, average monthly/annual number of rainy days equal or above 1mm
DN, average monthly/annual number of snowy days
DF, average monthly/annual number of foggy days
DH, average monthly/annual number of days of frost
I, average monthly/annual number of sunny hours

As it can be seen in the table 3, natural ventilation is possible in most of the months along the year, whenever outdoor temperature does not exceed 28ºC [21]. In addition, the Outdoor Air Quality [22-23] in Madrid has appropriate values to develop ventilation in buildings, considering values provided by AEMET related to the concentration (μg/m3) of NO2, NO, CO, O3 in the environment (table 4).

Table 4. Outdoor Air Quality in Madrid

Element	NO_2	NO	CO	O_3	PM_{10}
Concentration (μg/m^3)	50-75	10-20	100-200	100-120	20-31

It is difficult to quantify wind velocity and direction, as it is varying continuously and it also depends on the area where anemometers are located. It has been chosen a specific area in Madrid, which is called Retiro (Latitude: 40º 24’ 43’’ N; Longitude: 3º 40’ 41’’ O; Height (m): 667), to obtain the average values [24-25] of the wind that are going to be considered for this study (figure 1). Wind speeds above $5 m \cdot s^{-1}$ have a frequency of occurrence much lower than the ones below that value; therefore, the wind speeds considered in this study are: $0 m \cdot s^{-1}$ for wind speeds below $1 m \cdot s^{-1}$; $2 m \cdot s^{-1}$ for wind speeds of 1-3 $m \cdot s^{-1}$; and 4 $m \cdot s^{-1}$ for the rest of the values below 5 $m \cdot s^{-1}$.

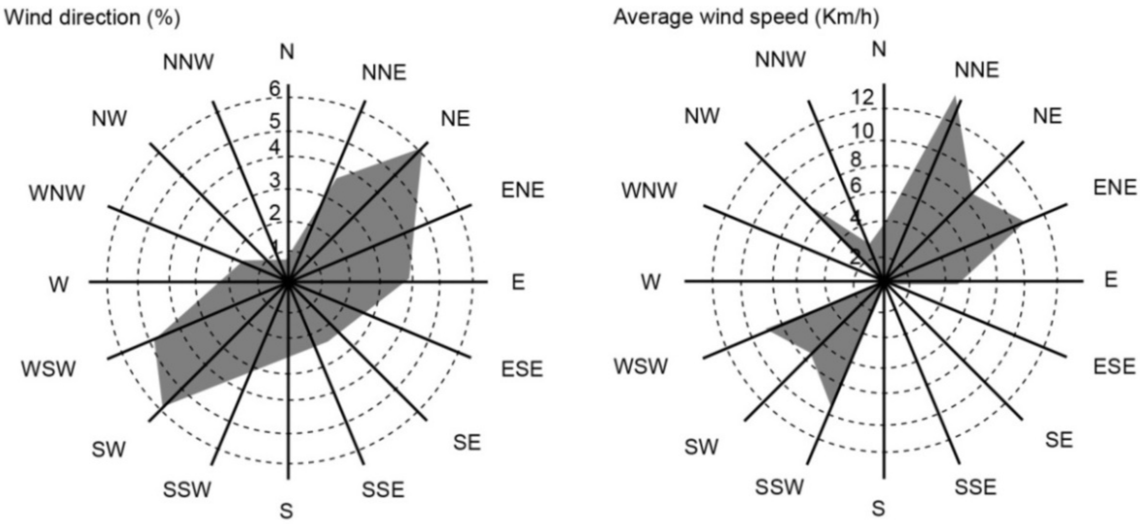

Figure 1. Wind direction (%) and average wind speed (Km/h) in Madrid

1.4. Spending per household on electricity

Considering a previous study, developed by AIS Group from 2010 to 2013, which measures the evolution of the average expenditure on energy in Spain; every home in the country spends an average of €725 for paying the electricity bill, although in most areas of the city of Madrid the electricity consumption is lower than €650 (figure 2).

