Effect of technical solutions on non-heating and non-cooling temperatures and free cooling potential in office buildings

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ABSTRACT

In this paper we analyze by means of building simulation the effect of different parameter combinations on the non-heating and non-cooling temperatures of a typical air-conditioned office building. The examined parameters are: thermal insulation, thermal inertia, ratio of glazed surfaces, type of windows and shading devices, envelope permeability, ventilation type, installed appliances and lighting power, heating and cooling set point temperatures..

The paper suggests the constructive solutions that lead to concept buildings with three distinct seasons: a heating season, two mid seasons without the need for heating or cooling, a cooling season. Moreover, we analyse the possibility to use free cooling during the heating and the mid seasons to avoid overheating.

This study is an introduction to the definition of a new concept of air-conditioned buildings, with optimized envelope and HVAC systems, called CLIMHYBU (Hybrid air-conditioning of office buildings).

1. INTRODUCTION

The improvement of thermal insulation and of envelop permeability in modern office buildings besides the increase of glazed façades area and the intensive use of computers and lighting, leads to contradictory effects on the heating and cooling demands.

On one hand, the heating loads decrease; and on the other hand, the cooling loads increase. Consequently the heating season becomes shorter and the cooling season becomes longer; in the mid seasons, heating and cooling demands can be simultaneous.

The object of this paper is to show how architectural, thermal and management choices can play a key role in the cooling and heating seasons.

In a first part, we describe the characteristics of the building used as reference. Its thermal behavior is simulated and two parameters, called non-cooling and non-heating temperatures, are defined to take into account the heating and cooling period lengths and their overlapping.

In the second part, we analyse through simulation the effect of different parameters on these temperatures, in order to observe their trends and identify the most promising choices. A modified building is thus defined and it is shown to reduce significantly the overlapping periods and the energy demand.

Finally, we study the possibility of using free cooling during heating and intermediate seasons to avoid overheating and consequently increase non-cooling temperature. The modified building shows a better potential of free cooling, both in the cold and in the mid seasons.

2. REFERENCE BUILDING

The reference building used in the present paper is issued from a building typology common among French air-conditioned offices (Filfli et al. 2006). It is composed of twelve identical floors with a total area of 15 000 m^2. Circulations and WC are not air-conditioned, leading to a total air-conditioned area of 12 150 m^2. Figure 1 shows the floor plan.

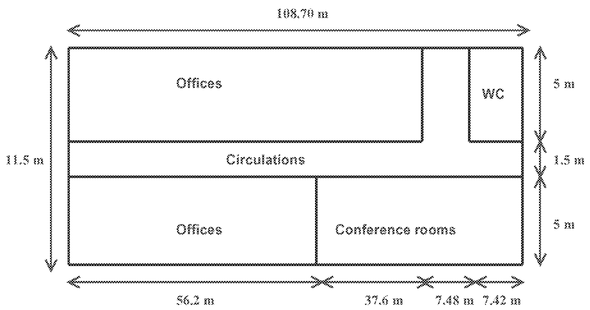

Figure 1. Building floor plant

The key features of the building are resumed in table 1. Thermal characteristics of the envelope correspond to good practices in building design, in accordance with the French thermal regulation (CSTB 2005).

Table 1: Key features of the building. Thermal inertia calculated according to the standard EN ISO 13786

Building surface area	15 000 m^2
Air-conditioned area	12 150 m^2
Floors	12
Ratio of glazed surface on the façades	50%
Wall U-value	0.35 W / m^2 K
Roof U-value	0.3 W / m^2 K
Thermal inertia	C_m: 110 kJ / m^2 K A_m: 2.5
Windows	U-value: 2.7 W / m^2 K Solar factor: 0.59
Integrated solar blinds	U-value: 2.0 W / m^2 K Solar factor: 0.14
Nominal occupancy ratio	1 person / 12 m^2
Installed appliance power	15 W / m^2
Installed lighting power	12 W / m^2
Permeability to air	1,7 m^3 / h @ 4 Pa per m^2 exterior wall
Hygienic ventilation	25 m^3 /person in occupancy hours Mechanical extraction
Set point temperatures	20 / 25 °C 15° C night set point

Occupancy and appliance use profiles are defined hour-by-hour according to Filfli (2006), while solar blind use and artificial daylighting are assumed depending on solar irradiance on the façade and natural daylight availability respectively, without seasonal variation (Marchio et al. 2006). Windows are assumed non-openable, as it is often the case in large fully air-conditioned buildings.

