POTENTIAL OF NIGHT VENTILATIVE COOLING STRATEGIES IN OFFICE BUILDINGS IN SPAIN. COMFORT ANALYSIS

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ABSTRACT

Night ventilation has been applied successfully to many passively-cooled or low-energy office buildings. This paper analyses the thermal comfort achievable according to European standard EN 15251:2007 by applying this strategy in office buildings in Spain. Specifically, the comfort level is evaluated using the Degree Hours (DH) criteria and the maximum indoor temperature. For the DH criteria, four base temperatures are considered: 25ºC and the three Categories for acceptable ranges of operative temperature around the adaptive comfort temperature established in the standard for free running buildings. Considering the interest of architects and engineers in the prediction of optimal comfort condition as a function of building typology (8 typologies), glazing ratio (30% and 60%) and climate (12 different Climate Zones), a total of 192 different study cases are obtained where an optimal air change per hour (ACH) that ranges from 1 to 50 ACH is defined. As an example of the obtained results, in Almeria, a city in the south of Spain characterized by hot summers with average daily temperature of 26ºC, in the case of a Linear Typology with 30% glazed façade, the best comfort result is achieved by a night ventilation flow of 20 ACH for Limit of Category II. Further increases in night ventilation flow produces marginal improves. In this case, the Mean Peak Temperature is reduced in 0.5ºC. Furthermore, in Soria, a city in the north of Spain characterized by mild summers with average daily temperature of 20ºC, in the case of a Linear Typology with 30% glazed façade, the best comfort result is achieved by a night ventilation flow of 6 ACH for Limit of Category II In this case Peak Temperature is reduced 0.6ºC. The research shows that passive night ventilation should be considered as an effective strategy to reduce cooling demand in buildings with high daily internal gains (i.e. offices buildings), improving comfort conditions and flattening peak temperatures.

KEYWORDS

Night Ventilation, Offices, Comfort, Building Typology, Climate Zones

1 INTRODUCTION

The use of air conditioning in the building sector is increasing rapidly. In almost the 46% of the houses in the Organisation for Economic Co-operation and Development (OECD) it has been rising by 7% each year. It is reasonable to think that in the case of office buildings this figure is even higher. Since 1990 the energy consumption in office buildings has increased by 300%, becoming, in 2008, the responsible for the 47.84% of energy consumption in the service sector (6% of the total energy consumption in Spain) (Segurado de Arriba, 2008).

Furthermore, the energy impact of this sector is expected to increase considering the proliferation of squanderer glass buildings in the last decade, since concepts related to modernity, technology and transparency are playing a predominant role in their design (Coyne

Intensive use of air conditioning is the result of many processes (Santamouris, 2007), in particular:

- adoption of an universal style of buildings that does not consider climatic issues and results in increasing energy demands during the summer period;
- increase of ambient temperature, particularly in the urban environment, owing the heat island phenomenon, which exacerbates cooling demand in buildings;
- changes in comfort culture, consumer behaviour and expectations;
- improving of living standards and increased affluence of consumers;
- increase in buildings' internal loads.

The environmental impact associated to the intensive use of air conditioning in terms of CO_2 emissions will have achieved the value of 18.1 Mt in Europe by 2020, far cry from the figure 0.516 Mt registered in 1990 (Adnot, 1999). This disproportioned increase in CO_2 levels does not reflect the international compromise adopted with the Kyoto protocol, where a reduction of 5% in CO_2 and CFC emissions, habitual in air condition systems, was established for the period 2008-2012,

In Spain, the panorama is particularly alarming. In 2007 the United Nations presented a report before the Bali Climate Change Conference (2007) exposing that Spain was at the head unfulfilling the Kyoto Protocol considering that the CO_2 emissions increased to 53% between 1990-2005, when a limit of 15% was defined. The level of CO_2 associated to air conditioning in Spain was 1.12Mt in 1996 and it is expected to increase to 7.13Mt by 2020 (Adnot, 1999).

