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Prof. A. Sayigh,
P. O. Box 362,
Brighton, BN2 1YH, U.K.
Tel. +44 (0)1273 625643
Fax +44 (0)1273 625768
E-mail: asayigh@netcomuk.co.uk

The use of transparent insulating materials in low energy consumption buildings, through the study of thermal and optical behaviour

Vito Baiamonte [a], Angelo Milone [a], Daniele Milone [a], Salvatore Pitruzzella [b]

[a] Dipartimento di Ricerche Energetiche ed Ambientali, Università di Palermo.
[b] Short term contract professor -. Facoltà di Architettura. Università di Palermo.

ABSTRACT - This article discusses the use of innovative transparent materials in residential buildings with low energetic consumption and describes a simulation of their performance during winter. The behaviour of these materials was studied both from a thermic point of view and from the point of view of the quality of daylight illumination

To simulate the behaviour of these materials, we used different forecasting software to measure and, at the same time, analyse their luminosity, their thermal characteristics and the resulting energy saving.

The results show a considerable saving in energy even in terms of the greater economic investment needed for the installation of these innovative surfaces. Results regarding drops in external temperature were also interesting, especially when the extra sunlight provided by these materials was considered. Another important aspect was the undeniable effects of low thermal dispersion guaranteed by the materials in question. The evaluation of the luminous microclimate, obtained thanks to a more efficient distribution of natural illumination, was also positive, as was that regarding thermal comfort created by the maximum exploitation of the material's thermophysical and spectrometric characteristics.

1. INTRODUCTION

The study of the energy and optical properties of transparent insulating materials is an integral part of the complex problem of energy saving in buildings.

There are two main aspects concerning the use of such materials in low energy consumption buildings.

The first regards their ability to let light pass into the building, thus ensuring good illumination during the day.

The second concerns their capacity to provide thermal insulation that is as effective as that offered by opaque walls.

This second aspect also requires that the materials in question admit solar radiation so as to heat the building for several hours during the day without, however, causing significant thermal dispersion during the colder hours [1] .

Other, more specific uses of these materials concern their implementation in museums.

In this context, they would provide excellent illumination (even in the presence of strong direct sunlight) that would be evenly distributed over all the exhibits, thus ensuring optimal vision even when natural illumination is less than perfect [2].

Transparent insulating materials can generally be divided into two types: Capillary and Honeycomb.

The section of the components of the latter types may be square, rectangular or hexagonal while the former types are circular.

The images 1,2 and 3 show the renders of a TIM Honeycomb with a hexagonal section crowned with two sheets of glass placed in a thermal aluminium frame.

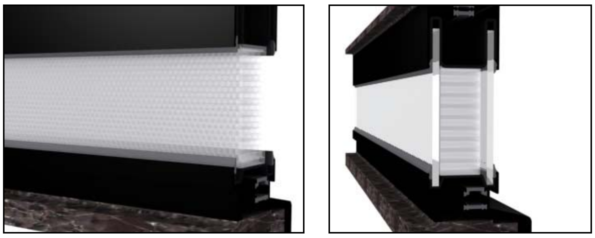

Figure 1 and 2. Side views of a TIM

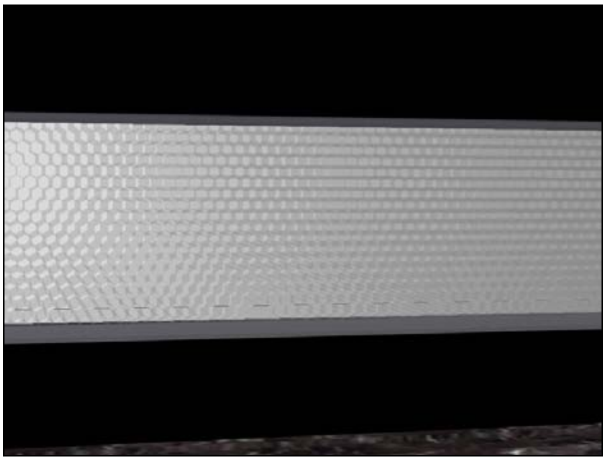

Figure 3. Frontal view of a TIM

The present article presents an experimental study focusing on the substitution of traditional materials, such as glass, with transparent insulating materials (TIM) in a low energy consumption building.

The study used a Honeycomb TIM and dealt with its use in the colder months of the winter, during which solar radiation is used both for heating and lighting.

The type of TIM in question is certainly the best in terms of insulation, thanks to the combination of high solar radiation transmittance and good thermal inertia.

