A COMPUTATIONAL INQUIRY INTO THE EFFECTIVENESS OF PASSIVE COOLING MEASURES IN BUILDINGS

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ABSTRACT

This paper applies parametric simulation studies to examine the effectiveness of various passive cooling measures (external and internal shading, natural ventilation, phase change materials) toward the reduction of overheating magnitudes in buildings in the middle-European and Mediterranean context.

INTRODUCTION

Various factors have been contributing to a recent steady increase in buildings' demand for cooling energy:

i) Growing expectations in view of acceptable thermal conditions in indoor environments;

ii) Increased internal gains in highly equipped office buildings;

iii) Extensive use of glazing in building envelope design;

iv) Increasing availability of easy-to-install mechanical equipment for cooling;

v) The heat island effect in urban areas;

vi) A rise in mean outdoor temperatures in many parts of the world.

Given this context, it is both environmentally and economically meaningful to further develop and implement passive cooling technologies toward the reduction of buildings' demand for cooling energy (see, for example, Lain and Hensen 2006).

In the present paper we use parametric simulations to compute the relative impact of various passive technologies including shading (external, internal), natural ventilation, and phase change materials (PCM). Toward this end, we considered both residential and office building located in Vienna, Austria and in Athens, Greece.

APPROACH

The research design involved the following steps:

1. Buildings: We considered a number of buildings as described in the Table 1.
2. Shading options: The following shading options were considered: *i)* No shading; *ii)* Fixed overhang; *iii)* External shades; *iv)* Internal shades.
3. Ventilation options: A number of ventilation schedules were considered (with effective air change rates ranging from 1 to 10 h^{-1}).
4. PCM options: Two commercially available (organic) PCM products were considered with crystallization and melting points of 26/28 ^{o}C and 25/26 ^{o}C respectively. The PCM heat absorption effect was modeled in terms of a heat sink via the reduction of applicable internal load assumptions. Likewise, the PCM heat rejection effect was modeled in terms of internal heat increase. The heat absorption and rejection rates were derived based on manufacturers' product data concerning PCM cooling power.
5. Climate: Some buildings were simulated for Vienna climate, some for Athens climate, and some for both climates. For Athens, the overheating tendency was captured for 6 months (April to September). For Vienna, a period of 3 months (June to August) was considered for simulations. Note that, due to this difference in duration, the resulting simulated absolute values for overheating tendencies (see Figures 1 to 5) cannot be directly compared. This difference of duration also explains the higher absolute values of overheating indicator in case of buildings located in Vienna as compared to Athens. Thus, rather than comparing the absolute overheating values for the two locations, for each climate the relative reduction of overheating tendency due to the simulated alternative measures should be considered.
6. Software: The thermal simulation program CAPSOL (2002) was used. Weather data for simulations was generated using the application METEONORM (2005).
7. Results: The simulation results were expressed in terms of an overheating measure ($\Delta\theta_{m,OH}$) defined as the mean temperature difference between the indoor air temperature and a reference overheating threshold temperature (see Equation 1) over all time intervals within the observation period, in which the room

temperature was higher than the overheating reference temperature.

$$\Delta\theta_{m,OH} = \frac{\sum_{i=1}^{n}(\theta_{R,i} - \theta_{OH})}{n} \quad [K] \qquad \text{Eq. 1}$$

Whereby,

$\Delta\theta_{m,OH}$ Overheating in K

$\theta_{R,I}$ Hourly room air temperature at interval i

θ_{OH} Overheating reference temperature (26 °C for Vienna and 27 °C for Athens)

n Number of hourly intervals in the observation period.

Table 1
Summary information on the buildings considered for the parametric simulation studies

Building	Description
A	Apartment (net floor area = 100 m²) in the uppermost floor of a multi-storey building. Massive construction. Windows' orientations: south (living room, kitchen) and north (bedrooms).
B	Double-story single house (net floor area = 200 m²). Massive construction. The ratio of glazing area to net floor area = 26%
C	Apartment/Office unit (net floor area = 140 m²) in the uppermost floor of a multi-storey building. Mixture of massive and light-weight construction. The ratio of glazing area to net floor area = 40%
D	Modern office floor in a high rise building (net floor area = 980 m²). Mixture of massive and light-weight construction. The ratio of glazing area to net floor area = 55%

RESULTS

Given the space limitation, only a selected set of results can be presented in the present paper. Specifically, Figures 1 to 5 illustrate the computationally derived overheating values ($\Delta\theta_{m,OH}$ as per equation 1) for various buildings (A, B, C, and D as specified in Table 1), types (residential, office), climates (Athens, Vienna), and options pertaining to shading (internal, external, overhang), ventilation, (i.e. air change rates ranging from 1 to 10 h^{-1}) and PCM application.