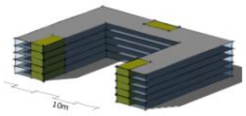
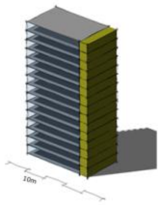
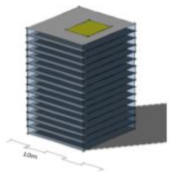
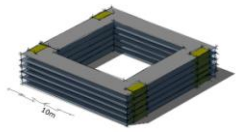
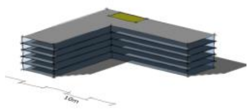
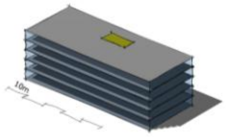
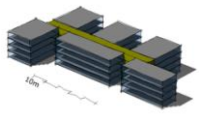
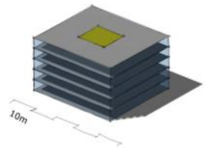
Because of all these reasons, counteracting the environmental and energy impact of air conditioning is one of the main objectives in the near future. Passive cooling is presented as an effective strategy in order to achieve the Kyoto Agreement, reducing the energy demand of buildings and providing an adequate thermal comfort (Santamouris, 2004).

2 OBJECTIVE

This work continues the research line started by the project "Energy Efficiency of Ventilated Active Façades applied to office buildings in Spain". The project was financed by the Spanish National Plan for Research and finished on 2009. Its main objective was to determine the energy saving achievable (reduction of cooling demand) by the use of a Ventilated Active Façade - VAF. For the analysis 192 study cases were considered. The study cases represented the 8 most common typologies of offices in Spain, the typical glazed surface in façades (30% and 60%) and 12 Spanish climate zones (Table 1). The software used in the study was LIDER.

The simulation results demonstrated that the achievable energy saving is very dependent on the building typology, the glazed surface and the climate zone. Furthermore, the work stated that using the VAF technology the cooling demand of office buildings could be reduced averagely into a 20%, and even up to a 40% in many cases.

Table 1: Denomination of the 8 most common typologies of office buildings in Spain. The number in the nomenclature of each building represents the percentage of glazed facade (30% and 60%)

U Typology (U30 / U60)	**Tower with commu-nication core in façade** (TF30 / TF60)	**Tower with central communication core** (TC30 / TC60)	**Ring typology** (O30 / O60)
			
L-Typology (L30 / L60)	**Linear Typology** (LI30 / LI60)	**Disperse Typology** (D30 / D60)	**Compact typology** (CP30 / CP60)
			

The present work evaluates a different strategy to reduce the cooling demand of office buildings in Spain. Night ventilation is particularly suited to office buildings because these are usually not occupied during the night.

Many studies evaluate the benefits of night ventilation (Kolokotroni 2006, Kolokotroni 2010, Santamouris 2007). Some researches state that the peak temperature inside office buildings can be reduced between 0ºC and 2.6ºC for cross ventilated buildings and between 0.2ºC and 3.5ºC in single-sided ventilation buildings (Geros, 1999). Other studies show that for day and night ventilation of 4 ACH, internal temperature is reduced about 1ºC and 1.5ºC in UK (Kolokotroni, 1998).

Based on it, this article studies the impact of applying passive night ventilation in the Spanish climate and the thermal comfort achievable, according to European standard EN 15251:2007.

Specifically, the comfort level is evaluated using the Degree Hours (DH) criteria and the maximum indoor temperature. For the DH criteria, four base temperatures are considered: 25ºC and the three categories for acceptable ranges of operative temperature around the adaptive comfort temperature established in the standard for free running buildings.

The Category III corresponds to a moderate expectation of the occupants, the Category II corresponds to a mid-expectation, the Category I is related to a high level of expectation.

Considering the significant influence of the air flow (air changes per hour - ACH) in the efficacy of night ventilation, a wide range of them is considered. The air changes per hour range from 1 to 50, while the operating period goes from 02:00 to 08:00 hours (coolest outdoor temperature).

The results of the research show, for every typology, glazed surface in façade and climate zone, an optimal night ventilation pattern to achieve the highest level of comfort.

