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The Use of Test Rooms to Determine the Thermal Performance of a Transparently Insulated Opaque Wall

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A side by side comparison between a test room equipped with an opaque wall clad with a proprietary polycarbonate, honeycomb transparent insulation material (TIM) and a reference room is described. The measured data are analysed in terms of straight forward comparisons between the energy consumptions of wall heat fluxes in the two rooms. The results are parameterized by a steady state specific heat loss (U-value: air to air) and a solar collection efficiency (ε) for the wall. Using these values the performance is extrapolated to a whole year under U.K. climate.

INTRODUCTION

THIS paper outlines the use of two test rooms at the ETSU/EMC (Energy Technology Support Unit/Energy Monitoring Company) test facility to assess the winter-time thermal performance of a polycarbonate honeycomb TIM clad opaque wall under U.K. climate.

TIM has many uses, e.g. coverings for opaque walls, glazing units and solar collector covers. The test described here is for the first area of application where the short wavelength transmission of the material allows solar energy to be absorbed by the opaque surface of the building. The insulating properties of the material then reduce the amount of this energy lost by reradiation and convection.

Tests of the properties and performance of building materials can range from laboratory measurements through to demonstration projects which measure the performance of real buildings. Laboratory tests allow extremely accurate estimates of materials and components properties to be made but the results may not be representative of the performance of a component under real conditions. This problem is likely to be particularly acute for TIM where:

—the complex dependence of shortwave transmission on angle of incidence makes performance under real diffuse skies difficult to estimate and
—the dependence of thermal properties upon temperature makes the material heat loss highly dependent upon operating conditions.

Trials with real buildings overcome these difficulties, however the results may be subject to large uncertainties. These are due to the fact that:

—disturbances such as the behaviour of the building occupants are difficult to disaggregate and
—the building will not have been designed to accentuate the performance of the component.

Purpose designed test rooms provide a middle path between the artificiality of laboratory tests and the uncertainty associated with measurements in real buildings. They allow tests to be performed under real conditions, under real climate and with realistic operating schedules. However the test room internal environment is tightly controlled, highly instrumented and monitored, and lacks the disturbances due to occupants. Furthermore the building can be designed to accentuate the performance of the component under test. Thus good estimates of component performance can be obtained.

The test described here is a side-by-side trial using a pair of matched, south-facing test rooms. One was fitted with a transparently insulated wall, the other with a reference wall with thermal performance comparable to that required by the 1990 U.K. Building Regulations, i.e. a *U*-value of 0.45 W/m^2K as normally required for walls used for both domestic and commercial applications. Data has been analysed in comparative and absolute terms.

In testing the TIM as a component of an insulated opaque wall, a philosophy was adopted whereby the material would demonstrate its best performance in this application. This philosophy ran throughout the test:

—the two walls were mounted on the south facing facades of the test rooms which are sited in an area with no overshadowing from trees or other buildings
—testing was performed using a heater schedule which would allow maximum utilization of the solar radiation captured by the TIM.

TEST ROOM CONFIGURATION AND MATCHING

Details of the test room construction are given in [1]. Both test rooms were fitted with a high-density concrete

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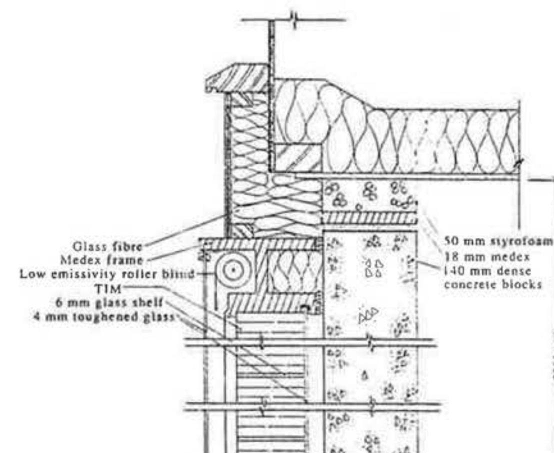

Fig. 1. Vertical section through TIM wall.

block wall as the south facing element. The walls were allowed to dry out for three months during the U.K. summer to avoid problems associated with condensation. To avoid significant edge effect problems, the block walls were entirely surrounded by a supporting frame of insulation. Construction details of the TIM wall are shown in Fig. 1 and those for the reference wall in Fig. 2.

