The impact of envelope insulation and ventilation on summer performance

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ABSTRACT

This work describes a study aiming to establish the coupled impact of the increase of the insulation of the building envelope and the adoption of night ventilation upon the thermal performance of buildings. A particular emphasis is placed upon the consequences in terms of increased temperatures in summer, potentially leading to increased needs for installation of air-conditioning. The methodology is based on parametric studies obtained through simulations. The requirements to avoid air-conditioning, in terms of window shading for each level of insulation, are presented.

1. INTRODUCTION

There is a strong tendency for prescribing more and more severe restrictions for the building envelope insulation in the European legislations, in particular after the recent European Directive on the Energy Performance of Buildings (EU Official Journal, 2003). E.g., the Portuguese thermal regulations for buildings (DGE, 1990) were recently revised and insulation requirements increased by about 50% in 2005.

The benefits of increasing the insulation thickness are evident in a typical winter situation, when a lower U-value directly reduces heating needs. However, in certain locations, where Summers are hot, insulation may cause a rise in the internal temperature which in turn may lead to the need of air-conditioning that would not be necessary with less insulation. This problem can be found more frequently in Southern European countries, where Summers have long periods with high outdoor temperatures and solar radiation exposure.

Figure 1 (Chvatal et al., 2003), shows the percentage of hours with temperature above 25°C in a typical residence in Porto, Portugal, for various insulation thicknesses of the external envelope (x axis) and shading factors of the glazings.

There are clearly different patterns of behavior depending on the shading factor. Well-insulated envelopes with insufficient shading factors (high solar gains) have a tendency for more hours of discomfort. This shows that the increase of the insulation of the envelope is favorable only when window solar gains are below certain limits. In this specific example, the *cross-over point,* i.e., the shading factor above which increased insulation results in worse building performance in Summer, is between 50 and 60%.

This paper describes the potential benefits of allowing night ventilation in buildings with high inertia together with the higher insulation and

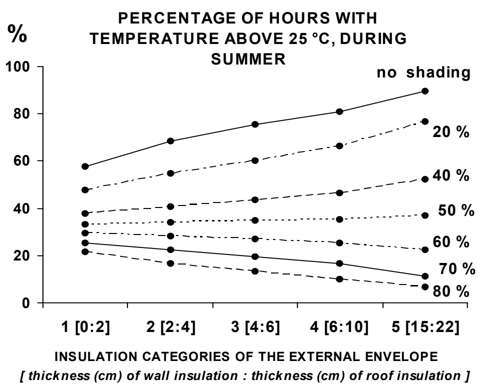


Figure 1: Percentage of hours with temperature above 25°C, for a residence, in summer, in Porto.

solar shading scenarios described in Figure 1. Adaptive comfort concepts have been used to evaluate the acceptability of the resulting indoor environments.

2. PARAMETRIC STUDIES

Three building models were selected and reasonable ranges of windows shading, type of use of the building, ventilation rates, envelope insulation and climate were considered for each of them (Chvatal et al., 2003). The simulations of the buildings thermal behaviour have been carried out with TRNSYS (Solar Energy Laboratory, 2002). The outputs from a total of 1260 simulations have automatically been processed and analysed. The input data for all the parametric studies are described in Table 1.

3. COMFORT ANALYSIS METHODOLOGY

The essential question that this study addresses rests on being able to set an objective criterion to define when an occupant feels enough discomfort, in terms of both intensity and length of exposure, to decide to install and use an air-conditioner. It is assumed that there are no economic constraints that would prevent occupants from installing and running AC equipment.

Comfort analyses of the indoor environments are covered by ISO 7730 (1994), based on the well-known Fanger theory (1970). However, more recent thermal comfort field studies have demonstrated some room for improvement in the predictions of the real mean vote (Humphreys and Nicol, 2002; Oseland and Humphreys, 1994). In these field surveys, the subjects demonstrated, with good statistical confidence, to accept a wider range of environmental conditions than those set by ISO 7730. One of the reasons for these differences is the capacity of adaptation of the subjects, e. g., the possibility that they have to make some changes in their thermal environment, like opening/closing windows, adjusting clothing, location, shading and ventilation conditions, etc. This would allow them to tolerate conditions outside the narrow limits prescribed by the ISO standard, where no adaptation possibility is taken into account. The recent revision of the ASHRAE Standard 55 (De Dear and Brager, 2002) also includes an adaptive model, which became an alternative to the deterministic method prescribed in its previous version. This approach can be used for naturally ventilated buildings that obey certain restrictions, on the basis of research carried out using an extensive world-wide database of thermal comfort field studies.