Table 2 reports the heating and the cooling demand and the peak heating and cooling loads of the reference building for different climates, calculated by means of ConsoClim (Bohler et al. 2000), a building energy simulation software. Simulations are carried out for 3 representative French climates: the region of Paris (Trappes, H1 in the table), the Atlantic coast (La Rochelle, H2) and the French Riviera (Nice, H3).

Table 2: Energy performance of the reference building.

	H1	H2	H3
Heating demand (kWh / m^2)	28	15	6
Cooling demand (kWh / m^2)	31	42	65
Peak heating load (kW)	713	669	609
Peak cooling load (kW)	905	913	877

3. DEFINITION OF NON-HEATING AND NON-COOLING TEMPERATURES

Figure 2 shows the distribution of the hourly energy demand of the building as function of temperature, while Figure 3 shows the cumulative heating and cooling demand in the Paris region as function of the outdoor temperature. A similar trend is observed for the other climates.

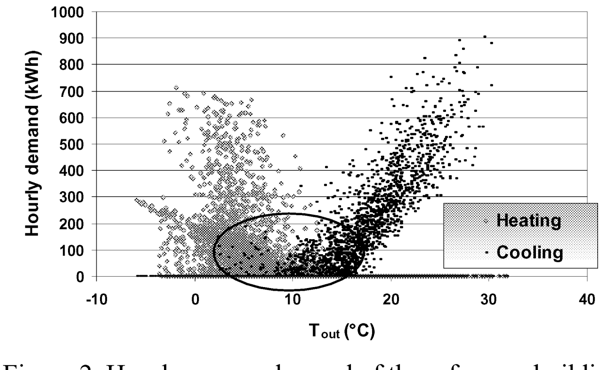

Figure 2. Hourly energy demand of the reference building in Paris region climate.

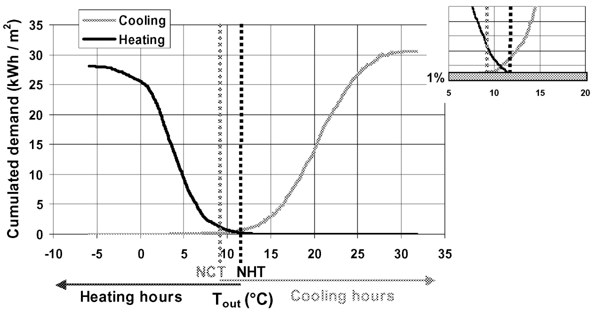

Figure 3. Cumulative heating and cooling demand of the reference building in the Paris region climate.

Some dispersed cooling loads appear already in correspondence to the cold season (2-8°C) in the offices exposed to the south, mainly due to solar gains. For temperatures above 8-10°C, important and more systematic cooling loads appear, even in the offices exposed to the north, while heating is still operating.

Based on Figure 3, two characteristic temperatures can be defined. The non-heating temperature (NHT) is the temperature above which the cumulative heating demand of the building exceeds the practical limit of 1% of the total heating demand, whilst the non-cooling temperature (NCT) is the temperature below which the cumulative cooling demand is lower than 1% of the total cooling demand.

The NCT-NHT difference is a practical parameter quantifying the length of the mid season, which is the season with simultaneous heating and cooling demand, if the difference is negative, or with no heating and cooling demand, if this is positive.

Table 3 shows the resulting NHT and NCT of the reference building for the three climates.

Table 3. NHT and NCT of the reference building.

	H1	H2	H3
NHT	11.4	12.1	12.8
NCT	9.7	7.1	11.3
Difference (NCT-NHT)	-1.7	-4	-1.5

Note that the difference between non-heating and non-cooling temperatures is always negative for the reference building. This means that heating and cooling loads often occur simultaneously or in rapid succession, and that no intermediate season without heating or cooling demand exists.

