Proceedings of CISBAT 2011

International Conference
14-16 September 2011, EPFL, Lausanne, Switzerland

CLEANTECH FOR SUSTAINABLE BUILDINGS –
FROM NANO TO URBAN SCALE

ISBN CD-version: 978-2-8399-0906-8
ISBN Print-version: Vol.I: 978-2-8399-0907-5 Vol.II: 978-2-8399-0918-1

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With the support of
Swiss Federal Office of Energy (SFOE)
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ACKNOWLEDGEMENTS

CISBAT 2011 would not have been possible without the efficient contribution of the secretariat of the Solar Energy and Building Physics Laboratory as well as that of our scientific and technical staff.

Our scientific partners from Cambridge University and the Massachusetts Institute of Technology as well as the members of the international scientific committee and the session chairs have enthusiastically supported the conference and ensured its quality. We would like to express our sincere thanks for the time and effort they have spent to make it a success.

CISBAT can only exist thanks to the financial support of the Swiss Federal Office of Energy. We are grateful for their continuing support.

We also owe sincere thanks to the two private sponsors of this edition, Bank Julius Baer and Energie Romande, whose support was vital for the conference. Through their presence, they have not only allowed us to extend the programme, but have also shown their commitment for a more sustainable built environment.

Finally, we cordially thank all speakers, authors and participants who have brought CISBAT 2011 to life.

Prof. Dr J.-L. Scartezzini

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THERMAL EVALUATION OF ENVELOPES OF NON AIR-CONDITIONED BUILDINGS

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ABSTRACT

Most of the studies on the thermal evaluation of building envelopes have been done for air-conditioned buildings. For that condition, the total energy per unit area consumed to maintain the indoor temperature constant at the comfort temperature is the evaluation parameter most used. In this study, three thermal performance indexes for building envelopes are proposed as parameters for their evaluation in non air-conditioned buildings. The envelope thermal performance index (ETPI), the hot thermal performance index (HTPI) and the cold thermal performance index (CTPI). The three indexes give a number from 0 to 100, a higher number means a better thermal performance. The ETPI is the average of HTPI and CTPI. HTPI quantify the ability of the envelope to avoid overheating and CTPI to avoid overcooling, both with respect to a comfort temperature. A one dimensional heat transfer model for periodic outdoor conditions for a typical day of a month is used to simulate heat transfer through the envelope. The effect of solar radiation, convection and infrared emission on the outdoor envelope surface is included via the sol-air temperature and the outdoor film heat transfer coefficient. The indoor film heat transfer coefficient is used to account for the effect of radiative and convective heat transfer on the indoor envelope surface. Four monolayered and three multilayered envelopes are tested. The four monolayered envelopes are made of high density concrete (HDC), aerated concrete (AeC), expanded polystyrene foam (EPS), and zinc (Zinc). The multilayered envelopes are made of HDC and of EPS, with different locations of the EPS: in the exterior side, in the middle, and in the interior side. The envelope performance of air-conditioned buildings is also evaluated using the total energy per unit area.

INTRODUCTION

Walls and roofs of the building envelope play an important role in the heat transfer between the exterior and interior of the building. From the thermal point of view a good wall/roof keeps the interior temperature as close as possible to the comfort temperature without the use of an air-conditioning system or minimizes the energy consumption if an air-conditioning system is used.

For air-conditioned buildings (A/C), parameters such as the total energy per unit area or the decrement factor with the time lag have been used to evaluate an envelope wall/roof [1], the decrement factor with the time lag has also been used to evaluate envelopes in non-air conditioned buildings (nA/C). In a previous work, the authors have used the decrement factor to evaluate six roof configurations in non-air conditioned buildings [2].

In this work, thermal indexes to evaluate the thermal performance of a wall/roof are proposed for nA/C. These indexes are used to evaluate the performance of seven roofs, these roofs are also evaluated in A/C buildings using the total energy as the performance parameter.

MODEL

The heat transfer equation through a roof/wall composed by N layers of different materials, with a total width L, is [3]

$$\frac{\partial T_j}{\partial t} - \alpha_j \frac{\partial^2 T_j}{\partial x^2} = 0 \tag{1}$$

This equation describes the temperature inside the *j*th layer, *Tj* as a function of time and position *x*. The coefficient α_j is the thermal diffusivity of the corresponding material. Given energy conservation, between layers the following condition must be satisfied

$$-k_j \left.\frac{dT}{dx}\right|_{j,j+1} = -k_{j+1} \left.\frac{dT}{dx}\right|_{j,j+1} \tag{2}$$

and in the exterior and interior surfaces

$$-k_1 \left.\frac{dT}{dx}\right|_{wo} = ho(To - Two) \qquad -k_N \left.\frac{dT}{dx}\right|_{wi} = hi(Twi - Ti) \tag{3}$$

where k_1 and k_N are the thermal conductivity of the first and last layer (from exterior to interior), and h_o and h_i are the film heat transfer coefficients for the exterior and interior, respectively. T_o and T_i are the outside and indoor air temperatures T_{wo} and T_{wi} are the surface wall temperatures at the outside and inside side of the wall/roof.