As an example of the results, in Almeria, a city in the south of Spain characterized by hot summers with average daily temperature of 26ºC, in the case of a Linear Typology with 30% glazed façade, the best comfort result is achieved by a night ventilation period of 6 hours, from 02 to 08 solar time, and 20 ACH. Further increases in air ventilation flow produces marginal improves in the comfort variables.

In comparison with the Base Case (1 ACH) the DH are reduced from near to 90% for the case of Category III to 68% for Category I, that means a very significant improve of the comfort level. The peak temperatures are reduced near to 2ºC.

The research show that passive night ventilation should be considered as an effective strategy to reduce cooling demand in buildings with high daily internal gains (i.e. offices buildings), improving comfort conditions and flattening peak temperatures.

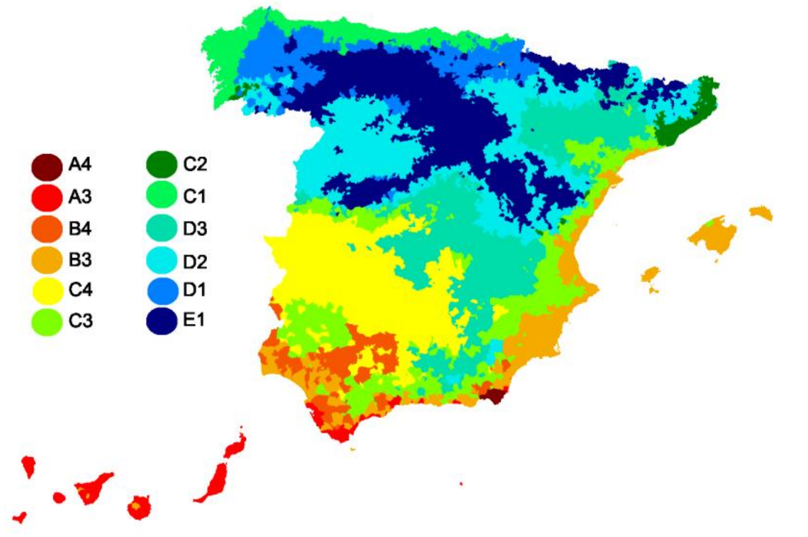
3 SIMULATIONS

In order to analyse the influence of night ventilation on the comfort of office building occupants in Spanish climates, a sample of 16 buildings representing the most common building typologies in Spain (8 different typologies and 30% and 60% of glazed surface in façade) is considered. The buildings are simulated in a free-floating mode in the 12 climate zones defined in the Spanish Technical Code -CTE. The results of the simulations cover a wide range of possible combinations providing very useful information to architects and designers.

The simulation program used is LIDER (Ministerio de Vivienda de España 2009), the calculation engine of the Spanish national tool used for regulation purposes in Spain performing dynamic and multi-zone simulations of buildings.

The Table 2 shows the 12 different Spanish Climate Zones and their representative cities considered for this study. The denomination of the Climate Zone is given by a letter and a number. The letter represents the winter climate severity, where "A" is the less severe zone, thus, the case with less heating demand. The letter "E" is the climate with most severe winter. The number represents the summer climate severity, where the number "1" is the climate with less cooling demand and the number "4" is the climate with highest cooling demand.

Table 2: Climate Zones in CTE and representative cities



Climate zone	Representative City
A4	Almeria
C4	Badajoz
C2	Gerona
C3	Granada
B4	Huelva
D3	Madrid
A3	Malaga
C1	Pontevedra
E1	Soria
D2	Valladolid
B3	Valencia
D1	Vitoria

3.1 Definition of buildings

The main constructive characteristics of the 16 study cases are described in the Table 3. The denomination and model of each case is depicted in Table 1.

