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Transparent insulation in practice: results from the new passive solar student residences in Glasgow

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ABSTRACT

The passive solar student residences at the University of Strathclyde, in Glasgow, with 1000m^2 of transparently insulated facade, have now been occupied for 18 months, including one full heating season. As yet the solar facade is not complete , with the low emissivity, reflective, roller blinds still being installed.

Performance of the TIM wall is discussed, indicating a long term negative effective U-value, Ueff = -0.07 Wm^{-2}K^{-1}, an un-illuminated U-value of 0.68 Wm^{-2}K^{-1} and solar collection effciency of 29%. Total annual energy consumption is compared to conventional Scottish halls of residence.

INTRODUCTION

The passive solar residences, housing 376 students at the University of Strathclyde in Glasgow, incorporate 1000m^2 of transparently insulated facade into a low energy building envelope [1,2]. The residences have been occupied since November 1989. The TIM facade was originally installed without the active shading system and is still incomplete, with the low emissivity, reflective, roller blind systems currently being commissioned.

The residences consist of four buildings, of five storeys each (see Fig 2), with flats shared between 4 or 8 students. A typical student bed-room layout is shown in Fig 3. The TIM facade has 100mm of polycarbonate honeycomb mounted between glass and a polycarbonate layer, in front of a mass wall of 150mm of high density concrete (Fig 4). There is air-to-air heat recovery in the common areas and electric heaters for "boost" space heating.

Full scale monitoring, under the CEC, DGXVII Energy Demonstration Scheme, has been underway for more than 12 months and will continue until June 1992. Monitoring is carried out at two levels; intensely, within parts of one block, in order to collect high quality data on thermal performance and energy use; and less intensely, over the whole development, to determine overall consumption [3]. We present here only selected results from the data being generated and analysed.

TIM WALL PERFORMANCE

The performance of a TIM wall is dependent upon a number of thermal and optical properties, which characterise its ability to collect solar energy, to store it, to deliver heat to the building and to inhibit heat loss to the ambient. Research facilities, such as test cells, allow us to accurately characterise the properties of the TIM component. In conjunction with this, we also need to study the interaction with real, occupied, buildings to fully understand the behaviour of TIM.

In practice the TIM modifies the internal environment and hence some of the parameters that determine its performance, such as room temperature. The net TIM performance depends upon "fixed" factors, such as the ratio of TIM wall area to volume of heated space, and to "variable" factors, such as occupant behaviour. The result is a complex, dynamic system that is difficult to interpret.

Figure 5 shows heat flux at the internal (room) surface of the TIM wall over a period of days during which the room was both occupied and unoccupied. It can be seen that for some periods the wall provides a net gain (negative value) to the room, at others there is heat loss. Room and ambient air and TIM wall temperatures are shown along with incident global vertical insolation.

Effective U-Value

Traditional wall constructions are characterised by a single constant U-value. Heat loss is driven by two primary functions, the temperature difference across the wall and the wind velocity at the external surface. The heat flux through a TIM wall, however, is a complex function that also depends upon the solar flux at the absorber wall surface and non-linear, dynamic temperature gradients within the structure. As a result, a U-value determined by an equation such as (1) is time dependent. One value of U, which we call the effective U-value, Ueff, is a measure of the net heat transfer and is most meaningful when taken over a long period:

$$U_{eff} = \bar{q}_i/(\bar{T}_r - \bar{T}_a) \qquad (1)$$

U_{eff} is a useful indicator of long term net flux across the wall, a negative value indicating net gains to the interior. Table 1 shows a measured Ueff for the Strathclyde residences, calculated from readings taken over several months in the winter 90/91. It should be remembered that this value needs to be referenced against a conventional U value, (U_{ref} = UK building regulations) to get a measure of the net benefit. Whilst Ueff is useful as a long term indicator of net heat flow it tells us little about the mechanisms by which this is acheived.