When simulating an air-conditioned room (A/C), the indoor temperature is kept constant and known. For non air-conditioned rooms (nA/C), the indoor temperature is assumed to be only a function of the heat transfer through the wall [3]

$$d\rho_a c_a \left(\frac{\partial Ti}{\partial t}\right) = hi(Ti - Twi) \tag{4}$$

where ρ_a and c_a are the density and specific heat of the air, *d* is a distance where the heat transfer is assumed to be zero.

ENVELOPE THERMAL PERFORMANCE INDEXES

The proposed indexes qualify the thermal performance of an envelope wall/roof. The indexes are scaled with the worst configuration. The indexes have values from 0 to 100 and the wall/roof is better as the value approaches to 100.

The hot thermal performance index (HTPI) evaluates the ability of the wall/roof to avoid overheating respect to the comfort temperature and is scaled with the maximum possible overheating, given by the sol-air temperature considering an absorptivity equal one. It is defined as

$$HTPI = \left[1 - \frac{\sum_j (Ti_j - Tc)}{\sum_j (Tsa(1)_j - Tc)}\right] \times 100 \tag{5}$$

such as $Ti_j > Tc$ and $Tsa(1)_j > Tc$. Where *Tsa(1)* is the sol-air temperature [1] for an absorptivity *a=1* and *Tc* is the comfort temperature [5]. The subindex *j* indicates the discretization of time.

The cold thermal performance index (CTPI) evaluates the ability of the wall/roof to avoid overcooling respect to the comfort temperature and is scaled with the maximum possible overcooling, given by the sol-air-temperature considering an absorptivity equal zero. Thus, it is given as

$$CTPI = \left[1 - \frac{\sum_j (Tc - Ti_j)}{\sum_j (Tc - Tsa(0)_j)} \right] \times 100 \qquad (6)$$

such as $Ti_j < Tc$ and $Tsa(0) < Tc$.

The envelope thermal performance index (ETPI) is defined as the average of the hot thermal performance index and the cold thermal performance index,

$$ETPI = \frac{HTPI + CTPI}{2} \quad . \qquad (7)$$

RESULTS

For all simulations the outdoor temperature was calculated using the equation proposed by Chow and Levermore [6], the solar radiation was approximated by a sinusoidal with the day duration according to the place and the month. The weather data needed to calculate the ambient temperature correspond to Torreon, Mexico, for the month of June. Roofs are evaluated considering $d=2.5m$ and the values for the film coefficients for the exterior and interior are ho=13W/m^2 ^{o}C y hi=6.6W/m^2 ^{o}C.

Seven roof configurations were chosen to prove the utility of the indexes. The configurations are described in Table 1 and all of them are evaluated considering A/C and nA/C rooms. The properties of the materials used are presented in Table 2. In all roofs the absorptivity was $a=0.2$ but for Zinc a$=0.8$, also all roofs have a total thickness of 0.10m, but Zinc is 0.01m. The first six configurations are the same than the ones used in [2].

EPS	Expanded Polystyrene Foam 0.10 m
AeC	Aereated Concrete 0.10 m
HDC	High Density Concrete 0.10 m
EPS_ext	EPS 0.02m + HDC 0.10 m
EPS_int	HDC 0.08 m + EPS 0.02 m
EPS_mid	HDC 0.04 m + EPS 0.02 m + HDC 0.04 m
Zinc	Zinc 0.01m

Table 1: Configurations described from the outside to inside.

Material	k [W/m^oC]	ρ [kg/m^3]	c [J/kg^oC]
AeC	0.12	550	1004
HDC	2.00	2400	1000
EPS	0.04	15	1400
Zinc	110	7130	390

Table 2: Properties of the materials, k thermal conductivity, xxx density and xxx specific heat.

The total energy per unit area used in A/C buildings for the seven configurations is presented in Figure 1. The EPS is the best configuration, followed by the EPS_ext. In this case, the roof made of Zinc is the configuration that has the largest energy consumption, almost 32 times more than the EPS, and the HDC is the second worst, using more than 6 times the energy needed by the EPS.