Table 3. Main construction and geometrical characteristics of the 16 buildings

Building nomenclature	Floors	Construction surface	Total Façade Surface	Façade surface facing South	Total glazed surface	Glazed surface facing South	Shape Factor: S/V
CP30	B+4	6480m^2	3240 m^2	810 m^2	972 m^2	243 m^2	0.2 m^{-1}
CP60	B+4	6480m^2	3240 m^2	810 m^2	1944 m^2	486 m^2	0.2 m^{-1}
DS30	B+3	12240m^2	8262 m^2	1620 m^2	2478,6 m^2	486 m^2	0.242 m^{-1}
DS60	B+3	12240m^2	8262 m^2	1620 m^2	4957,2 m^2	972 m^2	0.242 m^{-1}
L30	B+4	4680 m^2	4050 m^2	945 m^2	1215 m^2	283,5 m^2	0.281 m^{-1}
L60	B+4	4680 m^2	4050 m^2	945 m^2	2430 m^2	567 m^2	0.281 m^{-1}
LI30	B+4	7200 m^2	3780 m^2	1350 m^2	1134 m^2	405 m^2	0.205 m^{-1}
LI60	B+4	7200 m^2	3780 m^2	1350 m^2	2268 m^2	810 m^2	0.205 m^{-1}
O30	B+4	12960 m^2	9720 m^2	1620 m^2	2916 m^2	486 m^2	0.200 m^{-1}
O60	B+4	12960 m^2	9720 m^2	1620 m^2	5832 m^2	972 m^2	0.200 m^{-1}
TC30	B+14	18900 m^2	9720 m^2	2835 m^2	2916 m^2	850,5 m^2	0.145 m^{-1}
TC60	B+14	18900 m^2	9720 m^2	2835 m^2	5832 m^2	1701 m^2	0.145 m^{-1}
TF30	B+14	9720 m^2	7290 m^2	2430 m^2	2187m^2	729 m^2	0.196 m^{-1}
TF60	B+14	9720 m^2	7290 m^2	2430 m^2	4374 m^2	1458 m^2	0.196 m^{-1}
U30	B+4	7920 m^2	6480 m^2	1350 m^2	1944 m^2	405 m^2	0.270 m^{-1}
U60	B+4	7920 m^2	6480 m^2	1350 m^2	3888 m^2	810 m^2	0.270 m^{-1}

Following this geometrical parameters, all the buildings are modelled using the software LIDER. The configuration of the façade in every case is adapted to the severity of the climate zone, to comply-with the minimum requirements of energy demand established in CTE. The impact produced by the variation of the thermal inertia, is not studied in this work.

3.2 Description of simulations

The method followed for simulating all the buildings in every climate zone is described below:

a) Firstly, a Base Building is defined in order to have a comparison pattern that permits to evaluate the benefits of applying night ventilation. The Base Building consists of a building with 1 ACH, a daily constant value. 1 ACH is the typical ventilation flow for office buildings according to the Spanish Regulation about Salubrity – HS3. There are 16 Base Buildings in each of the 12 climate zones, this is, 192 Base Buildings.

b) For every building, simulations with different night ventilation flows are then conducted, considering the following ACH: 2, 4, 6, 8, 10, 13, 16, 20, 25, 30, 40, 50. Night Ventilation is applied during 6 hours (02:00 a 08:00), coinciding with the lowest exterior temperatures.

c) The occupancy schedule is set from 07:00 to 15:00 and from 17:00 to 20:00 during the week and from 07:00 to 15:00 on Saturdays. Internal loads in this period are:

-People: 10 W/m^2
-Lighting: 7.5 W/m^2
-Appliances: 7.5 W/m^2

The results obtained are an hourly register of air temperature for every space of the building and for the whole year. For evaluating the benefits obtained by applying night ventilation in every case, the following variables are considered:

a) Weighing factor, (wf). It is used the definition given in the Standard EN 15251:2007, Annex F, Method B "Degree hours criteria". With it, long term thermal comfort conditions are evaluated. Wf consists of an *hourly cumulative calculation of the difference between the operative temperature registered for one space and the acceptable maximum temperature*. In the A.2 Section of the former Standard there are defined three different Categories where a specific acceptable limit of operative temperature is as well determined. Category III (moderate expectation of the occupants), Category II (normal expectation of the occupants), Category I (high expectation of the occupants). These limits are calculated using an adaptive comfort method, so that do not correspond to a fix limit, but change with the time and the exterior temperature of every location. In this study, apart from the given three temperature limits, the limit of 25ºC is as well considered, that is the usual upper value for non-adaptive thermal comfort analysis.