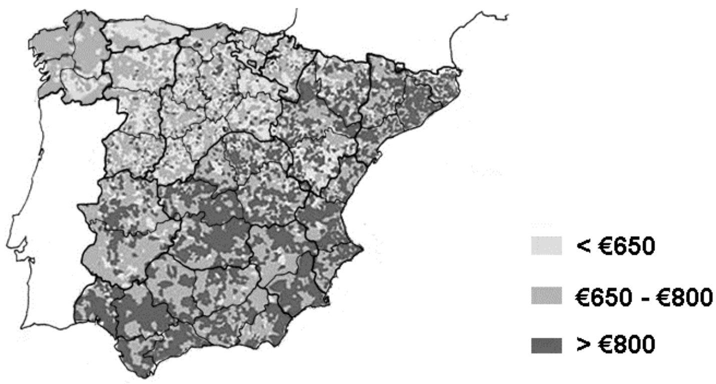

Figure 2. Average expenditure per household on electricity in 2013.

Air-conditioning in Madrid represents an average annual consume (per home) of 1220 KW/h per year and an annual cost of €246 per year. This data means that, considering the use of air-conditioning during the months from May to September, families in Madrid spend an average of €49.2 per month.

1.5. Social Housing in Madrid

The price per square meter of Private Market Housing was € 2,085.5in 2007; it was € 1,014.6higher than Social Housing. From 2013 until nowadays, prices of Private Market Housing (figure 3) in Spain have been reduced in such a way that differences between both types are about 300€ [26].

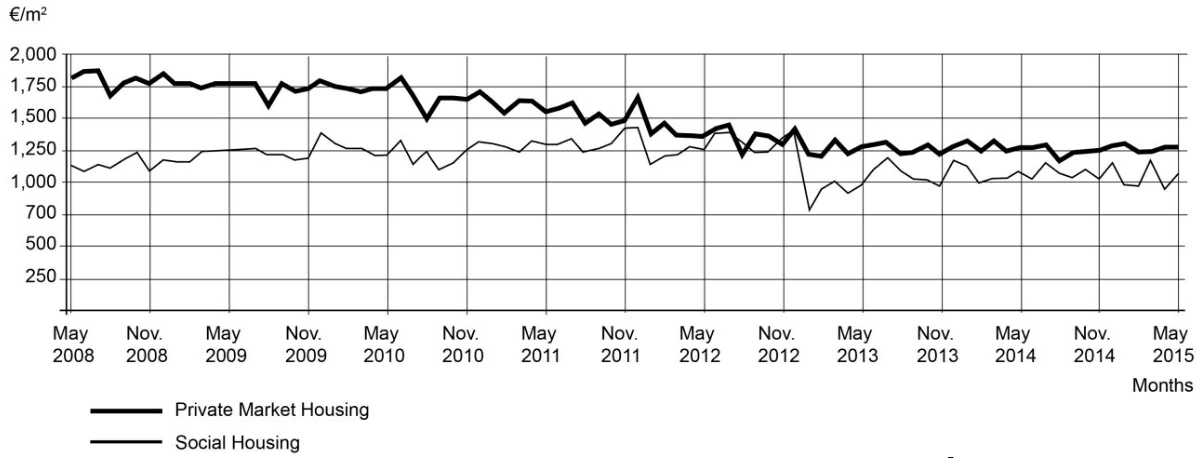

Figure 3. Private Market Housing prices vs. Social Housing prices (€/m^2). 2008-2015

People living in Social Housing Blocks usually have low income. Thus, providing different ways of economic saving reducing energy consumption supposes a benefit for them. What is intended to achieve in this paper is to acquire comfort conditions and good Indoor Air Quality in the areas of the home where occupants spend most of their time, bedrooms and living rooms, using natural ventilation whenever it is possible addressing therefore the minimum energy consumption.