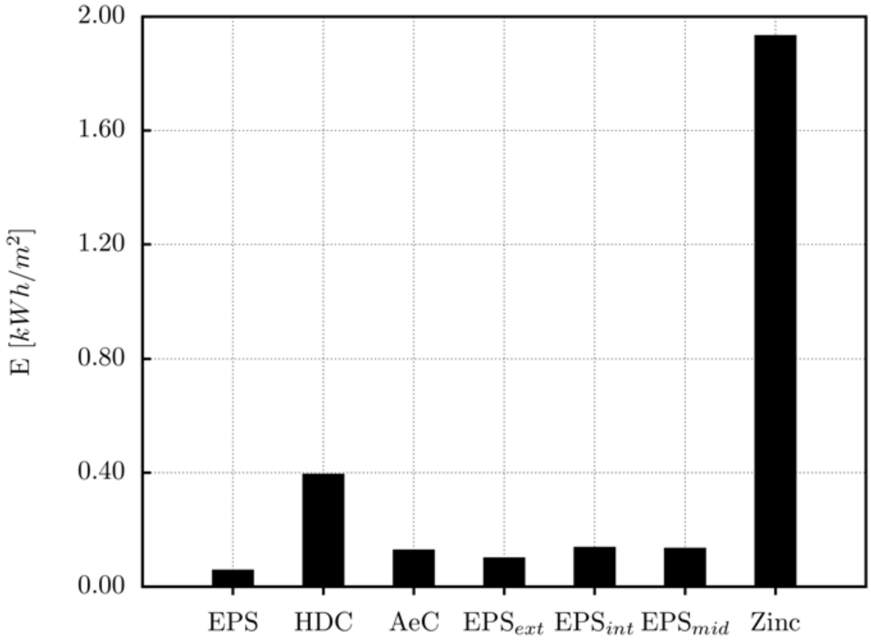

Figure 1: Energy per unit area used in A/C buildings .

In Figure 2, the three indexes are presented (CTPI, HTPI and ETPI) for the seven configurations in nA/C buildings. The best configuration according to the ETPI is EPS_ext (94), followed by EPS_mid (91), AeC (79), HDC (77), EPS_int (74), EPS (65), and Zinc (32). The HTPI and CTPI give the same order. This order is the same as obtained using the decrement factor as the parameter [2]. The Zinc was not considered in that work.

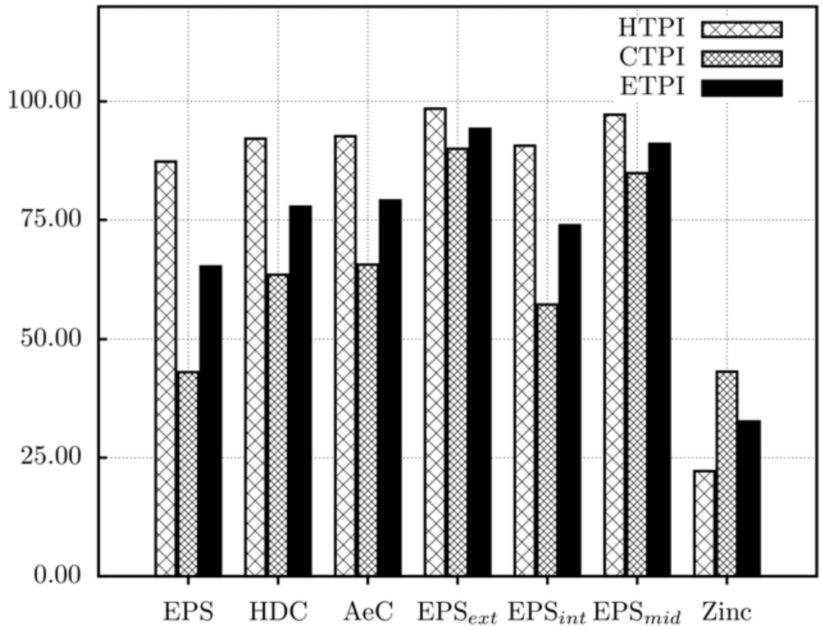

Figure 2: Thermal performance indexes for the six configurations.

CONCLUSIONS

The main conclusion of this work is that the use of the envelope thermal performance index (ETPI), as a parameter to evaluate the thermal performance of an envelope wall/roof in non air conditioned buildings orders the configurations in the same way than the decrement factor. The advantage of the ETPI is that it gives a grade ranging from 0 to 100, which is simpler to interpret than the value of the decrement factor. The results show that the best envelope for air-conditioned buildings (EPS) can be not suitable for non air-conditioned buildings.

ACKNOWLEDGEMENTS

Partial economic support from CONACYT and from CONACYT-SENER 118665 projects is acknowledged.

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