Wall Performance Characterisation - Two Methods

[A] The performance of the TIM wall can be understood with reference to a simple heat balance model for the room as a node:

$$q_i = U_L\,(T_r - T_a) - e G_v + q_s \qquad (2)$$

If we plot $(q_i-q_s)/(T_r-T_a)$ vs $G_v/(T_r-T_a)$, and then draw a best fit line, Fig 6, the negative slope is the efficiency with which the solar energy is delivered to the interior, e, and the intercept equals the dark U-value, U_L. It is not possible, in the occupied building, to discount the effects of the mass storage element, as is possible in controlled test procedures. Results from Fig 6 indicate a dark U-value, $U_L = 0.68$ ($^+/_-$ 0.05) $Wm^{-2}K^{-1}$ and a collection efficiency $e = 29\%$($^+/_-$ 3%).

[B] Measurements of heat flux at the absorber surface can take the form of the Hottel-Whillier equation for solar collection, allowing us to characterise the wall elements between the ambient and the absorber:

$$q_{abs} = U_{TIM}\,(T_{abs} - T_a) - G_v(\tau\alpha)_e \qquad (3)$$

A plot of qabs/dT vs Gv/dT, see Fig 7, has the U-value of the absorber-TIM-cover glass as the intercept and the effective transmittance-absorptance product as the negative slope. From data for the facade with no roller blind present we find $U_{TIM} = 1.16$ ($^+/_-$ 0.05) $Wm^{-2}K^{-1}$ and $(\tau\alpha)_e = 0.56$ ($^+/_-$ 0.05).

Eqn (1)	$U_{eff} = -0.07 \pm 0.03\ W/m^{-2}K^{-1}$
Eqn (2)	$U_L = 0.68 \pm 0.05\ W/m^{-2}K^{-1}$ $e = 29\% \pm 3\%$
Eqn (3)	$U_{TIM} = 1.16 \pm 0.05\ W/m^{-2}K^{-1}$ $(\tau\alpha)_e = 0.56 \pm 0.05\ W/m^{-2}K^{-1}$
General:	$U_{ref} = 0.45\ W/m^{-2}K^{-1}$

TABLE 1: SUMMARY OF RESULTS FROM THE EQUATIONS

Factors Affecting Performance

The behaviour of the wall is modified by a number of factors that are hard to measure or model mathematically. From the room layout (Fig 3) we can see, for example, that there are shelves on the TIM wall, which will affect heat transfer between the wall and the room. The varied use of shelves by each resident adds further complication by making the effect unpredictable.
There has been some degradation of the TIM, in the form of black staining has taken place within the TIM honeycomb. This leads to a reduction in solar transmission. Experiments are underway to measure this effect and to establish the cause. This is of particular interest for the next generation of TIM walling which may need to be in the form of factory assembled modular units to avoid degradation.

OVERALL BUILDING ENERGY CONSUMPTION

The overall conventional energy consumption of the buildings has been metered, on a weekly basis, for one year. Figure 8 shows the total consumption per capita per month from March 1990 to 1991. The annual total has been compared with data from another new residence at Strathclyde and a traditional one in Edinburgh, see Table 2. This shows that the solar residences have the lowest per capita consumption. The Normalised Performance Indicator (NPI), a standard measure of building performance, which is adjusted,primarily to the floor area of the building, shows that the new conventional halls at Strathclyde consume less energy per square metre.

	GAS/kWh	ELECTRICITY/kWh	TOTAL/Kwh	NPI /(kWh/m2)
SOLAR RESIDENCES (GLASGOW)	2530	1877	4406	311
GARNET HALLS (GLASGOW)	4210	1028	5239	277
POLLOCK HALLS (EDINBURGH)	8009	1355	9364	467

TABLE 2: ANNUAL ENERGY CONSUMPTION COMPARISON

These figure are not an indication of comparitive heating costs as they contain both service and space heating demand. Note that in the "solar residences", gas provides domestic hot water (DHW) only and back-up heating is provided by electricity. In Garnet and Pollock Halls, gas provides space heating and DHW, with no electric heating. These results, of course, give no indication of the levels of service or comfort provided, or of the temperatures attained. We expect to conduct surveys to establish such factors