b) Maximum interior temperature. This variable permits to evaluate, in a quite direct way, the effect of night ventilation since it is expected that interior temperature will reduce when ventilation flow increases. However, the inconvenience is that, for every space in a building, a different maximum temperature is registered. For this reason, the average maximum temperature for every room is calculated and then a weighted average value for the whole building is obtained, where the weight of every room is proportional to its surface area.

4 RESULTS

The results obtained for each variable are shown separately in the following two sections. In the first one it is studied the influence of night ventilation in the Degree Hours, while in the other one it is shown the effect on the interior maximum air temperature.

4.1 Weighing factor

As mentioned before, due to the wide range of building typologies and climate zones considered in this study, for the evaluation of the variation of the weighing factor, the "degree hour variation" (∇wf) will be used.

This variable is defined as the ratio between the weighing factor of the building with different ventilation flows (case_study) and the Base Building (1ACH).

$$\nabla wf = \frac{wf_{case\_study}}{wf_{base\_building}} \quad (1)$$

As an example of it, in the following graphs (Figure 1) the results for *Almeria (Climate Zone A4)* are represented. Almeria is a city in the South of Spain characterized by hot summers with average daily temperature of 26ºC. In the graphs, the former defined Categories III, II and I and the limit of 25ºC are studied. Each line represents the deviation of ∇wf for every building respect to its Base Building as the ventilation flow increases.
When the variation of ∇wf is *zero*, it means that the interior temperature is within the comfort boundaries.