4. PARAMETRIC STUDY

Based on the described building, we study the variation of the eight architectural, thermal and management parameters listed in table 4. Note that windows and shading devices are varied together because the shading device is considered integrated to the window.

For each parameter, up to 2 variants are identified, corresponding to technical solutions available on the French building market. The parameters are varied one-by-one with respect to the basic solution described in table 1. Table 4 shows the 12 resulting cases.

Table 4. List of identified variations of the reference building

Parameter	*Value*	*Symbol*
Windows - solar blind	U: 1.4 - 1.3 W/m^2K SF: 0.48 - 0.12	WIN1
	U: 1.1 - 1.2 W/m^2K SF: 0.36 - 0.09	WIN2
Thermal inertia	C_m: 260 kJ/m^2K, A_m: 3	INE1
	C_m: 85 kJ/m^2K, A_m: 2	INE2
Insulation roof - walls	U: 0.15-0.14 W/m^2K	INS
Permeability	0.7 m^3/h	PERM
Ventilation	Double flux with heat recovery	DF
Appliances / lighting	7.5 - 8 W/m^2	LC
Glazed surface ratio	30 %	GSR1
	70 %	GSR2
Set point temperature	19 / 26 *°C*	SP1
	21 / 24 *°C*	SP2

The investigated outputs are the NCT-NHT difference and the sum of the heating and cooling demands. Figure 4 and 5 show the results for the Paris climate.

The results show that the trends of the NCT-NHT difference and of the energy demand are similar, but not identical:

- the two types of windows and solar blinds tested show similar good energy demand performance, but the WIN2 almost avoid NCT-NHT difference;
- thermal inertia affects slightly the energy demand, but has a great effect on NCT-NHT

difference: the case INE1 (heavy inertia) is the only one with a positive temperature difference;

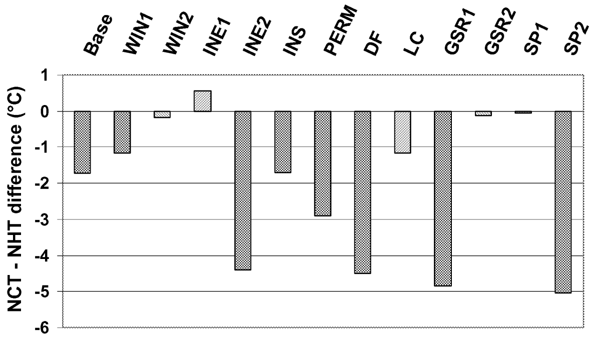

Figure 4. NCT-NHT difference variation in climate H1.

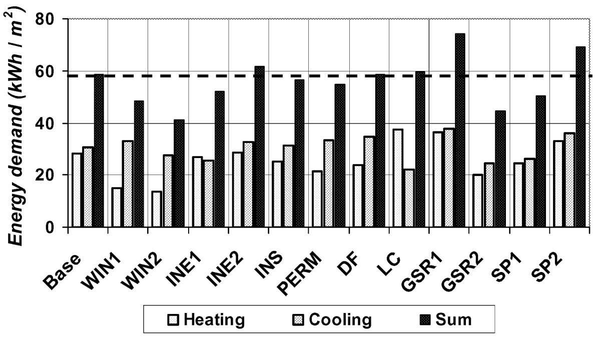

Figure 5.Energy demand variation in climate H1.

- thermal insulation has a weak impact on the energy demand and on the NCT-NHT difference. The result should not surprise, as the reference building is good insulated;
- reducing the permeability has a good effect on energy demand, but the NCT-NHT difference worsens, due to the reduced over ventilation in winter and subsequent overheating;
- heat recovery on the extracted air slightly increases the energy performance, but it makes the NCT-NHT difference worst. This fact, apparently surprising, can be explained by the by-pass of the heat exchanger, based on the outdoor temperature. As seen, cooling demand can appear even at low temperatures, and in this case the heat recovery still work, preventing the building from evacuating the exceeding heat by ventilation;
- low consumption appliances and lighting are positive for the NCT-NHT difference but negative for the energy demand, due to the increase of the heating demand. Note that the reduction of electrical consumption of this solution is not taken into account;
- the ratio of glazed surface strongly affects both the energy demand and the NCT-NHT difference. Less glazed surface makes it possible to reduce both the parameters. This suggests that solar gains play a key role in the thermal behavior of the building. Perhaps, the same or a still better result could be obtained by the use of seasonally regulated solar protections.
- set point temperatures affect both the parameters in a similar way. Total energy demand is decreased of 10% passing from the set point 20/25 °C to the one 19/26 °C. Moreover NCT-NHT difference is near zero.