In the adaptive comfort theory, comfort temperature is closely related to the prevailing outdoor ambient temperature, as described by equation (1) (McCartney and Nicol, 2002):

$$T_c = a.T_{out} + b \tag{1}$$

where:

- T_c: Comfort temperature, corresponding to the neutral comfort vote in the ASHRAE scale (ASHRAE, 1992),
- T_{out}: outside temperature index, for example, the average outside temperature,
- *a, b*: constants obtained from regression analysis of measured data in field studies.

The adaptive comfort theory fits exactly into the traditional life-style of Southern Europeans in their dwellings and unconditioned offices. It thus seems more realistic to use this approach rather than the more deterministic ISO 7730.

A recent European study, with the main purpose to develop an adaptive control algorithm fitting equation (1), provided data for calculation of the *a* and *b* constants fine-tuned to the Southern European population. It included field studies in Portugal, France, Greece and other more northern climates (McCartney and Nicol, 2002) and provided adaptive algorithms for each country. For Portugal, equation (1) thus becomes:

$$T_c = 0.381.T_{RM} + 18.12\ (^\circ\mathrm{C}) \tag{2}$$

In equation (2), T_{RM} is the running mean outside temperature. It is the outside temperature index that produces better accuracy and can better reflect the time-dependency of the comfort temperature. It is similar to the half-life decay calculations, and it is calculated on a daily basis. In this case, it corresponds to a half-life of approximately 3.5 days, according to the following equation (3):

$$T_{RM}^{n} = 0.80.T_{RM}^{n-1} + 0.20.T_{DM}^{n-1} \tag{3}$$

where:

Table 1: Input data for the parametric studies.

<table>
<tr><th colspan="2">Simulated buildings</th></tr>
<tr><td colspan="2">One-storey building (133 m^2)/Apartment A (97 m^2)/Apartment B (82 m^2)</td></tr>
<tr><th colspan="2">External envelope</th></tr>
<tr><td colspan="2">Walls: double Ceramic hollow bricks/Concrete flat roof/Concrete slab (apartments)
Walls always have an intermediate air layer with insulation (external bricks + air + insulation + internal bricks). The external envelope is always the same, but the insulation thickness changes.</td></tr>
<tr><th colspan="2">Envelope insulation</th></tr>
<tr><td colspan="2">0/2, 2/4, 4/6, 6/10 and 15/22 cm (wall insulation/ slab insulation thicknesses)
Thermal conductivity of the insulation material 0.04 W/m.°C
The apartments are located in intermediate floors and consequently have no slab insulation.</td></tr>
<tr><th colspan="2">Percentage of window area</th></tr>
<tr><td colspan="2">Around 10 % (window/floor area) for all the three buildings.</td></tr>
<tr><th colspan="2">Window shading</th></tr>
<tr><td colspan="2">Fixed external shading in the Summer: no shading, 20, 40, 50, 60, 70 and 80 % *
There is no shading in the Winter.
* The shading index is the ratio of the shaded area to the whole glazing area.</td></tr>
<tr><th colspan="2">Types of use</th></tr>
<tr><td colspan="2">Housing (the original purpose of the buildings or apartments)
Services (a small office, for example - this type of adaptation is common in the Portuguese reality</td></tr>
<tr><th colspan="2">Occupation schedule</th></tr>
<tr><td>Use: housing
Between 18:00 and 09:00 hours, on weekdays
24 hours on weekends</td><td>Use: services
Between 09:00 and 18:00 hours, on weekdays only</td></tr>
<tr><th colspan="2">Internal gains</th></tr>
<tr><td>Use: housing
3.3 W/m^2 – average over 24 hours</td><td>Use: services
14.8 W/m^2 – average over 24 hours</td></tr>
<tr><th colspan="2">Ventilation</th></tr>
<tr><td colspan="2">Without night ventilation: Constant (natural) rate of 0.6 air changes/hr
With night ventilation: if the outdoor temperature is lower than indoors:
For the dwellings, night ventilation between 18:00 and 24:00 hours (3 air changes/hr), every day.
For the offices, night ventilation between 18:00 and 09:00 hours (5 air changes/hr), on weekdays.</td></tr>
<tr><th colspan="2">Climate</th></tr>
<tr><td colspan="2">Porto, Lisbon and Évora (typical of the three Portuguese Summer climate zones, according to building Regulations (DGE, 1990)).</td></tr>
</table>

T_{RM}^{n} : Running mean temperature on day ‘n’,
T_{RM}^{n-1} : running mean temperature on day ‘n-1’
T_{DM}^{n-1} : daily mean temperature on day ‘n-1’.

At day 1, T_{RM}^{n} is the same as mean outdoor ambient temperature.

Using the above equations, daily comfort temperatures were obtained for the three cities for a whole typical year. The maximum values of the comfort temperature were 26.7°C for Porto, 27.4°C for Lisbon and 27.7°C for Évora.