1.6. Objectives for this study

Considering the information provided, the main objectives for this study can be resumed as the following:

- Determine ventilation rates and air changes per hour in living rooms and bedrooms
- Define the stages when cooling by air conditioning can be replaced by natural ventilation
- Determine both energy saving and economic saving that supposes the use of natural ventilation

2. Methodology

2.1. Previous data

- Wind speeds considered for this study:
  - 0m·s^{-1} for wind speeds below 1m·s^{-1}
  - 2m·s^{-1} for wind speeds of 1-3 m·s^{-1}
  - 4 m·s^{-1} for the rest of the values below 5 m·s^{-1}
- Wind directions: Northeast and Southwest
- Indoor comfort conditions:
  - Summer: temperatures of 23-25 ºC and relative humidity of 40-60%
- Minimum ventilation flow
  - Bedrooms: 5l/s per occupant
  - Living rooms and dining rooms: 3l/s per occupant
  - Considering the study of C. Dimutroulopoulou and J. Bartzis [27] where they determine that several health problems can started to be developed by the occupants of indoor spaces (irritations or allergies can be suffered) above air flows of 10L·s^{-1}·person^{-1} , a maximum threshold of 10L·s^{-1}·person^{-1} has been established for natural ventilation air flow indoors.
- Periods of the year when people uses air-conditioning [21].

- Bedrooms: 13:00-7:00 (18 hours per day)
- Living rooms: 13:00-22:00 (9 hours per day)

2.2. *Morphologic characteristics of the housing block studied*

In Spain, the most common typology of housing is the 6-7 storey building. Linear housing blocks with rectangular shape in floor plan. This paper have considered the next type of housing block to develop the study located in Madrid [29], oriented to Southeast (figure 4).

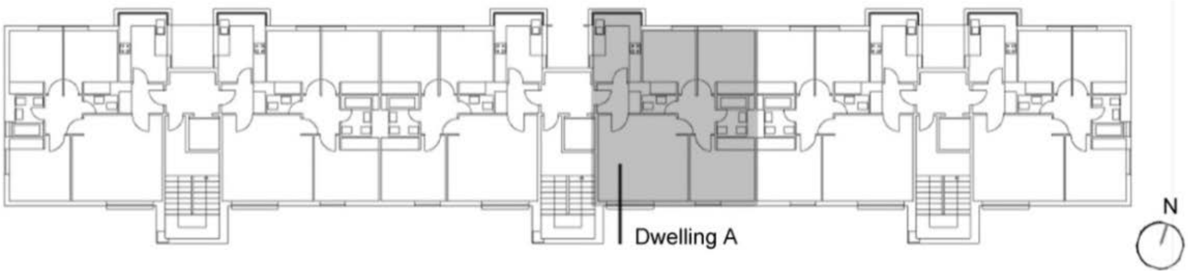

Figure 4. Housing block considered for this study. Floor plan of 6 storey building located in Madrid

Dwelling A highlighted in figure 4 represents the floor type of every dwelling in the housing block and it is detailed in figure 5. It has a total of 67.53 m^2. The living room and bedroom 3 face the southeast façade and the rest of bedrooms (bedroom 1 and bedroom 2) are located in the northwest area of the dwelling. The rest of dwellings are equal to dwelling A o symmetric to it.

