Consequences of Increasing Insulation on the Annual Energy Consumption of Air-Conditioned Office Buildings

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ABSTRACT

The aim of this work is to study the influence of global heat transfer coefficient (U_{tot} en W/m^2.K) of the opaque walls (walls and roofs) and of the glazed walls (bays) on the annual consumption of heating, cooling and overall consumption energy. We analyze the number of hours of heating and cooling under operation with partial load and full load. Profiles of indoor temperatures are also given.
The work is established on several office buildings defined according to a typology built within the framework of a study on energy savings in air-conditioned office buildings in France.
Simulations are carried out according to two types of buildings. The parameters of the first one are totally optimized. The elements concern management of ventilation, lighting, office automation, inertia, HVAC system and distribution network parameters. The second building is taken with high internal gains, i.e non-efficient lighting and plug-in consumptions. The two buildings are compared from both points of view of consumption and comfort. Insulation of the walls is systematically increased, by considering approximate values of 1960 passing by actual values and up to future possible values even if they are technically unachievable. At this stage the only parameters that varies are U_{tot} of opaque and glazed walls. The choice of two indicated types of buildings helps to evaluate the interference of the over-insulation with the other parameters of the building and the system.
Simulations are carried out for two climatic regions in France, Trappes (near Paris) and Nice. The first climate is cold in winter and moderate in summer in contrary to the second climate. This choice reflects two extreme configurations of loads: high heating with average cooling demands and high cooling with average heating demands.

KEYWORDS
Office buildings, energy consumption prevision, energy savings, insulation, over-insulation, building and system simulation.

INTRODUCTION
The question of negative effect that can be obtained on the cooling loads because of an over-insulation of buildings have been evocated in the recent years especially with the technical evolution of insulating materials.

It is obvious that the introduction of computers, printers and other electronic devices have a direct effect on increasing cooling demands. The attitude of installing powerful lighting and the architectural tendency towards largely glazed buildings have constituted the major reasons behind the necessity to cool office buildings in northern Europe. Even the temperate or cold climatic regions need more and more efficient cooling.
At the same time, the research of better insulating materials to reduce the heating demands is advancing. In France, existing office buildings are designed in a manner to limit the main energy consumptions i.e. heating. The insulation of exterior walls and roofs was systematically added, outside insulation or inside insulation, double glazed windows are very commonly used.

For sure, the annual consumptions of heating have been decreased but inefficient management of ventilation and solar shades besides the non-optimization of distribution pipes insulation and of building permeability lead to an average annual consumption of 283 kWh/m^2 in French office buildings of which 162 kWh/m^2 are due to heating and hot domestic water consumption. [ADEME]

The authors have shown in a previous work [Filfli and al, Clima 2005] that the optimization of all the influent elements of office buildings can lead to important reduction of energy consumption up to five times. In 2005, 35 % of French total area office buildings are equipped with an air-conditioning system.

To quantify the effect of over-insulation on cooling, heating, and total energy consumption, Consoclim [Marchio and al 2005], a building hourly simulation dynamic program developed between the CEP and CSTB[1] was used.

Building Description

The base case is an office building of 15 000 m² (12 levels), broad plate and conference non-glazed room, open offices with largely glazed façades (southern and northern).