In light of these results, we selected the five variations which reduce the NCT-NHT difference: WIN2, INE1, LC, GSR2 and SP1. Insulation is excluded due to its reduced effect. Thus, we applied the five variations to the reference building. Figure 4 shows the cumulative energy demand curve of the modified building , which can be compared to Figure 6.

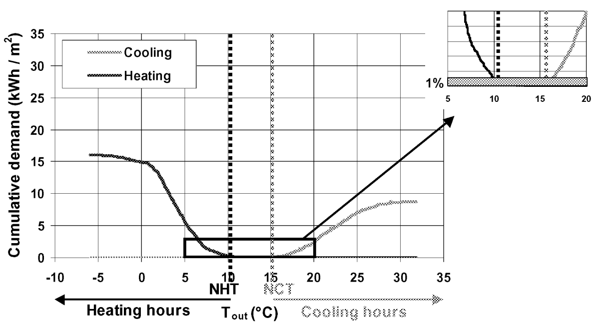

Figure 6. Cumulative energy demand of the modified building in climate H1.

The intermediate temperature range for which neither heating nor cooling is demanded is clearly visible in the graph.

The same analysis carried out for the other two climates leads to similar conclusions. Table 4 reports the NCT-NHT difference, the energy demands and the peak loads of the modified building for all the climates, and the comparison with the reference building.

Table 5. NCT, NHT and energy performance of the modified building.

	H1	H2	H3
Non-cooling temperature (°C)	15.1	15.6	15.4
Non-heating temperature (°C)	10.7	12.7	13
NCT-NHT difference	*4.5*	*2.9*	*2.4*
Heating demand (kWh / m^2)	16	8	2
Reduction of heating demand	*43%*	*47%*	*67%*
Cooling demand (kWh / m^2)	9	14	25
Reduction of cooling demand	*71%*	*67%*	*62%*
Peak heating load (kW)	582	572	320
Reduction of peak heating load	*18%*	*14%*	*47%*
Peak cooling load (kW)	408	439	423
Reduction of peak cooling load	*55%*	*52%*	*52%*

The selected variations makes it possible to obtain in the three climates a positive NCT-NHT difference. In addition, energy demand and peak loads are strongly decreased compared to the reference building.

5. FREE COOLING POTENTIAL

The free cooling consists in introducing into the building a rate of outdoor fresh air exceeding the hygienic rate, by using purpose-provided openings (natural ventilation) or mechanical fans, in order to avoid active cooling. Here, we examine the free cooling potential of window opening.

On first approximation, we can calculate the airflow rate necessary to avoid a given cooling load as:

$$\dot{q}_V = \frac{\dot{Q}_{cooling}}{\rho \cdot c_P \cdot \Delta T}$$

where q_v is the over ventilation airflow rate, $Q_{cooling}$ is the cooling load to offset, ρ and c_P are the density and the specific heat of air, ΔT is the temperature difference between indoor (set-point temperature) and outdoor

Based on this sample equation, it is possible to calculate hour-by-hour the air flow rate necessary to avoid active cooling, as shown in Figure 7 and 8 for the two buildings in the Paris climate.

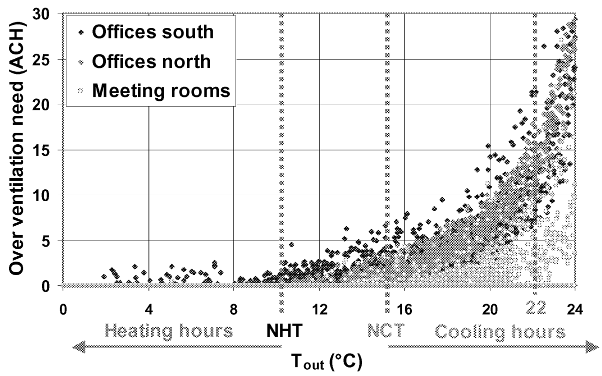

Figure 7. Additional ACH needed in the reference case.