Transparent insulation materials prevent loss of heat caused by convection.

At the same time the transmittance of solar radiation is very high due to the fact that reflections are channelled inwards through the capillaries [3],[4].

2. ENERGY SAVING

The calculation of the quantity of energy saved was made through a simulation of a hypothetical three-floor terraced house situated in different areas characterised by differing climactic conditions.

The calculations aimed to demonstrate the usefulness of the materials in question when utilized in present construction practices, by simulating the substitution of traditional fittings with the aforementioned TIM materials.

2.2 Experimental methodology

The study was carried out on the middle floor of a three-floor house, shown in figure 4, with a heated surface area of 105 m^2.

The internal temperature was fixed at 20°C during the day and 16°C during the night (from 11pm to 6 am).

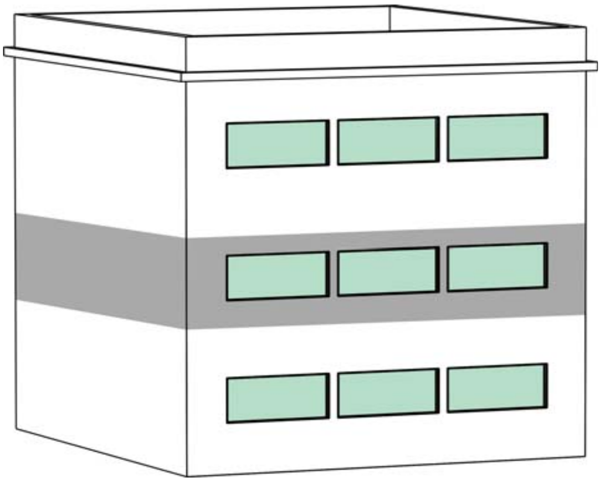

Figure 4. The model of the building for the simulation with the experimental roof .

Ventilation values were fixed at 0.7 changes of air per hour.

On the floor in question there were 6 windows, each with a surface area of (2*1,25)= 2,5 m^2, and equally distributed on two walls: one north-facing and one south-facing.

Five different cases were assumed for the substitution of glass with innovative transparent materials and the following scenarios were developed:

- Case A: the basic case study used to compare the other, improved situations. In this case all the windows (15 m^2) were of the traditional air-space type, Simple Glass-Air-Simple Glass;
- Case B: the substitution of one traditional glass window (2.5 m^2) on the north side with a TIM of an equal surface area;
- Case C: the substitution of two traditional glass windows (5.0 m^2) (one on the north

side and one on the south side) with a TIM of an equal surface area;

- Case D: the substitution of three traditional glass windows (7.5 m^2) with a TIM of an equal surface area, 5.0 m^2 of which on the north side and 2.5 m^2 on the south side;
- Case E: the substitution of 10 m^2 of traditional glass windows with a TIM of an equal surface area, 5.0 m^2 of which on the north side and 5.0 m^2 on the south side.

Later, with the aim of obtaining more significant and extensible results, a simulation using the calculation program TRNSYS® 16 (Transient System Simulation Program) [5] was carried out for three cities with considerably different climactic characteristics: Palermo, Rome and Milan.

Table 1 shows the climactic data of the three cities, while table 2 shows the characteristics of the three main types of layers used in building [6], [7].

For the TIM it was assumed that the frames of the aluminium fittings had an effect of 10%.

Table 1. Climactic characteristics of the three cities

City	**Climatic zone**	**Deg. day**	**Heating on period**	**Hours of heating**
Palermo	B	751	1/11-15/4	8
Rome	D	1415	15/10-15/4	12
Milan	E	2404	1/12-15/4	14

Table 2. Thermophysical characteristics of layers

Layer	**Dimensions (mm)**	**U (W/m^{2}K)**
SG-AIR-SG	6-12-6	2,73
SG-TIM-SG	2-50-2	1,51
BR-AIR-BR	12-10-8	0,81

2.3 Results

Figure 5 shows the heating demand for the three climactic types, having proposed the maximum value as being Δt (Palermo 15°C, Roma 20°C, Milano 25°C), and assuming a stationary rate.