The comfort temperature corresponds to a neutral thermal sensation vote. The comfort zone was established as ± 2°C around the comfort temperature, according to Nicol and Humphreys (2002). This is the recommended range for the situations when there are few available adaptive opportunities, to represent the most unfavourable situation.

Figure 2 shows the variation of the outdoor and indoor temperatures, as well as the upper limit of the comfort zone, during six days in summer. These values correspond to apartment A, located in Porto, being used as an office, with 80 % of external shading, 15cm of wall insulation and with no night ventilation.

For the discomfort analysis, it is important to observe the part of the indoor temperature curve located above the upper comfort limit during the occupied periods. It is important to count both the number of degrees above the comfort temperature, the duration of these periods, and the

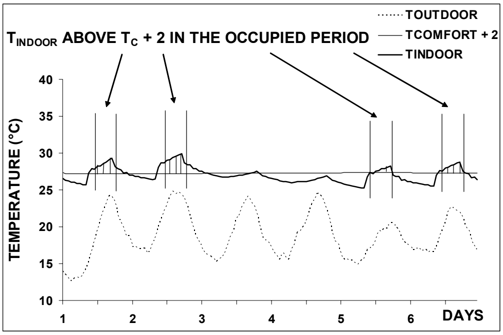


Figure 2: Outdoor, Indoor and Comfort temperatures for the Apartment A, during 6 days, in summer, in Porto (office use).

number of days and consecutive days when overheating occurs.

Thus, in order to characterize the comfort conditions, all the simulation results were post-processed in order to obtain the seven parameters described in Table 2. Each parameter was calculated for each of the occupied rooms and then averaged to obtain the whole building indicator. All of these results refer to the occupied period only.

The analysis of the results showed that parameters 2, 3, 4 and 6 were found to be the most representative for characterizing a building. The others added little additional useful information.

4. RESULTS

For lack of space, only the results for Apartament A, in Evora, the warmest summer zone of Portugal, will be presented. The results obtained

Table 2: Types of parameters defined to characterize the comfort conditions

1.Number (or percentage) of discomfort days (1)
2.Number (or percentage) of discomfort hours
3.Number of consecutive days of discomfort (1)
4.Average duration of the discomfort period per day of discomfort (1)
5.Average overheating (ºC of discomfort) (2) per day of discomfort (1)
6.Average maximum overheating (ºC of discomfort) (2) per day of discomfort (1)
7.Degree-hours of discomfort (^{0}C.hour)

(1) A day is considered uncomfortable when it has at least one uncomfortable hour.
(2) Overheating (ºC of discomfort): temperature above the upper comfort limit.

in the other climate zones and for the other buildings follow identical patterns, though with obviously different values.

4.1 Housing

Figure 3 shows the results for the apartment A when used as a dwelling. The "x" axis represents the various insulation thicknesses of the external envelope. Each curve corresponds to a particular windows shading and to a pattern of ventilation, i.e., with or without night ventilation.

Depending on the shading factor, all the graphs clearly show different patterns of behaviour as the insulation increases:

- When there is little shading (high solar gains), there is a tendency towards more discomfort in all aspects (duration, maximum overheating, etc) as the insulation increases.
- However, when shading is more effective (low solar gains), the discomfort is low and it decreases (or, at least, it does not increase) as the insulation increases.

So, the *cross-over point* of shading, as presented in Figure 1, is again visible. In this specific example, for all the comfort parameters, the cross-over points are very similar, between 40% and 60% of shading (Table 3).