NOMENCLATURE

C_p	Heat capacity of mass wall, J kg^{-1} K^{-1}
G_v	Global vertical insolation, south facing, Wm^{-2}
q_i	Heat flux at inner surface of TIM mass wall, Wm^{-2}
q_{abs}	heat flow through absorber, Wm^{-2}
q_s	heat flux due to heat stored in mass wall, Wm^{-2}
T_a	External ambient air temperature, °C
T_{abs}	Absorber surface temperature, °C
T_i	Inner mass wall surface temperature, °C
T_r	Internal, room air temperature, °C
U_{eff}	Effective U-value, time averaged, Wm^{-2}K^{-1}
U_L	Overall heat loss coefficient, Wm^{-2}K^{-1}
U_{TIM}	Heat loss coefficient, absorber wall to ambient, Wm^{-2}K^{-1}
U_w	heat loss coefficient, room to absorber surface, Wm^{-2}K^{-1}
ε	Efficiency of delivery of solar energy to the room
ρ	Wall density, kg m^{-3}
$(\tau\alpha)_e$	effective transmittance-absorptance product for TIM absorber elements

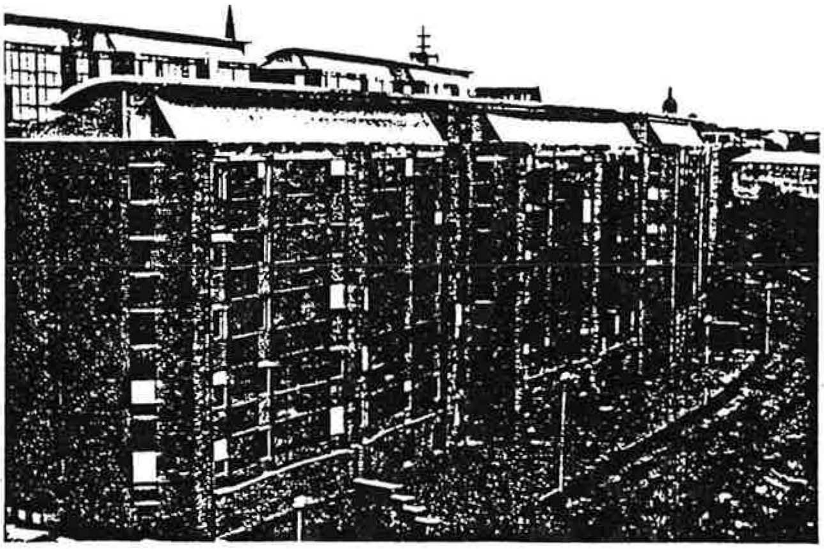
REFERENCES

[1] Forrest, R.J. Transparent Insulation - Student Residences in Glasgow, Proceedings of the Northsun 90 Conference, p72-, 1991

[2] Forrest, R.J., Stuart, C.F. and Twidell, J.W., Transparent Insulation - Student Residences in Glasgow, Northsun [illegible] Conference, to be published

[3] Forrest, R.J., Twidell, J.W. and Stuart, C.S., "Transparent Insulation - Preliminary Results from Monitoring the Passive Solar Student Residences at Strathclyde", Northsun 90 Conference, 1990

Fig.1



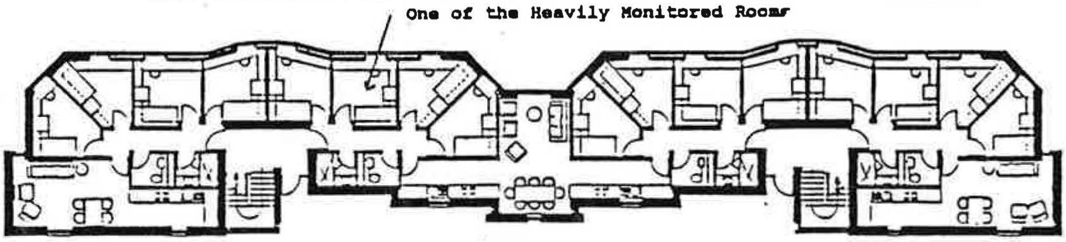
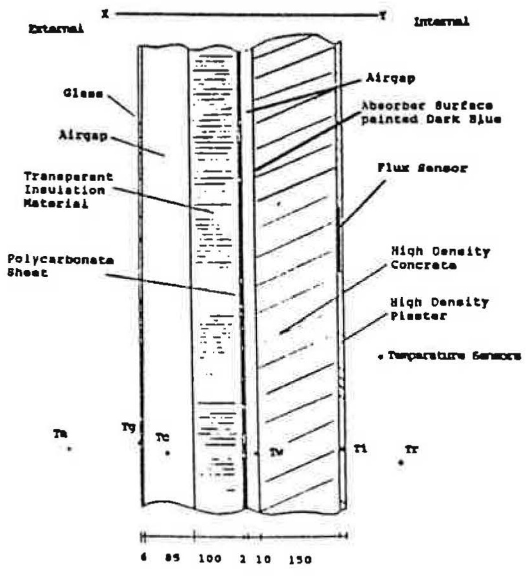