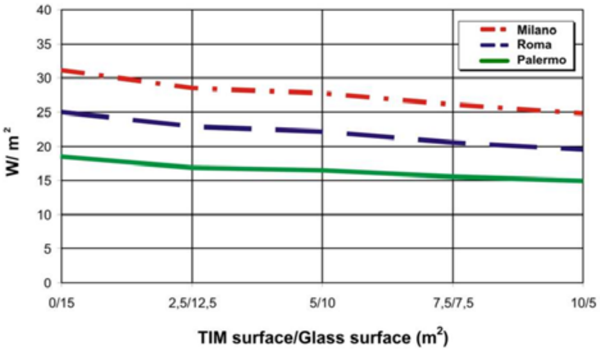

Figure 5. Heating demand (W/m^2)

An examination of this figure demonstrates an energy reduction of 22% when four windows were substituted in climactic zone B (from 18.59 W/m^2 to 14.9 W/m^2).

This value is slightly lower (20%) in climactic zone E (from 31.1 W/m^2 to 24.9 W/m^2).

Another interesting aspect is that when the fitting on the north side was substituted, the relative reduction in percent (9%) is greater than that recorded when the south-facing fitting was substituted.

Figure 6 shows the variable state simulation, which takes the recovery of heat from the sun's rays into account.

This is in relation to the length and period for which the heating system was in use.

It is evident that the greatest reduction (40%) is always in climactic zone B (from 13.38 KWh/m^2 to 8.2 KWh/m^2), while the absolute value for the reduction in climactic zone E is 20 KWh/m^2, passing from 74.36 KWh/m^2 to 54.6 KWh/m^2.

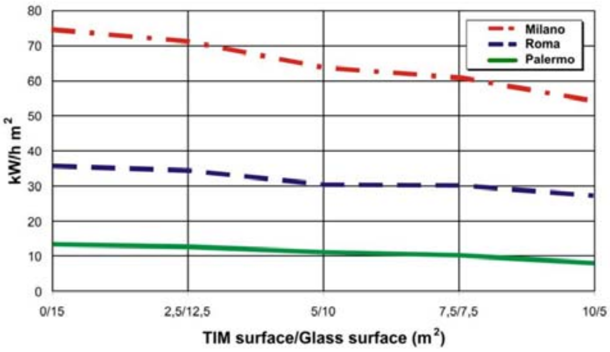

Figure 6. Heating demand (KWh/ m^2)

3. NATURAL ILLUMINATION

3.1 Methodology

To study the luminous behaviour of these materials, simulation software with the Radiosity algorithm was used [8]. Two cases were assumed for a window: one with traditional clear double-glazing and one using a TIM.

The model shows the spectrophotometric characteristics of the two materials [9] as well as the physical characteristics of the environment. It is well known that the distribution of natural light in an environment depends, above all, on the angle of incidence of the sun.

To study this phenomenon using the transparent insulating materials (TIM) employed in the present study, different angles of incidence were taken into account. The results were compared with those for traditional glass.

Figure 7 schematises the process of vision through a TIM system.

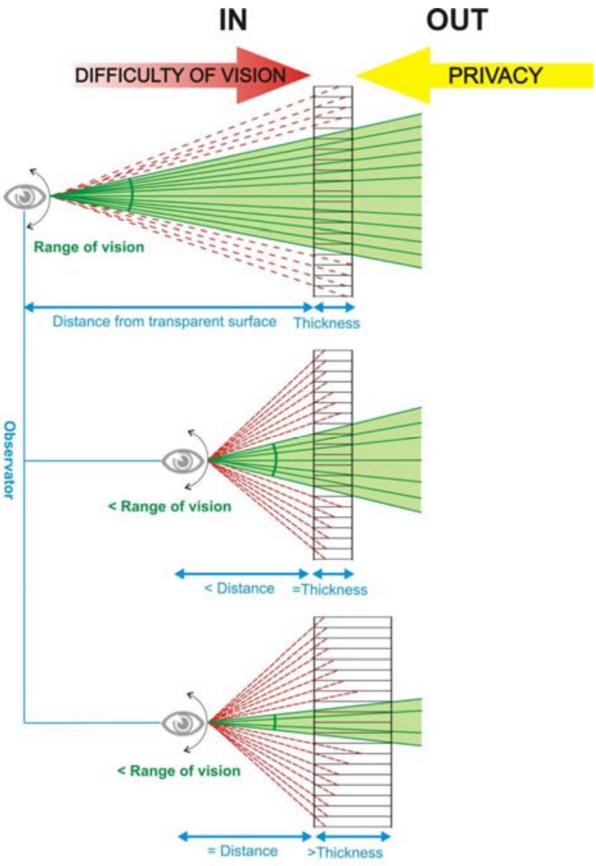

Figure 7. A synthesis of the principle of vision from the exterior towards the interior.

3.2 Results

The day chosen for this simulation was the 22nd December, the winter solstice, when the sun is at its lowest declination.