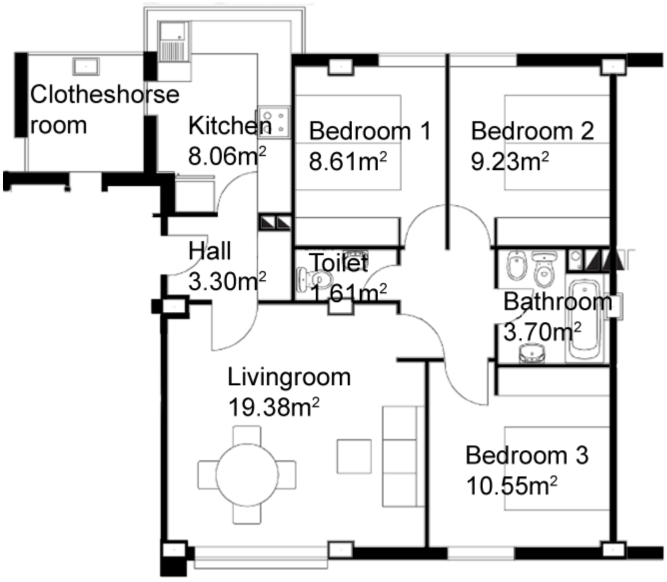

Figure 5. Floor plan of dwellings in the housing block. Dwelling useful floor area: 67.53 m^2

2.3. *Air flow simulation*

To develop methodologically this work, previous studies have been taken into account. Bangalle et al. [17] developed flow simulation considering wind pressure differences as the main tool for natural ventilation; this occurs in buildings through openings in façade causing a circulation of flow due to differences in indoor and outdoor temperatures and pressure differences in façades (faces) of the building. This is why windows (and the influence on one into other) play an important role in natural ventilation processes. Even if there is no external wind, natural ventilation in rooms can occur because of recirculating flow due to temperature differences. However, as it has been shown, natural ventilation can be much more effective under certain climate conditions. Having an appropriate outdoor environment, with an adequate outdoor air quality, is essential [28].

Different approaches can be established to study ventilation flows. The most important ones are experimental studies, empirical models and numerical simulations by computational fluid dynamics (CFD). CFD simulations have several advantages such as the reduction of costs. Different models can be also considered modifying the architectonic design to predict which the best one in terms of ventilation is. In this study, air flow simulation has been carried out using the CFD package called FLUENT in order to predict wind pressures in façade.

3. Results

3.1. Natural ventilation rates in rooms

CFD simulations have been developed [21] within a flow rate domain with the next dimensions:

- Length: 22H; width: 16H; height: 3H

Being H the height of the building which has been considered for this study (19m). The right-side and left-side limits all along the length of the domain have been established as the inlet and outlet planes of the wind flow through the flow domain. The symmetry planes considered are the top part of the flow domain and the rest of the sides; therefore, normal speeds values are zero in those planes.

CFD simulations have been based on k-epsilon turbulence model and the Quick scheme and Simplec algorithm have been used in order to obtain more quickly a converged solution.

CFD simulations have been developed to obtain wind pressures in openings in the. The studied block is an 8-storey building, which has been considered in its whole to obtain the pressures. The cross ventilation rates can be obtained by modeling a single storey of the building, taken into account its location height, and by using the software COMIS. In every floor there are 24 openings (windows) in the façade, where wind pressures have been assessed using CFD predictions. Figure 6 shows wind pressure coefficients in floors between the first one and the fourth one (4F) and from the fifth one and the eighth one (8F) considering the wind directions from the South direction.