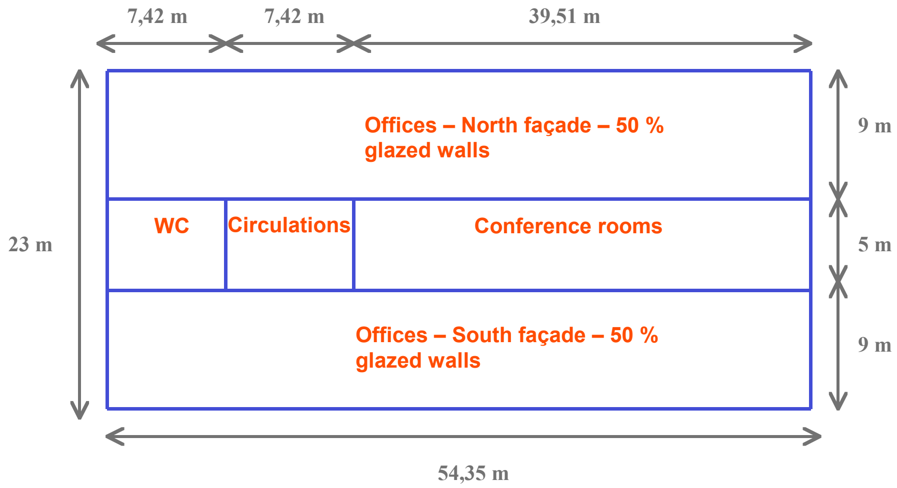


Figure 1: Building geometry description

Simulations are carried first with optimized ventilation, low energy lighting and energy star office automation. The only parameter that varies is the thermal resistance of opaque and glazed walls. Four levels are considered while passing from the approximate values of the seventies up to actual values and even to the possible future values. In a second time, the same procedure is repeated with a similar building equipped with inefficient lighting and office automation. Table 1 resumes these four levels:

TABLE 1

Different insulation levels (thermal transmittance) from 70th to future

	Level 1	Level 2	Level 3	Level 4
U_{walls} (W/m^2.K)	3	0.4	0.1	0.05
U_{roofs} (W/m^2.K)	2.5	0.2	0.1	0.05
$U_{windows}$ (W/m^2.K)	4.5	2	1	0.5

The solar and light transmission factors of glazed surfaces are equal to 0.6 without the solar shades and to 0.2 with the solar shades.

[1] CEP : Center for Energy and Processes, CSTB : Centre Scientifique et Technique du Bâtiment

Brief description of building, envelope and automation models

Consoclim calculation method [Alessandrini and al 2002] is based on the principal of thermal homogenous zones of the building (ventilation, occupation, ec…). The main inputs of each zone are: occupancy profiles, internal gains profiles, characteristics of HVAC system terminal units, outside walls characteristics and solar shades management, lighting and ventilation management, set points temperatures.

For the whole building, the main characteristics to be specified are: permeability, climatic data, central HVAC system characteristics and distribution network. All main elements impacting energy consumption are considered. For the outside walls, are taken into consideration: inclination, orientation, thermal transmittance calculated from wall composition, thermal bridges and absorption coefficient. For glazed outside surfaces, solar and light transmission factors are also considered. The model considers the interactions between artificial and natural lighting besides different control systems (dimming or moving detector, graduator, switch) [Filfli and al 2006]. Real use measurements were carried out to obtain average positions of solar protection as a function of occupation and illumination of the façade. [Millet, 2002]

Annual Energy Consumption

In Trappes, the improvement of thermal insulation produces the following variations:

- cooling consumption increases systematically,
- heating consumption decreases between levels 1 and 2 ; then reaches a limit,
- consumption in primary energy is minimal between level 2 and level 3.

It is important to indicate that the sizing of the HVAC system is kept constant with insulation level. The variation of indoor auxiliary consumption is due to the variation of the number of hours of operation, fans being stopped when the unit is off.

TABLE 2

Variations of annual energy consumption (kWh/m^2) with the insulation level at Trappes – Low IG

In kWh/m^2	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Cooling	2.2	5.2	7.5	8.9
Heating	58.1	18.9	16.2	16.2
Auxiliaires FC units	4.6	3.7	3.6	3.6
Total paying energy	105.9	68.9	68.4	69.8
Total primary energy	181.5	148	150.9	154.5

The values of the other sectors annual consumption (unchanged) are:

- 19 kWh/m^2 for office automation, 18.2 kWh/m^2 for lighting,
- 2.4 kWh/m^2 for fresh air ventilation fans, 1.5 kWh/m^2 for distribution pumps.