Figure 8 and 9 they show the studied model with the course of the sun from start of simulation (09.00 am) to end (12.00 am) [10].

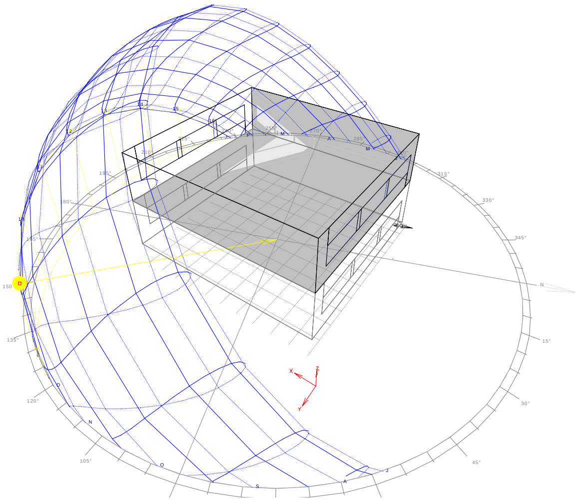

Figure 8. Solar trace at 09.00 am of 22nd December

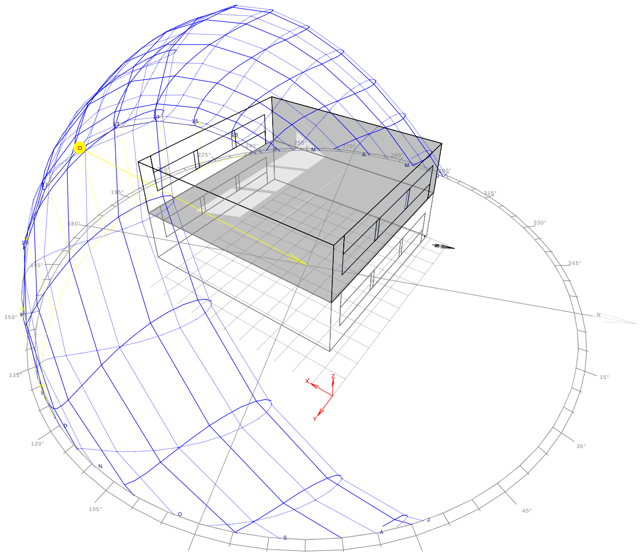

Figure 9. Solar trace at 12.00 pm of 22nd December

Figures 10 and 11 show the simulations before and after the glass was substituted.

The simulation carried out at different times of the day (shown in figure 11 – a, b, c, d) and shows how the distribution of light is significantly better when TIM are used trough valuation of luminance levels [11].