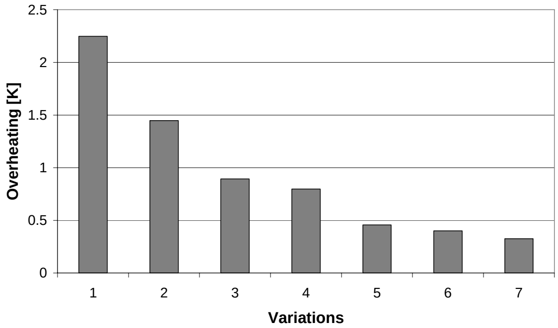

Figure 1 Overheating in building A (apartment, Athens, overheating threshold=27°C). 1: base case without shading, ACH=1h⁻¹; 2: Similar to 1, with internal shades; 3: Similar to 1, with exterior shades; 4: Similar to 1 with fixed overhang; 5: Similar to 4, ACH=5h⁻¹; 6: Similar to 4, ACH=10 h⁻¹; 7: Similar to 6 with PCM (26/28 °C)

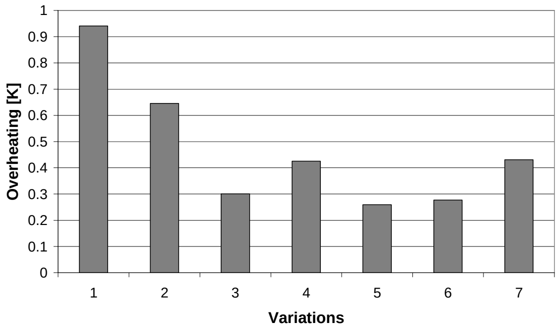

Figure 2 Overheating in building B (single house, Athens, overheating threshold=27°C). 1: base case without shading, ACH=1 h⁻¹; 2: Similar to 1, with internal shades; 3: Similar to 1, with exterior shades; 4: Similar to 1 with fixed overhang; 5: Similar to 4, ACH=5 h⁻¹; 6: Similar to 4, ACH=10 h⁻¹; 7: Simular to 6 with PCM (26/28 °C)

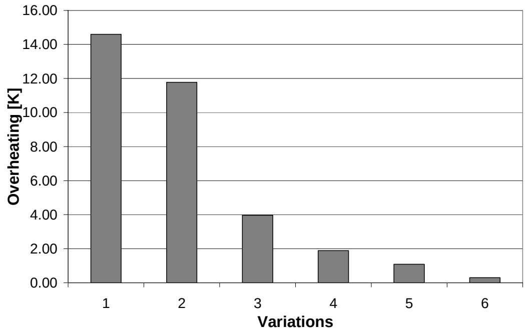

Figure 3 Overheating in building C (office use, Vienna, overheating threshold=26°C). 1: base case without shading, ACH=1 h⁻¹; 2: Similar to 1, with internal shades; 3: Similar to 1, with exterior shades; 4: Similar to 3, ACH=5 h⁻¹; 5: Similar to 3, ACH=10 h⁻¹; 6: Similar to 5 with PCM (25/26 °C)

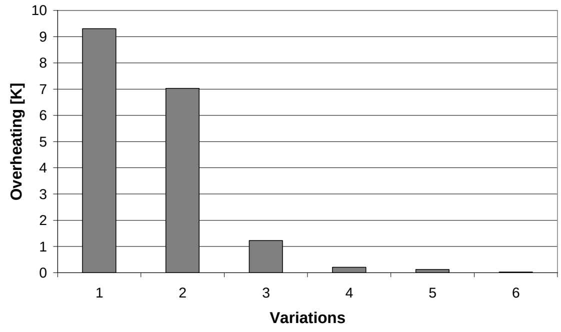

Figure 4 Overheating in building C (apartment, Vienna, overheating threshold=26°C). 1: base case without shading, ACH=1 h^{-1}; 2: Similar to 1, with internal shades; 3: Similar to 1, with exterior shades; 4: Similar to 3, ACH=5 h^{-1}; 5: Similar to 3, ACH=10 h^{-1}; 6: Similar to 5 with PCM (25/26°C)