In Nice, the effect of the studied parameters is less visible than in Trappes but minimal energy consumptions remain around level 2,

TABLE 3

Variations of annual energy consumption (kWh/m^2) with the insulation level at Nice – Low IG

In kWh/m^2	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Cooling	7.3	10.2	12.2	13.1
Heating	21.7	8.7	8.4	8.4
Auxiliaries FC units	5.6	5	4.9	4.9
Total paying energy	74.1	63.5	65	66
Total primary energy	156.9	150.1	154.6	157

The values of the other sectors annual consumption (unchanged) are:

- 19 kWh/m^2 for office automation, 16.5 kWh/m^2 for lighting,
- 2.4 kWh/m^2 for fresh air ventilation fans, 1.7 kWh/m^2 for distribution pumps.

Figure 2 shows the evolution of total consumption with low and high internal gains (dotted), at Trappes and Nice and in terms of bill and primary energy (bold).

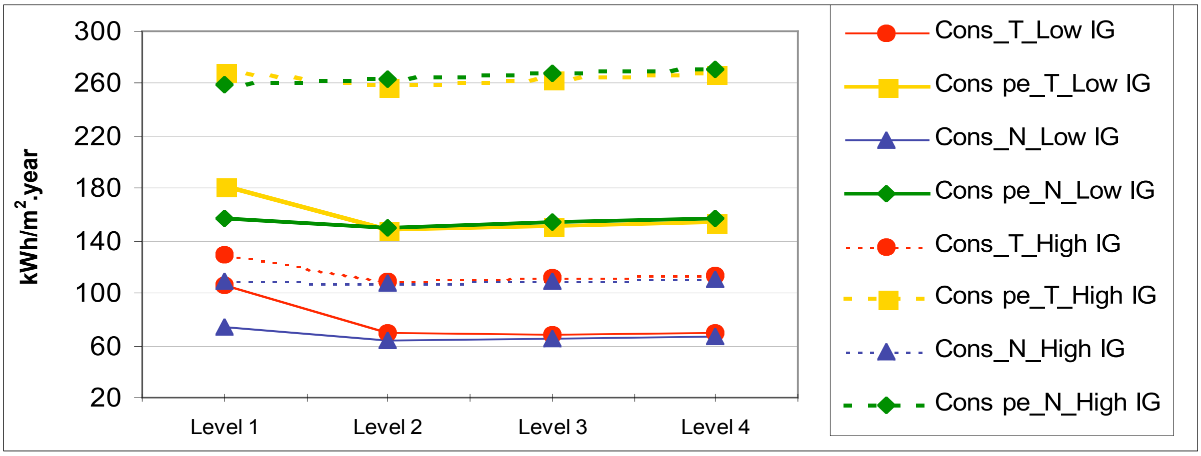


Figure 2 : Total consumption as a function of insulation level, climate and internal gains

Annual number of heating and cooling hours

Figure 3 shows an increasing number of cooling annual hours with the increasing of the insulation level on the contrary of the number of heating hours. It is seen that this number tends to be stable at high insulation levels. In cooling, this is due to the effect of internal and solar gains even with very efficient glazing chosen. In heating, it is due the loads of fresh air and infiltrations.