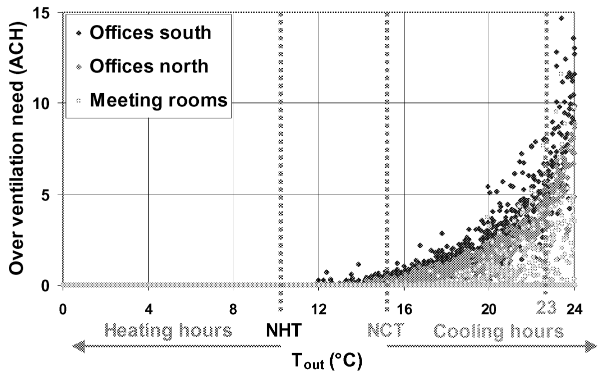

Figure 8. Additional ACH needed in the modified case.

Note that the necessary over ventilation required in the modified building is reduced with respect to the base building, increasing the free cooling potential of window opening.

To give an idea, the openable windows area necessary to provide the required over ventilation rate in the two buildings is estimated by use of the simple sizing methods described in Allard (1998) for single-sided ventilation:

$$A = \frac{q_{design}}{C_d} \cdot \sqrt{\frac{(T_{out,design} + 273)}{\Delta T \cdot g \cdot h}}$$

where q_{desing} is the design airflow rate in correspondence of the design outdoor temperature $T_{out,design}$, C_d is the discharge coefficient (taken as 0.6), ΔT is the difference between the outdoor and indoor (set-point) temperature, h is the height of the opening.

The calculation is carried out for the offices exposed to the south. As suggested in CIBSE (2005), the design outdoor temperature is supposed 3°C lower than the desired indoor temperature (22°C for the base building and 23°C for the modified building), and no wind effect is considered to size the openings. Table 6 shows the resulting opening area.

Table 6. ACH and subsequent opening size required for single-side buoyancy- driven ventilation in offices exposed to the south. Opening height: 0.9 m.

	Reference building	Modified building
Design flow rate	28 ACH	8 ACH
Opening area	929 m^2	288 m^2
% of façade	46 %	14 %

To provide the required amount of over ventilation by windows opening in the reference building it is necessary to left opened all its glazed surfaces. This is clearly unrealistic. At the contrary, in the modified building the required opening area is the 14% of the façade, corresponding about to the half of the overall glazed surface. Thus, the potential for effective free cooling is higher in the modified building than in the reference building.

However, a detailed analysis of the flow trough the windows and of the generated velocity field is required to check the applicability and the performance of window opening. This analysis is currently under development using multi-zone network and CFD models (Orme 1999).

6. CONCLUSIONS

This paper investigates the effect of the application of different technical solutions on the overlapping periods and the season lengths of heating and cooling demand for a common building office type.

A characteristic parameter is defined as the difference between the non-cooling and the non-heating temperature of the building.

The simulations carried out show that some solutions are more favorable than others in order to reduce the simultaneous heating and cooling demand. In particular, the reduction of glazed surfaces, the improvement of their thermal characteristics, the increase of the building thermal mass, the use of low consumption appliances and the adoption of less stringent set-point temperatures are found to be the best way to increase the NCT-NHT difference. The application of all these options to the reference building leads to a building in which the temperature range corresponding to the heating demand is well distinct from the temperature range corresponding to the cooling demand. An intermediate temperature range appears in the middle, corresponding to no heating and no cooling demand. Additionally, the application of these solutions leads to a building presenting less total heating and cooling demand.

A simplified analysis of the free cooling potential in the reference and the modified building suggests that the second one is more favorable for free cooling by window opening during the intermediate season, due to the decreased over ventilation needed. However, further study is required in order to evaluate the actual free cooling potential of window opening for the modified building.

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