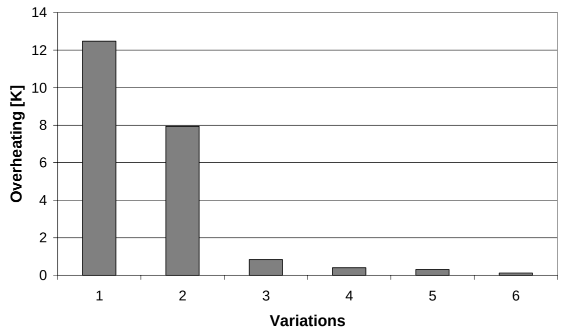

Figure 5 Overheating in building D (office use, Vienna, overheating threshold=26°C). 1: base case without shading, ACH=1 h^{-1}; 2: Similar to 1, with internal shades; 3:Similar to 1, with exterior shades; 4: Similar to 3, ACH=5 h^{-1}; 5:Similar to 3, ACH=10 h^{-1}; 6:Simular to 5 with PCM (25/26°C)

DISCUSSION

The simulation results warrant a number of conclusions. There are, of course, valid within the context of buildings, options, and climates considered in the underlying parametric simulations:

i) Shading appears to be the most effective measure toward reduction of overheating tendencies in the buildings studied. The kinds of internal shades applied in our simulations could reduce overheating somewhere from 20% to 35%. The application of external shades and overhangs resulted in a simulated reduction of overheating ranging between 55% and 90%.

ii) Natural ventilation (night-time cooling of the building mass via ventilation) can further reduce overheating. Taking the options with exterior shades as the reference, increasing the effective air change rates from 1 h^{-1} to 5 h^{-1} resulted in overheating reductions ranging from 15% to 80%. Given the relative high outdoor temperatures in Athens even during the night, a further increase in effective air change rate (up to 10 h^{-1}) was not found to be effective. The same measure was, however, somewhat more effective in Vienna.

iii) The application of the PCM solutions of the kind considered in our simulations did not prove to be effective in the context of Athens. This is again due in part to the high outdoor temperatures that are often above the comfort threshold temperature even during the night hours. Moreover, PCM application appears to be more effective in the case of light-weight buildings. The buildings considered in our parametric studies (particularly those simulated for Athens climate) could be classified as having rather high-mass constructions. PCM application was found to be more effective in the climatic context of Vienna. In this case, besides the construction mass issue, a better match between the PCM properties and the range of night-time outdoor air temperature was possible.

CONCLUSION

Passive cooling methods (particularly shading and night-time ventilation) can significantly contribute the reduction of overheating in buildings. According to the parametric simulation studies presented in this paper, a combination of external shading and natural ventilation (involving an effective air change rate of about 5 h-1) can reduce overheating around 70% to 80% in Athens and around 90% to 95% in Vienna. Significantly higher ventilation rates may not be feasible practically (e.g. due to draught risk and issues pertaining to storm safety) and can further reduce overheating only in climatic contexts where the external air temperature sinks over night well below the comfort temperature threshold. Likewise, the PCM potential toward overheating reduction appears to be rather limited and requires a good match between the comfort temperature requirements, material properties (i.e. melting and crystallization temperatures), and prevailing outdoor air temperatures during the night phase in the cooling period.

REFERENCES

Capsol 2002. Multi-zone transient heat transfer. Version 4.0w. URL: www.physibel.be

Lain, M. and Hensen, J. 2006. Passive and low energy cooling techniques in buildings. Proceedings of the 17th air-conditioning and ventilation conference. Prague, Czech Republic. ISBN 80-02-01811-7. pp. 183 – 188.

Meteonorm 2005. Global meteorological database. Version 5.1. URL: www.meteonorm.com.