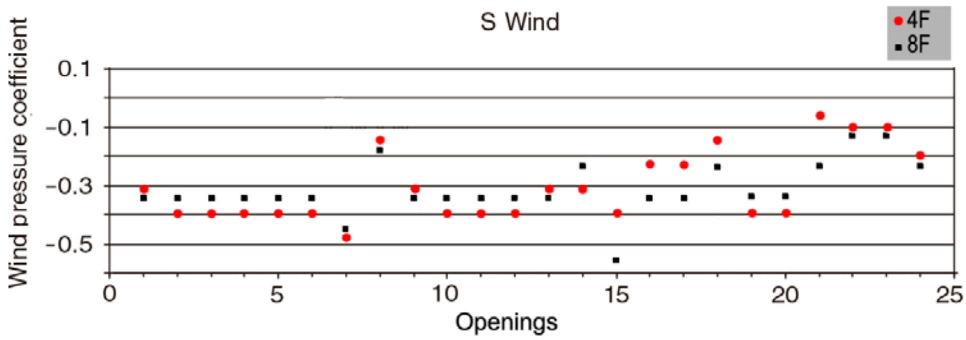

Figure 6. Wind pressure coefficient in the South façade with Southwest wind

It is important to take into account the vertical variation of the wind speed all along the height of the building, having as reference point the terrain. In COMIS, this variation is established by the use of power law model. To simulate the air flow, the process was simplified to reduce time for the converged solution but acquiring correct outcomes, this is why, in view of that network model which was developed had into account all the rooms of a single floor, air flows between the different storey of the building were not considered nor infiltrations by the façade through cracks. The model in COMIS includes 68 flow links which represent the windows and the doors in the whole floor and also 24 nodes in the external façade, one per window of each floor for which a wind pressure coefficient (obtained by the CFD simulation) is assigned.

3.2. Energy saving by means of natural ventilation

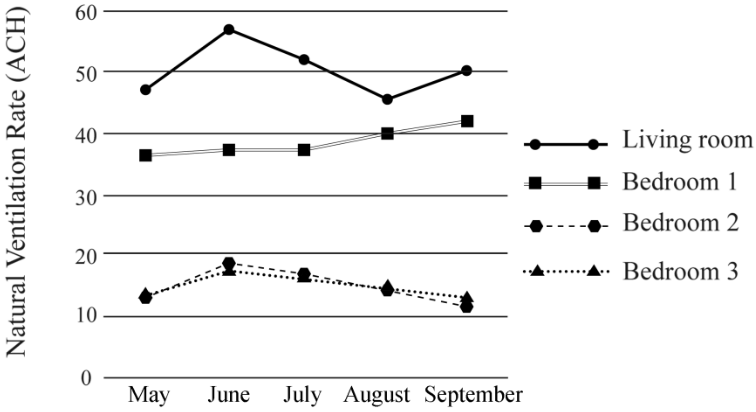

Figure 7. Mean natural ventilation rates reached in living rooms and in bedroom in the housing block

The average natural ventilation rates have been calculated through the method shown above per each of the rooms where air conditioning is installed (living rooms and bedrooms) in both 4F and 8F group of floors. Figure 7 shows the average natural ventilation rates determined for living rooms and bedrooms of the flats 8F (floors between 5 and 8) of the studied housing block. It can be seen that, in some cases, air changes above 50ACH can be reached in some rooms and in every case the current regulation about ventilation is met. This study has shown that indoor temperatures suffer a wide variation when air changes per hour go from 2ACH to 30ACH. Figure 9 illustrates the energy saving that supposes natural ventilation use (avoiding air-conditioning use).

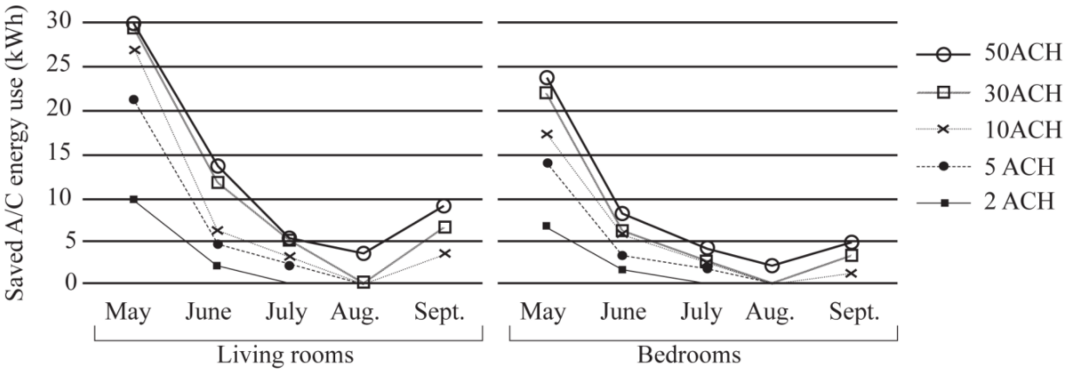

Figure 8. Saved air-conditioning energy by means of natural ventilation in living rooms and bedrooms