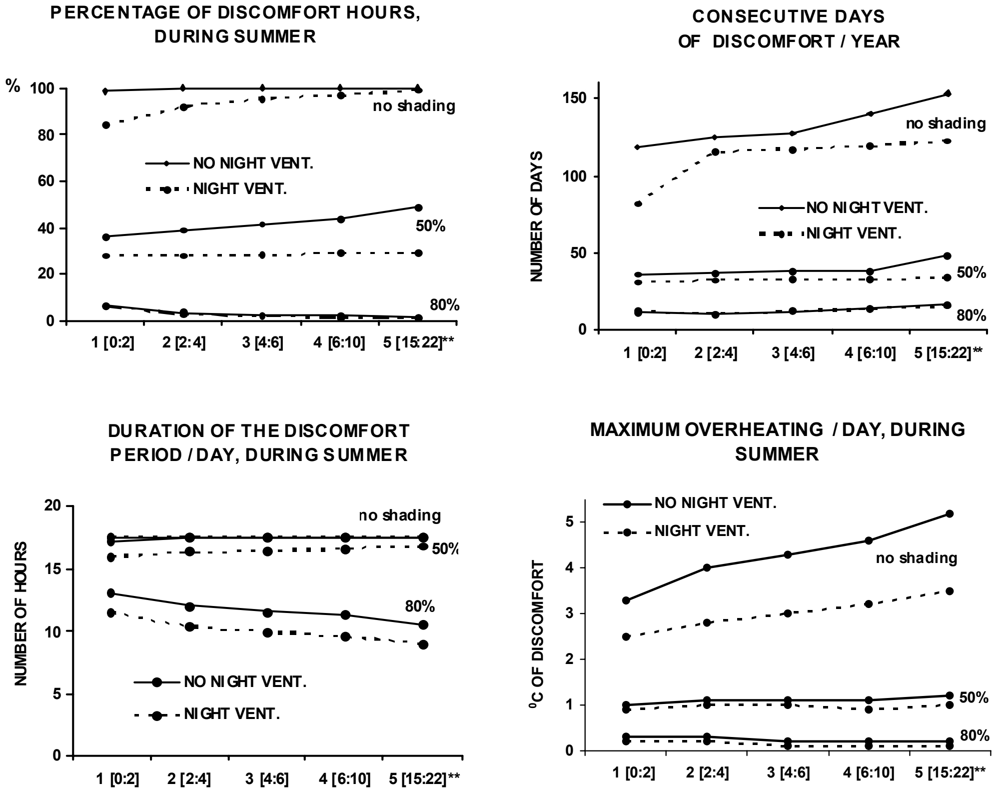
When there is night ventilation, the cross-over point is lower, i.e., with night ventilation the building can accept higher solar gains (less shading) than without night ventilation and still be comfortable with higher insulation of the envelope. Night ventilation gives an important contribution to remove the heat accumulated inside of the building during the day.

These results show that the solar gains need to be carefully avoided, especially when night ventilation is not possible. This is required for insulation to be increased to obtain energy savings in the winter, without increasing the discomfort (duration, maximum degrees, etc), in

Table 3: Cross-over points of shading.

Comfort parameter (1)	No night vent.	With night vent.
2	58%	51%
3	60 %	50 %
4	51 %	38 %
6	57%	50%

(1) According to the Table 2



**** INSULATION CATEGORIES OF THE EXTERNAL ENVELOPE**
[thickness (cm) of wall insulation : thickness (cm) of roof insulation]

Figure 3: Results for the Apartment A, used for housing.

the summer, which, in turn, could lead to AC consumption that would displace heating energy savings in winter.

4.2 Office

Offices, with higher internal gains, behave in a totally different way than housing (Fig. 4). Discomfort is clearly much higher, even with efficient shading, and this type of use usually requires the use of air-conditioning.

When there is no night ventilation, there is always more discomfort as the insulation increases, even for the lowest solar gains (high shading). Discomfort is permanent (close to 100% of the time). When there is night ventilation, the discomfort is uninfluenced by the insulation thickness (Table 4). Figure 4 also shows that discomfort is reduced to 70% of the time, still too frequent but clearly better than without night-ventilation.

With night-ventilation, the *cross-over point* is between 70% and 80%. Without night-ventilation, discomfort always increases with higher insulation thicknesses.

5. CONCLUSIONS

This study aimed at evaluating the influence of the increase of the envelope insulation upon overall building performance. It clearly has a beneficial effect in winter, but not always in summer. The main conclusions are as follows.

- When the gains (internal or solar) are not adequately controlled, there is a tendency towards more discomfort as the envelope insulation increases.
- If there is night ventilation, the building remains comfortable in a higher proportion of

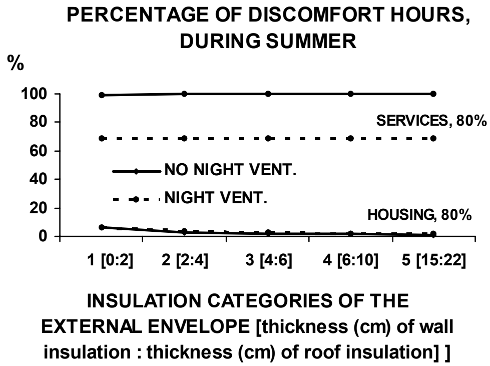


Figure 4: Behavior of Apartment A, used for housing and as an office, with and without night ventilation.

Table 4: Percentage of discomfort hours.

Difference between the highest and the lowest insulated envelopes (%)				
Shading percentage	No night vent. housing	No night vent. office	With night vent. housing	With night vent. office
0 (zero)	+1.4 (1)	0.0 (1)	+14.9	+1.5 (2)
80 %	-5.3	+0.9 (1)	-4.7	-0.6 (2)

(1) These values are low because the percentages of discomfort hours are equal or close to 100%.for all insulation levels
(2) These low values mean that there is little variation in discomfort levels as the insulation increases.

the time.

- In some cases, night ventilation can be high enough to practically eliminate the influence of the increase of insulation of the envelope.
- The level of envelope insulation should remain below the threshold that would lead to the probable installation of air-conditioning, to avoid increased investment and running costs.

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