Fig.2 Floor Plan of one of four Buildings (each building has five storeys)

Fig.4 CROSS SECTION THROUGH TIM WALL



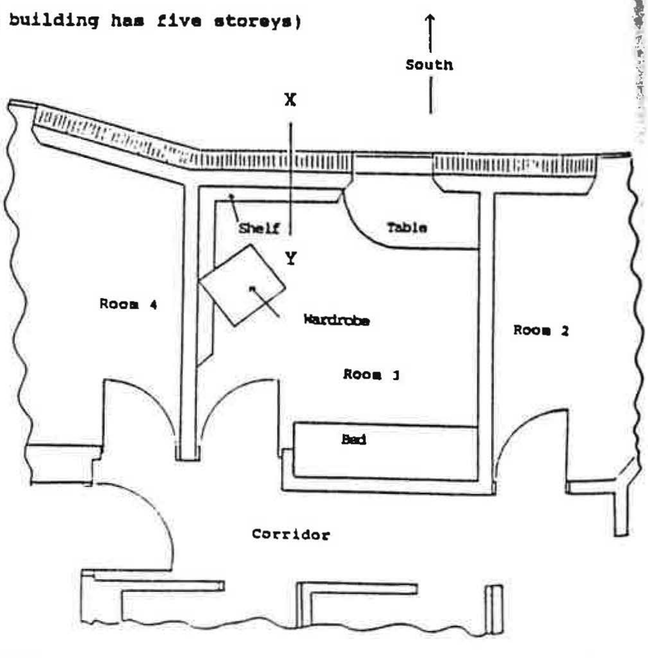


Fig.3 Floor Plan of Room 3 and Adjoining Rooms