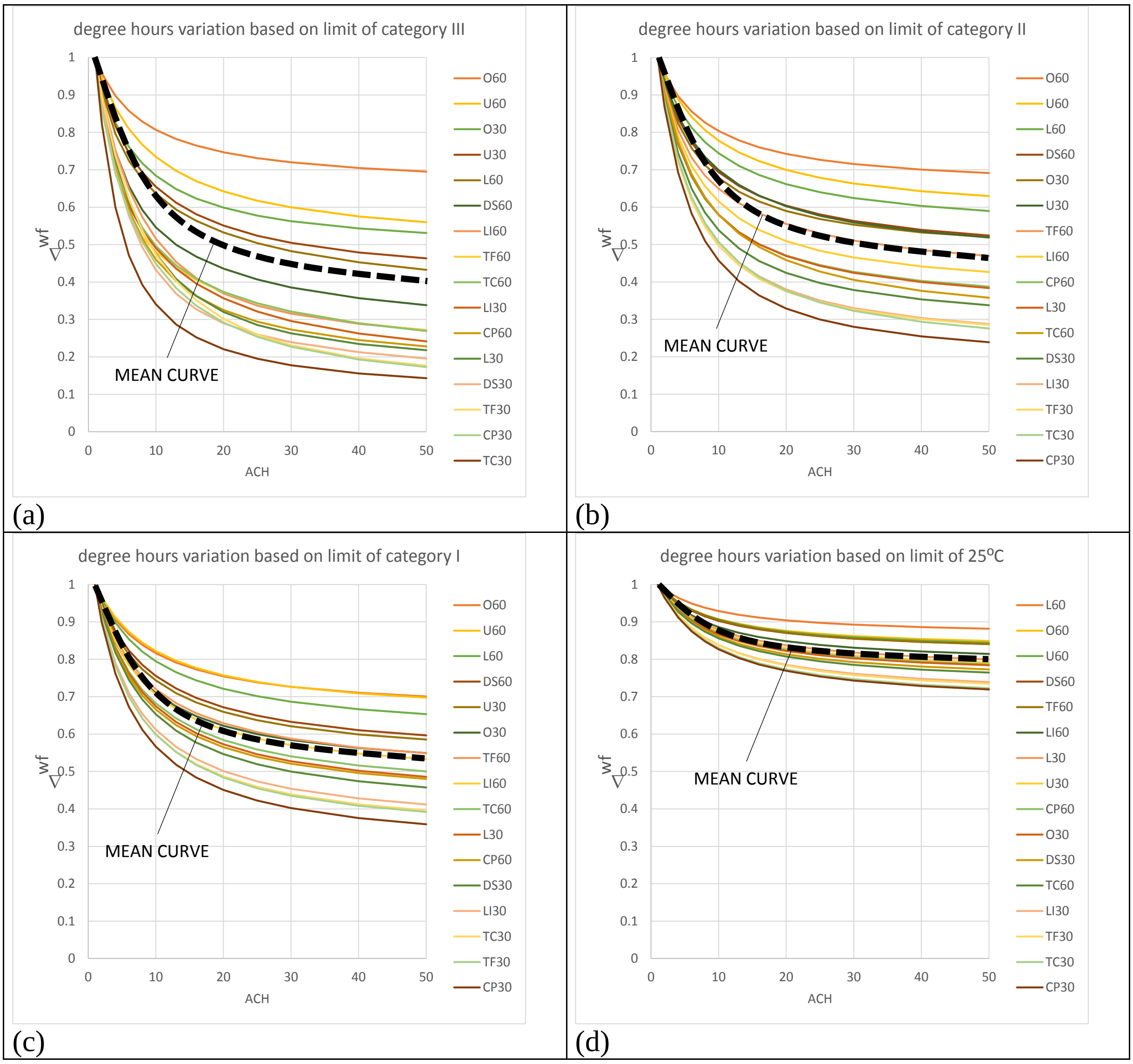


Figure 1. Degree Hours based on the limit of Category I (c), Category II (b), Category III (a) and limit of 25ºC (d) in Climate Zone A4

It has to be highlighted that the influence of the building typology on ∇wf is very significant, but a detailed study of it exceeds the scope of the present article.

In the Figure 2 the values for 10, 20 and 50 ACH of the "mean curve" for every climate zones are shown.

a)Mean values of ∇wf for Limit of Category III

b) Mean values of ∇wf for Limit of Category II

c) Mean values of ∇wf for Limit of Category I

d) Mean values of ∇wf for Limit of 25ºC

Figure 2. Degree Hours variation respect to Base Building (∇wf), for all the climatic zones

It is observed that in warm climate zones, the ∇wf value is higher than in cool climates, that indicates that the reduction of the DH is lower in warmer climates than in the cooler ones. The reason for it is that the night-time temperature in cool climates is usually lower and the daytime temperature is not very distanced from the comfort limit.

In addition, for the ∇wf variation based on the limits of Category II and I, (Figure 2, b, c) the reduction of DH is similar in the climate zones with a climatic severity for summer of 4, 3 and 2, resulting remarkable that the same occurs for all the climates zones with limit of 25ºC (Figure 2, d).

The results show that:

- Considering the comfort limits established for Category II and I, the proportional improvement of the comfort is almost the same in the warm and moderate climates. In the coolest climates, it is possible to achieve the comfort in a greater number of hours.

- If the limit is 25ºC, for all the climate zones, the interior temperatures are located in a distance from the comfort that is proportionally very similar in all the cases.

The variables considered in this study measure the relative variation of the DH. Although the variation is proportionally similar in warm and cool climates, the absolute value is different, resulting lower in the coolest ones. Relating this fact with the values of the variation shown for the limits of Category II and I, thanks to night ventilation in the coolest climates it is possible to stay within comfort limits in almost the whole day.

4.2 Effect on maximum temperature

The Table 4 shows the influence of night ventilation in the maximum indoor temperature for every building, climate zone and ventilation flow respect to its Base Building (1 ACH). The temperature difference is represented by ∇Tmax. In the Table, for every climate zone the “coldest case” corresponds to the building with the lowest maximum temperature. “the hottest case” to the building with the higher maximum temperature and the “Mean” corresponds to the average value for all the buildings.