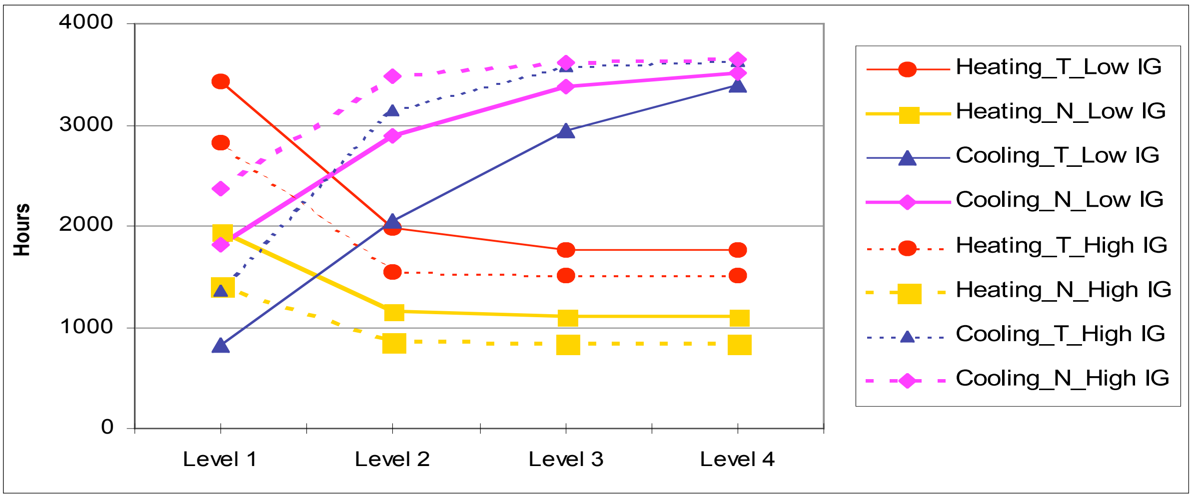


Figure 3 : Hours of cooling and heating as a function of insulation level, climate and internal gains

Indoor temperature profiles evolution

The evolution of indoor air temperature with the variation of insulation level is studied for all the considered cases. It is noted that for low internal gains, the temperature profile is distributed between the two set points at Trappes and at Nice for the normal insulation level (level 2). For the south offices, in summer, temperatures close to cooling set point (25°C) are more frequent than in north oriented offices. Cooling loads in winter are more important with high internal gains.

In the meeting rooms, without windows, in winter, the temperatures remain close to the heating set point (20°C) and in summer near the cooling set point. In medium season, the temperature obviously follows the outdoor temperature; this is mainly due to the insensitivity of these rooms to internal gains considered as negligible.

With respect to other levels, the profile of indoor temperature follows essentially the number of heating hours, as much as we insulate, the more the cooling needs are higher, the temperatures being very near to the set point. (Vice-versa with respect to heating).
Cooling supply power limited to system capacity has been noted slightly insufficient at the stage where the isolation and internal gains levels are very high. The need to resize the system can be revealed as a function of the margins taken in the sizing procedure.

In fact, the regulation of the system is defined as the following:

- during occupation, if indoor temperature > cooling set point => cooling
- if indoor temperature < heating setpoint during occupation or
  < reduced heating setpoint in inoccupation => heating
- indoor temperature between heating and cooling set points => nothing

Figure 4 presents an example of indoor temperature profiles with 2 extreme insulation levels: 1 and 4, south oriented offices, low IG at Trappes. Note that during occupation, only cooling or heating modes occurred. In inoccupation, free evolution of temperature at medium season takes place. (not presented in the figure)

Partial load ratio
Besides the effect on the consumption and indoor temperature profiles, the partial load behavior of chiller and gas boiler are taken into account. The rating power of cooling is rather more important at Nice than at Trappes (948 kW vs 630 kW, for Tc =35 °C, Td = 7°C) while that of heating is less important (345 kW vs 630 kW). Rating EER of the chiller is 3.3 for the studied case.