Fig.5.A TEMPERATURES OF TYPICAL STUDENT ROOM

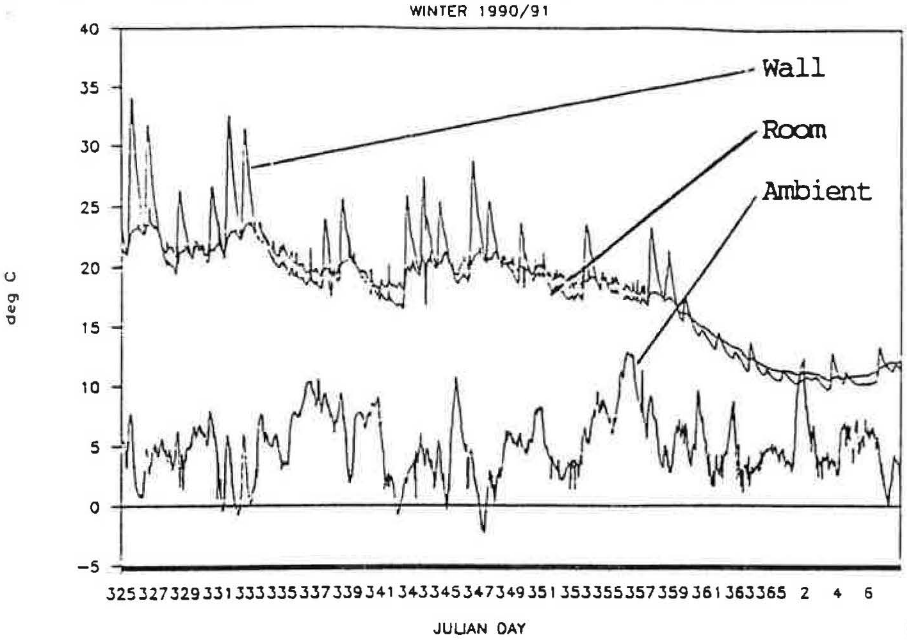


Fig.5.B Global Vertical Insolation

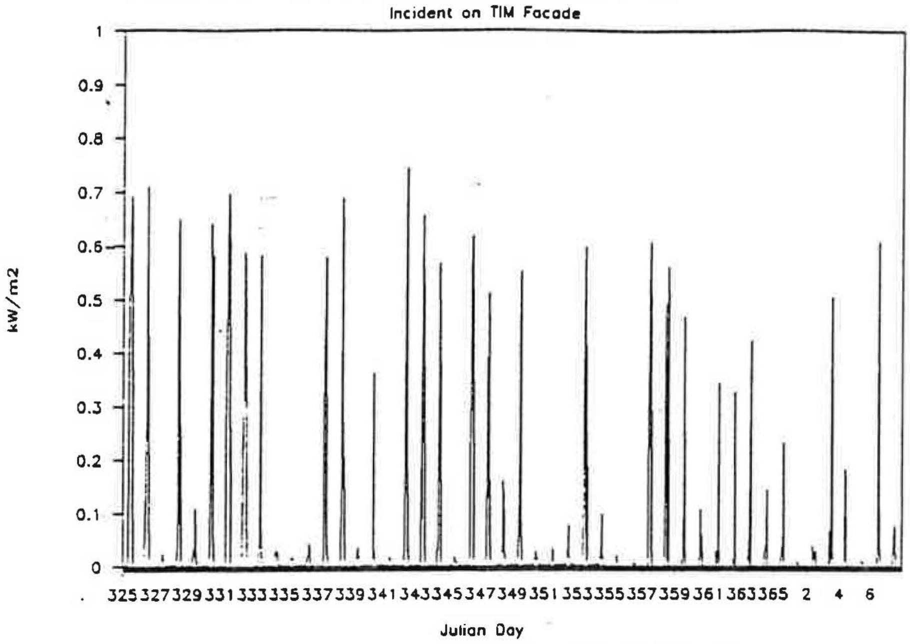


Fig.5.C Heat Flux at Inner TIM Wall Surface

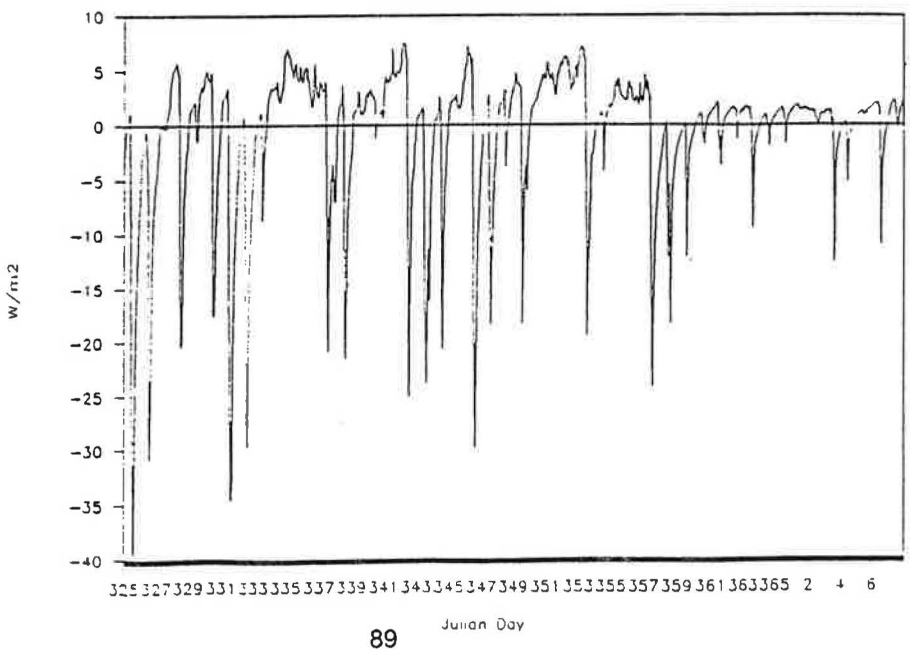