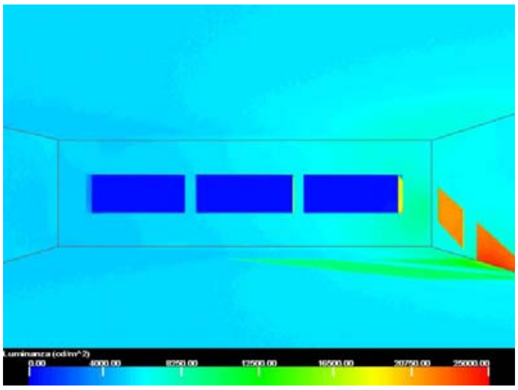

Figure 10a. 9.00 am

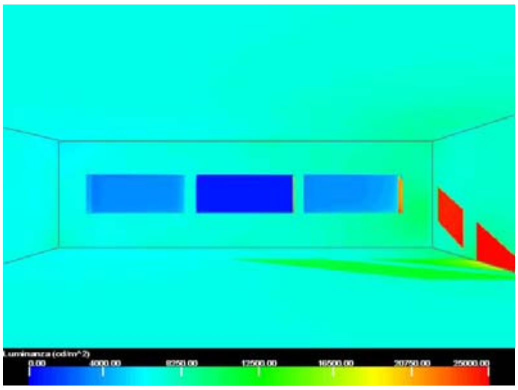

Figure 11a. 9.00 am

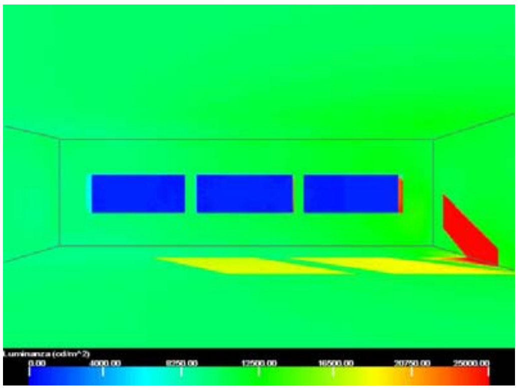

Figure 10b. 10.00 am

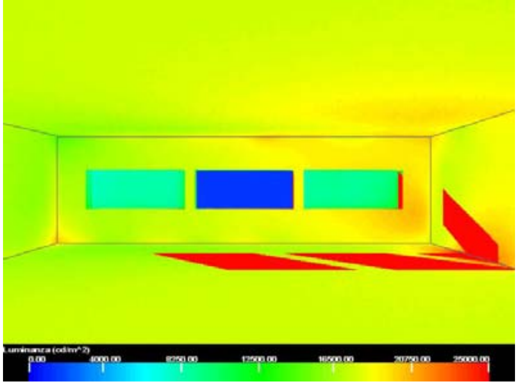

Figure 11b. 10.00 am

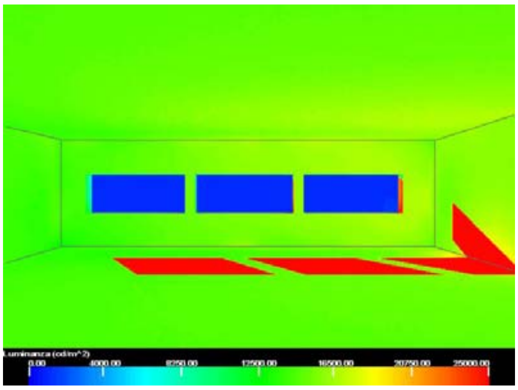

Figure 10c. 11.00 am

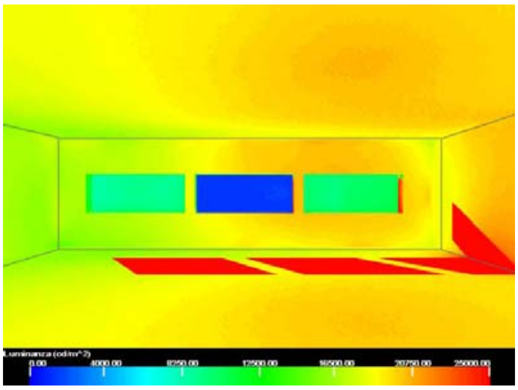

Figure 11c. 11.00 am

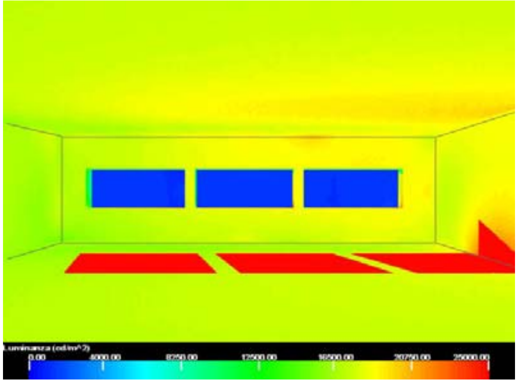

Figure 10d. 12.00 am

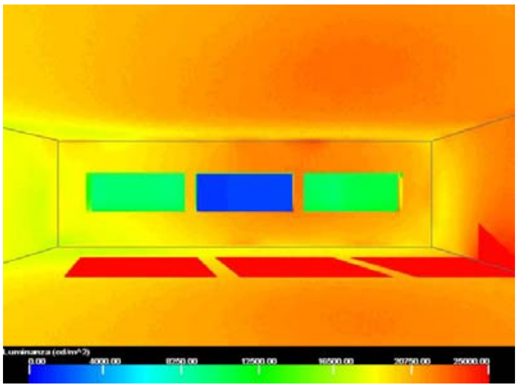

Figure 11d. 12.00 am

Figure 10 (a-d) and 11 (a-d). Luminance of simulated room with three window with traditional glass (fig.10) and two Two lateral window with TIM and central with traditional glass (fig. 11).

4. CONCLUSIONS

As has been demonstrated, the use of innovative materials such a TIM can significantly reduce heating requirements. This is particularly true for colder climates.

It has also been shown that the use of these materials does not affect illumination of the environments in question during the day, even if, in the present study, a traditional window was always retained.

It is possible to affirm, therefore, that against a reduction of light transmission equal to 25%, there is an improvement of 40% in the request for energy for heating.

The use of innovative windows rather than traditional ones, characterized by the same internal and external sheet but with an air cavity, is, at present, more common in the cold climates of north Europe. It is to be hoped, however, that they can also be used in the colder areas of Italy.

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