The instrumentation at the test site is fully described

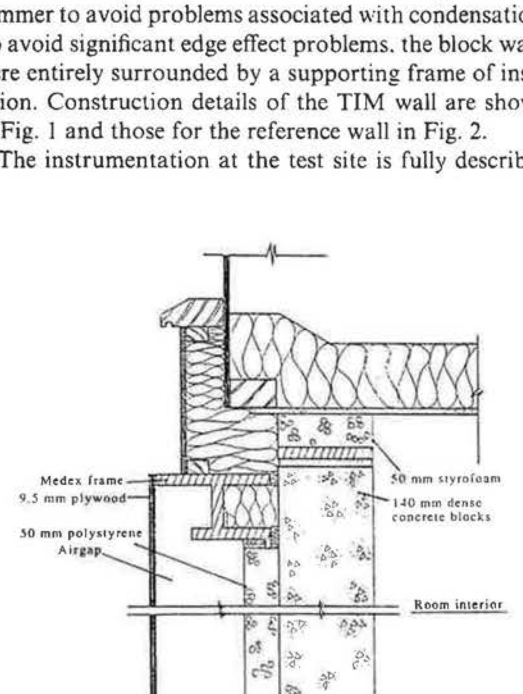

Fig. 2. Vertical section through reference wall.

in [1]. The instrumentation used for the test described in this paper consisted of:

—5 air temperatures
—10 surface temperatures
—a black globe temperature
—heat flux mats on the inner and outer faces of each test wall and
—electrical power meters.

Further information on the construction of the walls and the instrumentation is given in [2].

An important aspect of the study was to establish that the test rooms were matched, i.e. that they have very similar thermal performance characteristics. Establishing that the rooms were matched would dispel certain doubts which could be raised concerning the validity of the data interpretation. The matching experiment, performed prior to the installation of the TIM, followed the procedure which is detailed in [3].

Matching was performed over a 10 day period. A heater schedule was used which maintained the test rooms at 25°C between 18:00 and 06:00 hours the following day. Throughout daylight hours the room temperatures were allowed to float. During the time that the rooms were under thermostatic control, the difference in room temperatures was minimal. This indicated that the two control systems, operated independently of the data acquisition system, were closely matched. The cooling rates of the test rooms were very similar during the daytime. Analysis demonstrated that the thermal performance of the rooms differed by less than 2% [2].

PERFORMING THE TEST

As described earlier, the underlying philosophy of the test was to assess the likely maximum energy benefit that TIM could provide by selecting operating conditions which were favourable to the TIM component. As part of this philosophy, a realistic definition of performance was selected which centred on the amount of auxiliary energy saved. For a room that is heated to a predefined setpoint, any energy delivered by the TIM clad wall will make a useful contribution to the wall's performance provided that the energy:

—arrives at a time of day that there is an energy demand, and
—is not so plentiful that the building is overheated, i.e. the setpoint is exceeded.

To maximize the utilization of energy delivered by the TIM wall it was necessary to satisfy both of these criteria. The first was readily accomplished by using a 24 hour/day setpoint.

The second is related to the building heat load and the area of TIM installed. If the heat load is low at the setpoint, then the auxiliary energy demand will quickly be reduced to zero by energy supplied from the TIM wall. Overheating could easily occur. If however the heat load is high then all the energy supplied by the TIM wall will be useful. Similar arguments follow for selecting the area of TIM to install on a building—the more that there is, the greater the potential for overheating.

The test rooms have a realistic heat loss. It would have

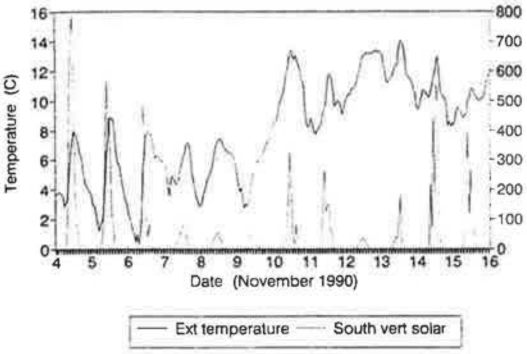

Fig. 3. Test site climatic data during the test.

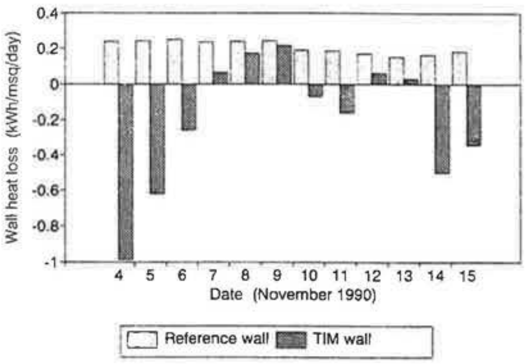

Fig. 5. Daily heat flux through the test walls.

been unrealistic to degrade the construction. In order to maximize the sensitivity of the test and hence the quality of the results, it was considered desirable to install as large an area of TIM as possible. Therefore the course of action followed was to use a setpoint of 25°C which would avoid overheating implying full utilization of TIM gains.