Table 4: Variation of the peak temperature (∇Tmax) for the coldest, hottest and mean building, for every climate zone and ventilation flow. The temperature difference is respect to its Base Building (1 ACH)

Climate Zone		**1 ACH**			**10 ACH**			**20 ACH**			**50 ACH**		
		Coldest case	**Mean**	**Hottest case**	**Coldest case**	**Mean**	**Hottest case**	**Coldest case**	**Mean**	**Hottest case**	**Coldest case**	**Mean**	**Hottest case**
A3	Tmax	28.6	30.2	31.3	28.5	29.1	30.9	28.4	29.0	30.7	28.3	28.9	30.6
	∇Tmax				-0.1	-0.3	-0.4	-0.2	-0.4	-0.6	-0.3	-0.5	-0.8
A4	Tmax	29.3	31.1	31.9	29.2	29.8	31.5	29.1	29.7	31.4	29.0	29.5	31.2
	∇Tmax				-0.1	-0.3	-0.4	-0.2	-0.4	-0.6	-0.3	-0.5	-0.8
B3	Tmax	27.9	28.6	30.5	27.7	28.3	30.0	27.6	28.2	29.9	27.5	28.1	29.7
	∇Tmax				-0.2	-0.3	-0.5	-0.2	-0.4	-0.6	-0.3	-0.5	-0.8
B4	Tmax	29.3	30.0	32.1	29.1	29.7	31.6	29.0	29.6	31.4	28.9	29.5	31.2
	∇Tmax				-0.2	-0.3	-0.5	-0.2	-0.4	-0.7	-0.3	-0.6	-0.9
C1	Tmax	24.3	25.1	27.2	24.3	25.0	26.7	24.3	24.9	26.6	24.3	24.9	26.4
	∇Tmax				0.0	-0.1	-0.5	0.0	-0.2	-0.8	0.0	-0.2	-1.0
C2	Tmax	26.4	27.2	29.0	26.4	26.8	28.4	26.2	26.7	28.2	26.0	26.6	28.1
	∇Tmax				0.0	-0.4	-0.6	0.0	-0.5	-0.8	0.0	-0.6	-1.0
C3	Tmax	28.7	29.6	31.8	28.4	29.1	31.0	28.2	28.9	30.8	27.9	28.7	30.5
	∇Tmax				-0.3	-0.5	-0.8	-0.4	-0.7	-1.1	-0.6	-1.0	-1.4
C4	Tmax	29.5	30.5	32.6	29.2	30.0	31.9	29.1	29.8	31.6	28.8	29.6	31.4
	∇Tmax				-0.3	-0.5	-0.7	-0.4	-0.7	-1.0	-0.6	-0.9	-1.3
D1	Tmax	22.9	23.7	25.6	22.9	23.6	25.1	22.9	23.5	24.9	22.9	23.5	24.8
	∇Tmax				0.0	-0.1	-0.5	0.0	-0.1	-0.8	0.0	-0.2	-1.0
D2	Tmax	26.0	26.9	29.3	25.7	26.4	28.5	25.5	26.2	28.3	25.2	26.0	28.1
	∇Tmax				-0.3	-0.5	-0.8	-0.5	-0.8	-1.1	-0.6	-1.0	-1.4
D3	Tmax	28.0	29.0	31.3	27.7	28.5	30.6	27.5	28.3	30.4	27.4	28.1	30.2
	∇Tmax				-0.3	-0.5	-0.7	-0.4	-0.6	-0.9	-0.5	-0.8	-1.2
E1	Tmax	24.6	25.5	28.0	24.6	25.3	27.2	24.6	25.2	27.0	24.6	25.1	26.8
	∇Tmax				0.0	-0.2	-0.8	0.0	-0.3	-1.1	0.0	-0.3	-1.3

In general, the temperature variation (∇Tmax) is relatively little. The value decreases when the ventilation flow increases, with an asymptotically trend. It is clear that for some buildings the peak temperature reduction continues increasing for high ventilation flows, when in other cases, the reduction is almost marginal. It is observed that the difference between the minimum and maximum values for every case moves around 0.5ºC. Moreover, the results achievable by increasing the ventilation flow or changing the climate zone are similar. That confirms, once again, that the building typology is more significant than the absolute increase of ventilation flow when night ventilation is applied.