Figure 8 shows that the saved air-conditioning energy increases with the natural ventilation rate. Only with a ventilation rate of 2ACH a high saving can be reached in both months May and September but this saving is very low during June, July and August. By increasing the natural ventilation rate, the energy saving also increases, until values of 30ACH are reached, from which the growth is no longer significant. The outcomes shown in figures 7 and 8 can be explained as follows:

- In the Mediterranean climate, in wild months such as May (shown in table 3), outdoor temperature is below 26ºC. Low ventilation rates during this month will maintain indoor temperature under 26ºC therefore, air-conditioning energy can be avoided.
- When temperatures during the day start to be closer to 26ºC, it is necessary to increase air change rates to obtain a higher natural ventilation.
- When outdoor temperature has values of 26ºC or higher, the use of natural ventilation shall be limited, it will be used whenever outdoor temperature is below 26ºC. As is can be seen in figure 8, the saving values in the hottest months (July and August) are minimum compared to the rest of the months considered.

Figure 9 in percentage of saving during the months concerned. This analysis shows that, by using natural ventilation, a percentage of 13% of annual saving in air-conditioning energy use is achieved.

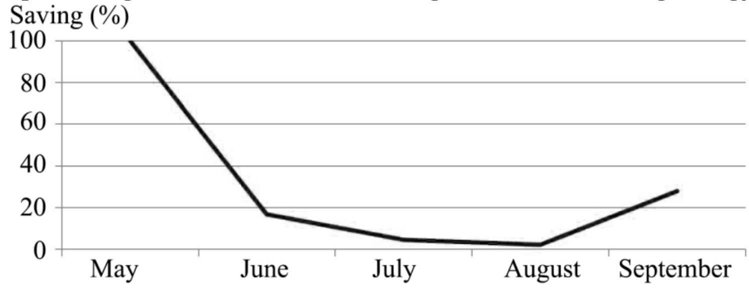

Figure 9. Economic saving percentage (%) in every month by means of using natural ventilation

4. Conclusions

In this study a practical approach and its application is presented and exemplified with a case-study in which natural ventilation rates achievable in living rooms and bedrooms are shown, as well as the minimum energy saving that can be reached by means of using natural ventilation in social housing in a widely used architectonic typology in Spain for this kind of building.

The modeling approach involves the use of CFD simulation software for predicting wind pressures on the windows on the façade of the building, using a network model to predict natural ventilation flow rates in residential flats. Cooling energy saving achievable was taken as the use of cooling energy that can be avoided due to the presence of natural ventilation during the periods in which the outdoor environment permits its use, so that the indoor temperature can be maintained below the tolerable upper limit (26ºC) through natural ventilation without using air-conditioning energy. However, within a nominal air conditioning period, once the indoor temperature exceeds the tolerable limit and air conditioning has been turned on, the assumption has been made that the air conditioners were maintained working during the remaining nominal air-conditioning period. The results reflect that natural ventilation can be highly effective to reach optimal thermal comfort conditions by reducing the use of air-conditioning, meaning a 13% of saving considering the total cooling energy use.

Acknowledgments

The authors would like to express their gratitude to Rebirth Inhabit Research Group of Escuela Politécnica Superior and to Universidad CEU San Pablo for the facilities sand resourced provided.