Fig.6 TIM WALL PERFORMANCE CHARACTERISATION

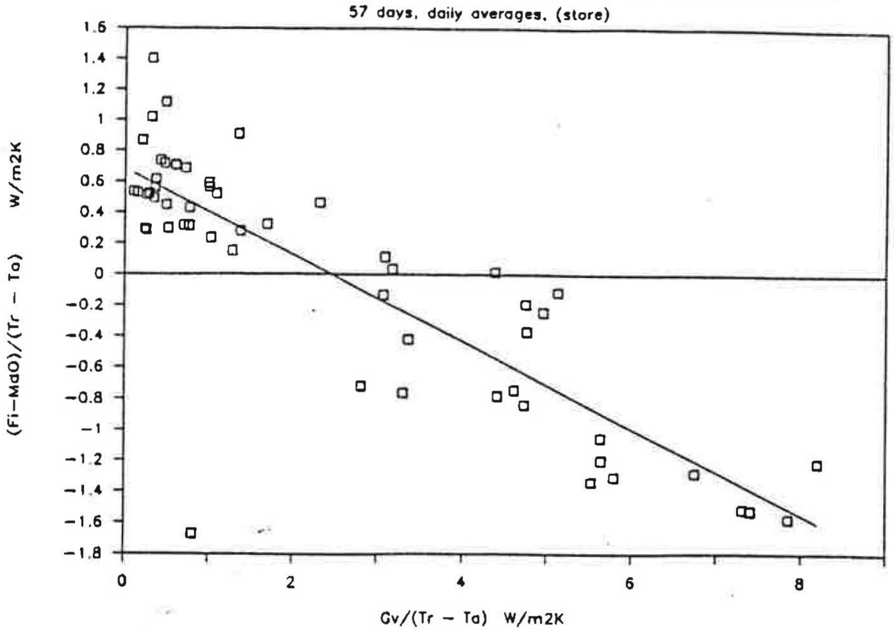


Fig.7 TIM-ABSORBER CHARACTERISATION

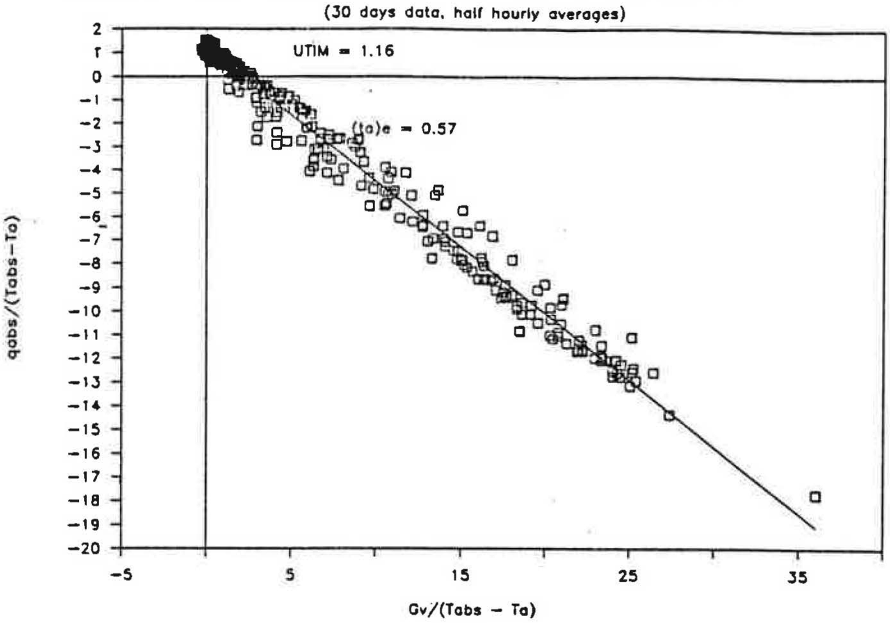


Fig.8 Electricity and Gas Consumption