As shown in Fig. 1, the TIM wall incorporated a low emissivity roller blind which in the summer would assist in preventing overheating and in the winter, and for this experiment, reduces heat losses. An operating strategy was used which:

—lowered the blind when $s < 5$ W/m^2 and
—raised it when $s > 10$ W/m^2

where s was the solar radiation level measured in the plane of the component. The strategy essentially kept the blind open during the daytime when solar gains were available and closed at night.

RESULTS ANALYSIS

Testing began early in November 1990 and lasted for 12 days. This period contained both dull and bright days. Figure 3 shows the solar radiation on the component and the corresponding external air temperature. When compared to mean solar radiation data [4], the mean solar radiation level was considered reasonable for the time of year.

Figure 4 shows the energy consumption in the two rooms. The TIM room consistently used less energy than the other room, however, the difference is small on days with low insolation. Figure 5 shows the integrated daily heat flux at the internal surface of each of the test walls per unit area. Table 1 summarizes the total energy consumption of the two rooms and the heat flux of the two test walls.

In the following analysis, heat flux measurements were used to determine thermal performance. Wall surface heat flux is assumed to be a linear function of the temperature drop across the wall and the level of incident solar radiation, S (kWh/m^2/day). The surface heat flux over a time interval I (in this case 24 hours) is given by

$$F(I) = (T_i(I) - T_e(I)) - \varepsilon S(I) \quad (1)$$

where, $F(I)$ is the heat flux per unit area out of the room at the internal surface of the test wall; $T_i(I)$ is the test room internal temperature; $T_e(I)$ is the external temperature; and ε is the efficiency with which the solar radiation is transferred to the room.

A plot of $F/(T_i - T_e)$ against $S/(T_i - T_e)$ should be a straight line with a slope equal to minus the solar collection efficiency and an intercept equal to the wall U-value. A plot of the analysis is shown in Fig. 6 for both walls. A summary of the analysis is given in Table 2. The quoted error bars include both random and systematic components.

The results demonstrated that the reference wall did not achieve the standard set by the 1990 U.K. Building Regulations. This was as expected from a U-value calculation considering the construction materials: The thickness of insulation used was constrained to that which was readily available and was thinner than required. The wall's solar collection efficiency was negligible.

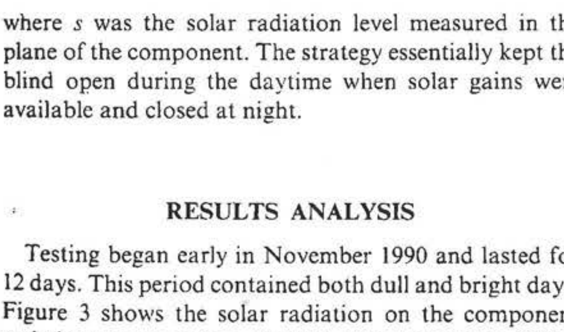

Fig. 4. Test room daily energy consumptions.

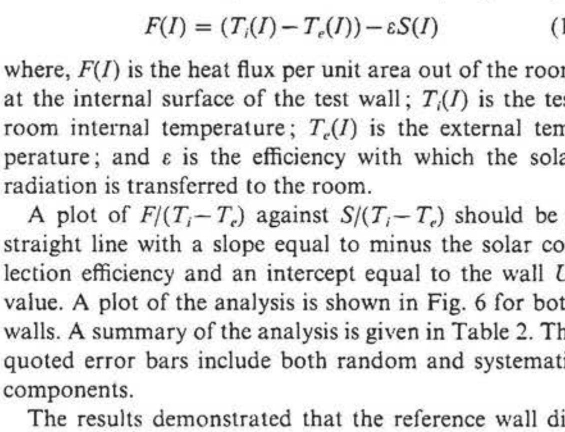

Fig. 6. Determination of wall U-value and solar collection efficiency.

Table 1. Test room energy consumption and wall heat flux over the 12 day test

	Energy consumption (kWh)	Wall heat flux (kWh)
Room with reference wall	41.3	6.6
Room with TIM wall	29.5	−4.7

Table 2. *U*-value and solar collection efficiency of the walls

	U-value (W/m^2K)	Collection efficiency
Reference wall	0.54 ± 0.03	0.01 ± 0.01
TIM wall	0.54 ± 0.16	0.40 ± 0.04

The TIM wall also had a *U*-value which did not comply with the current U.K. Building Regulations although in this case the uncertainty in the result prevents firm conclusions being drawn. For the TIM wall the solar collection efficiency is 40%.