References

[1] Liddament MW, 1996, A Guide to Energy Efficient Ventilation, 2nd ed., Air Infiltration and Ventilation Centre, Berkeley, 254.
[2] Elkilani A, Bouhamre W, 2001, Estimation of Optimum Requirements for Indoor Air Quality and Energy Consumption in Some Residences in Kuwait, *Environment International*; **27**: 443-447.
[3] Chela F, Husaunndee A, Inard C, Riederer P, 2009, A New Methodology for the Design of Low Energy Buildings, *Energy Build*; **41**: 982-990.
[4] Kavgic M, Mumovic D, Stevanovic Z, Young A, 2008, Analysis of Thermal Comfort and Indoor Air Quality in a Mechanically Ventilated Theatre, *Energy Build*; **40**: 1134–1343.
[5] Joo J, Zheng Q, Lee G, Kim JT, Kim S, 2012, Optimum Energy Use to Satisfy Indoor Air Quality Needs. *Energy Build*;**46**:62-67.
[6] Kukadia V, Palmer J, 1998, The Effect of External Atmospheric Pollution on Indoor Air Quality: a Pilot Study, *Energy Build*; **27**: 223-230
[7] Orme M, 1991, Estimates of the Energy Impact of Ventilation and Associated Financial Expenditures. *Energy Build*; **33**: 199-205
[8] Perez-Lombard L, Ortiz J, Pout C, 2008, A Review on Building Energy Consumption Information, *Energy Build*; **40**: 394–398.

[9] Orosa JA, Oliveira AC, 2009, Energy Saving With Passive Climate Control Methods in Spanish Office Buildings. *Energy Build*;**41**(8):823-828.
[10] Knudsen HN, 2005, HOPE. Health Optimisation Protocol for Energy-efficient Buildings Pre-normative and Socio-economic Research to Create Healthy and Energy Efficient Buildings, 1st ed., Intelligent Energy Europe.
[11] Schulze T, Eicker U, 2013, Controlled Natural Ventilation for Energy Efficient Buildings. *Energy Build*; **56**: 221-232.
[12] Kukadia V, 1998, Work Package 2: Performance of Naturally Ventilated Buildings – Final Monitoring Report, in: NatVent (Ed.), Pan-European Project Encouraging the Use of Natural Ventilation in Office-type Buildings.
[13] Bluyssen PM, de Richemont S, Crump D, Maupetit F, 2010, Actions to Reduce the Impact of Construction Products on Indoor Air: Outcomes of the European Project;19(3):327-339.
[14] Ministerio de fomento. Código Técnico de la Edificación. Documento Básico HS. Salubridad.
[15] Ministerior de Industria, Energía y Turismo. RITE.
[16] Bangalee MZI, Lin SY, Miau JJ, 2012, Wind Driven Natural Ventilation Through Multiple Windows of a Building: A Computational Approach. *Energy Build*; **45**:317-325..
[17] Omer AM, 2008, Renewable Building Energy Systems and Passive Human Comfort Solutions, Renewable and Sustainable Energy Reviews; **12**: 1562–1587.
[18] The physical environment of Madrid. Available at www.madrid.org (Accessed 3 September 2015).
[19] State Meteorology Agency. AEMET.
[20] Yik FWH, Lun YF, 2010, Energy Saving by Utilizing Natural Ventilation in Public Housing in Hong Kong. *Indoor Built Environ*; **19**(1):73-87.
[21] State Meteorology Agency. AEMET. Outdoor Air Quality in Spain. Available at http://www.aemet.es/ (Accessed 3 September 2015).
[22] Particulate Matter (PM10): annual mean concentrations in Europe. Available at http://www.eea.europa.eu/themes/air/interactive/pm10 (accessed 17 April 2015).
[23] Madrid. Climate. Available at: http://www.meteoclimatic.net/ (Accessed 4 September 2015)
[24] Madrid. Retiro. Wind Statistic and climate. Available at: http://es.windfinder.com/ (Accessed 4 September 2015).
[25] Consejo General del Notariado. Centro de información estadística del notariado. Available at: http://www.notariado.org/liferay/web/cien/estadisticas-principales/inmuebles/relacion-vivienda-libre-vs-vpo (Accessed 4 September 2015).
[26] Dimitroulopoulou C. Ventilation in European dwellings: A review.
[27] Social Housing Architecture awards. Available at www.madrid.org (Accessed 20 August 2015).
[28] Chen Q, 1997, Computational fluid dynamics for HVAC: successes and failures, ASHRAE Transactions; **103**: 178-187.