In order to describe a detailed performance of buildings according to the variation of peak temperature, a detailed example for Almeria (Climate Zone A4) is described in the Figure 3. It is perceived that for all the cases, the maximum temperature shows a decreasing trend with an asymptotic trend by increasing the ACH. The values of maximum temperature vary appreciably among buildings.

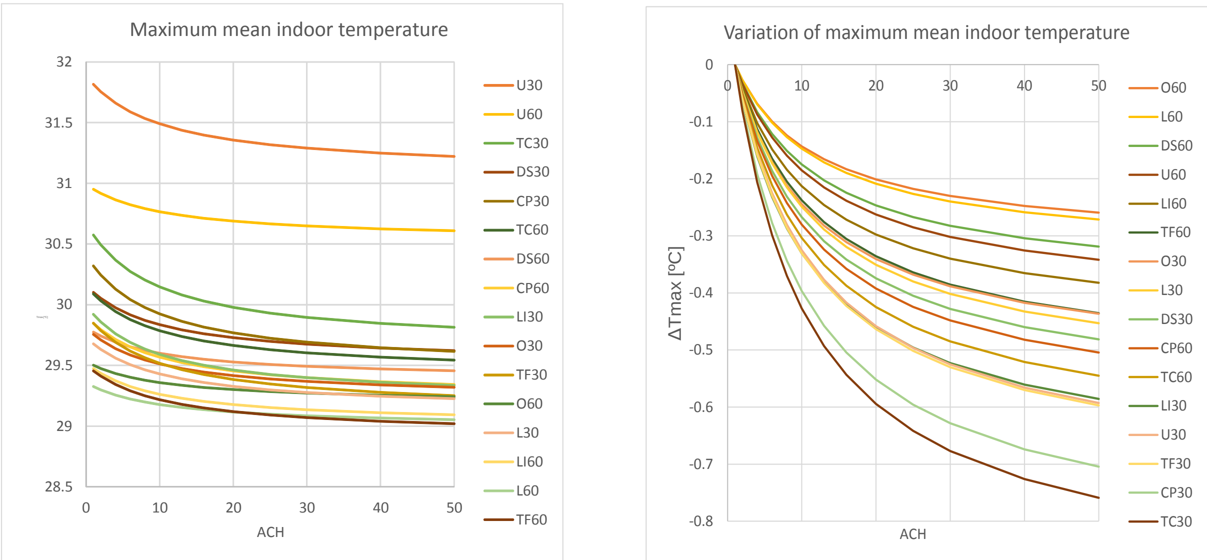


Figure 3 Maximum mean indoor temperature for all the buildings situated in Almeria, Climate Zone A4. Variation of the maximum mean indoor temperature for all the buildings situated in Climate Zone A4

5 CONCLUSIONS

Night ventilation is an operative strategy to improve comfort conditions in the users of office buildings in Spain. Depending on the level of request and the climate zone it is possible to maintain comfort conditions in 100% of the working schedule, making not necessary the use of air conditioning. Some studies suggest (Geros 1999, Kolokotroni 1998, Kolokotroni 2007) that peak temperature can be reduced up to 3.5ºC. The results of this paper show that in the case of Spain, the achievable reduction is approximately 1ºC. It has to be pointed that this variations are the mean of the maximum temperatures and not the maximum absolute. In addition, different construction materials were not considered in this work, where the influence of thermal inertia could help to reduce peak temperatures.

Although it was not an initial objective of this work, the results show that the building typology is an important factor for evaluating night ventilation as *effective or significant* to improve comfort conditions. Two main variables in buildings are identified as relevant for optimal and effective night ventilation: low glazed surfaces in façade and a low shape factor (compact buildings).

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