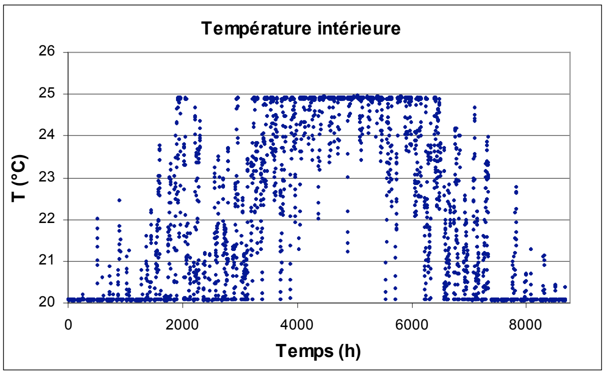
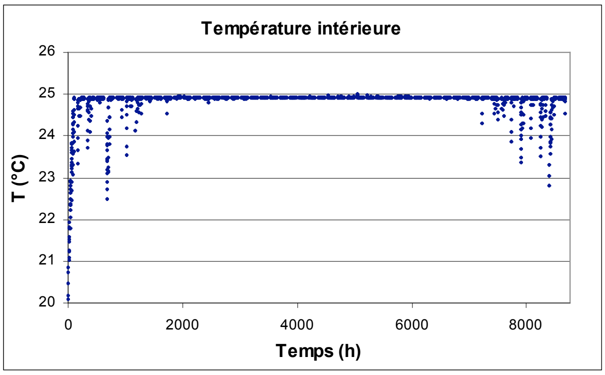
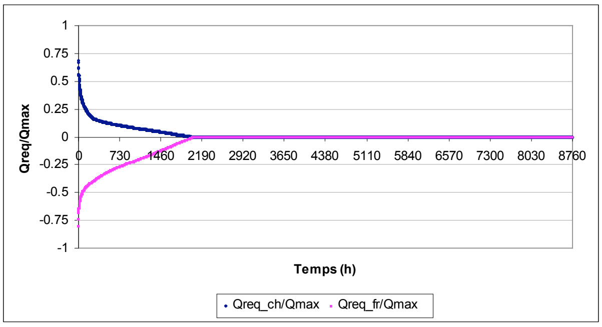
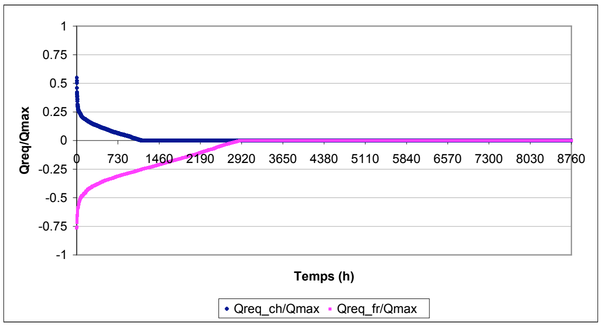
	
Trappes – low IG – level 1 – during occupation	Trappes – low IG –level 4 – during occupation

Figure 4 : Indoor temperature variation for different insulation levels

Figure 5 shows the evolution of partial load factor (required capacity/maximum capacity) in heating and cooling for insulation level 2 for Trappes and Nice. One interesting indicator is the equivalent number of hours at full rating capacity rate of the above cases : Eq nb (hours) = energy cooling / cooling capacity
Results are presented in table 4. Note that, the maximum cooling capacity as well as heating capacity are not the same in Trappes and in Nice.



Trappes – low IG- insulation level 2



Nice – low IG- insulation level 2

Figure 5 : Partial load factor as a function of insulation level

TABLE 4
Number of equivalent hours corresponding to operation at full rating capacity

	Equivalent cooling hours	Equivalent heating hours
Trappes, low IG, insulation level 2	459	195
Trappes, low IG, insulation level 4	880	135
Nice, low IG, insulation level 2	635	118
Nice, low IG, insulation level 4	884	103

Conclusion

It is has been seen that very high insulation will increase cooling levels. Total bill consumption is not very variable between actual and possible future levels; level 2 is close to minimal value for the studied building. It is very important to install efficient lighting and electric equipments; their par of total energy consumption is about 50%.

In terms of primary energy, the effect of inefficient lighting or office equipments is more obvious. High internal gains with high level of insulation increases largely the cooling loads and thus the primary energy consumption.

It is essential to note that this study is specific to the type of building studied; different results can be obtained for other buildings having different characteristics. The sizing of the system has to be reviewed according to the initial margin considered. A future cost study will be carried.

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