EXTRAPOLATING PERFORMANCE TO U.K. ANNUAL CLIMATE

The results of the test relate to a short period. A more desirable result would be the approximation of the annual performance of the component. Testing could be performed over an entire year, however, this would prove costly in both time and money. A method for resolving this exists whereby an extrapolation is performed using one of the sources of long term climatic data [4, 5, 6]. Data from [4] was used here. Whilst the method is somewhat crude it does serve to give an approximation of the likely thermal performance that can be expected over a year. Indeed this method may in fact treat the TIM wall favourably: The low sun-angle during the test period, resulting in lower transmission losses when compared to summer sun angles, was used for the entire annual extrapolation. It is anticipated that the angle of incidence will affect the solar collection efficiency: A higher efficiency is likely for the winter months.

For the following assessment the performance of the TIM clad wall was compared to a 'traditional' wall with a *U*-value of 0.45 W/m^2K, i.e. one satisfying the 1990 U.K. Building Regulations. This philosophy was adopted as TIM is likely to be used in place of an alternative viable strategy. A mean internal temperature of 20°C was assumed to be maintained for 24 hours. Results were obtained for a site in London and one in Glasgow to determine the sensitivity to geographic location.

$$\text{Reference Wall heat loss } (kWh/m^2) = 0.45 \times (20 - T_e) \times 24 \times D/1000 \quad (2)$$

where D is the number of days in the month.

$$\text{TIM Wall heat loss } (kWh/m^2) = 0.54 \times (20 - T_e) \times 24 \times D/1000 - [0.4 \times S \times D] \quad (3)$$

Table 3 shows a sample calculation of TIM benefit using meteorological data for London.

In evaluating the performance of the TIM component it was assumed that the wall was south facing, not obstructed and was used on a building that was heated 24 hours/day to the setpoint. Heat gains from the TIM will be useful when a heat load is placed on the building. In this study, which seeks only to determine sensitivities and the likely magnitude of energy savings that could be expected, the CIBS Building Code definition of heating season was used [7]. This defines the heating season for London as being 210 days (October to April). The TIM benefit associated with this period is 132 kWh/m^2.

For Glasgow if the same heating season is used the TIM benefit is 121 kWh/m^2. However if the 12°C criterion of [5] is used, which assumes that a heating load is incurred when external ambient temperature falls to 12°C or lower, then the benefit is 155 kWh/m^2. Clearly the energy benefit is highly sensitive to the length of the heating season which is itself a function of building design and building use, geographic location, and, in the case of a TIM clad wall, a function of the installed area.

Table 3. Calculation of TIM benefit for a London site

Month	Mean temp. °C	Solar radiation $kWh/m^2/day$	Ref wall heat loss kWh/m^2	TIM wall heat loss kWh/m^2	TIM benefit kWh/m^2
January	4.2	0.89	5.3	−4.7	10.0
February	4.5	1.55	4.7	−11.7	16.4
March	6.6	2.22	4.5	−22.1	26.6
April	9.5	2.36	3.4	−24.2	27.6
May	12.6	2.58	2.5	−29.0	31.5
June	15.9	2.73	1.3	−31.2	32.5
July	17.5	2.57	0.8	−30.9	31.7
August	17.1	2.62	1.0	−31.3	32.3
September	14.9	2.61	1.7	−29.3	31.0
October	11.6	2.05	2.8	−22.0	24.9
November	7.5	1.43	4.1	−12.3	16.4
December	5.3	0.90	4.9	−5.3	10.2

CONCLUSION

A pair of matched test rooms have been used to compare the thermal performance of a TIM clad opaque wall to the performance of a more traditionally constructed wall satisfying the U.K. 1990 Building Regulations.

Test site data has been gathered which permitted the TIM wall to be characterized in terms of a U-value (0.54 W/m^2K) and a solar collection efficiency (40%). Thermal performance has been extrapolated to a full U.K. heating season for sites in London and Glasgow.

The analysis was performed assuming:

—the building was orientated due south
—the south facade was not overshadowed
—a long heating season
—all energy made available by the TIM wall was useful during this period.

Of all the assumptions made the analysis is most sensitive to the length of the heating season.

Further work is in progress that will parameterize the thermal performance of TIM clad opaque walls for use with a detailed thermal simulation model. The study will also develop guidelines for design advice on such issues as orientation and sizing.

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