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**Summary** This paper presents measured results from a 'superglazed' and an otherwise identical double-glazed house, and compares the monitored data with predictions from a dynamic hour-by-hour simulation model (SERI-RES) and a degree-day model (DESIGNER). The 'superglazing' has a measured $U$-value of $0.8 \pm 0.1\ \mathrm{W\,m^{-2}\,K^{-1}}$, and the double glazing of $2.8 \pm 0.1\ \mathrm{W\,m^{-2}\,K^{-1}}$. Five superglazed and three double-glazed houses at Milton Keynes were monitored for two years. SERI-RES was driven with weather data measured on site, and the observed schedules of casual gains. Agreement between measurements and predictions is very good over the whole heating season and fairly good on a month-by-month basis. Internal temperatures are underpredicted, and solar gains and building heat loss overpredicted, during the summer. In DESIGNER the weather conditions are represented as monitored degree-days. The annual consumption figures compare well with those measured; but there is little scope for examining the performance of each building component in relationship to energy use.

# Thermal simulation models: Comparison with monitored data for houses with large areas of advanced glazing

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## 1 Introduction

Comparison of monitored thermal performance data from a highly driven direct-gain passive solar house has been made with performance predictions from the SERI-RES V1.2[1] dynamic building simulation model, and the non-dynamic ENERGY DESIGNER[2,3].

The direct-gain house, built in 1985/86, is one of five superglazed dwellings at Faraday Drive, Milton Keynes, which formed part of the 1986 Energy World Exhibition[4]. Monitoring was supported by the European Commission Demonstration Programme and the UK Department of Energy[5]. Comprehensive details concerning the construction are available in the Final Report to the Commission[6] and a PhD thesis[7]. The superglazed houses are adjacent to three identical houses differing only by a reduced area of double glazing. Various papers have been published describing the design process and initial results[8]. Designs for the exhibition had to meet an energy cost index (ECI, defined below) of 120. DESIGNER calculations suggested that the superglazed houses would have an ECI of 72. This was not borne out in practice and comments are made about the ECI 'as built' and 'as designed'.

Figure 1 shows the particular superglazed house discussed in this paper. The design centred on the large areas of south glazing, providing extensive solar heating. The offsetting glazing heat loss was minimised by the use of several layers of glass with low-*e* coatings and inert gas fill. The architect Peter Clegg[9] successfully avoided the problems of privacy associated with large areas of unobstructed glazing by forming a private courtyard between each pair of houses and by placing the houses at right angles to the street (Figure 2). Heat recovery ventilation (HRV) was used to distribute the solar heated air, and modestly high levels of insulation reduced the overall winter loss coefficient, calculated using SERI-RES and including ventilation at $0.7\ \mathrm{ac\,h^{-1}}$, to $1.79\ \mathrm{W\,m^{-2}\,K^{-1}}$. (The measured value by regression of data over several months was $1.78 \pm 0.25$[7], and that by a coheating experiment was 1.67.)

The single-storey courtyard houses have floor areas of $144\ \mathrm{m^2}$ (including external walls) and were fitted with $27\ \mathrm{m^2}$ of superglazing or $15\ \mathrm{m^2}$ of double glazing (including frames). The overall heat loss coefficient of the double-glazed houses was $2.20\ \mathrm{W\,m^{-2}\,K^{-1}}$ (SERI-RES).

Comparisons between measured and predicted building performance can only be successful if the input data reflect the situation as it really existed. Hour-by-hour weather data recorded on site were used to drive SERI-RES. Great care was taken to assemble an accurate description of the building. Test room measurements on the glazing $U$-value and shading coefficient[10], and tracer gas measurements of infiltration rates were used as inputs to the model. Monitored data were used to simulate space heating and casual gain schedules.

The houses were monitored between 1987 and 1989 and comparisons between the superglazed version and the doubleglazed one are presented in Reference 6. One of the superglazed houses was monitored very intensively and is used in this presentation. The next section relates to comparisons between SERI-RES predictions and measured data and the third section relates to DESIGNER.

## 2 SERI-RES

A large number of data are entered to describe a building and the user has latitude over some issues. Section 2 examines some of these issues.

### 2.1 *Use of site weather data*

External air temperature, global horizontal and south vertical insolation, wind speed and wind direction were recorded hourly; however SERI-RES uses ambient air temperature, wind speed, direct normal and global horizontal insolations.

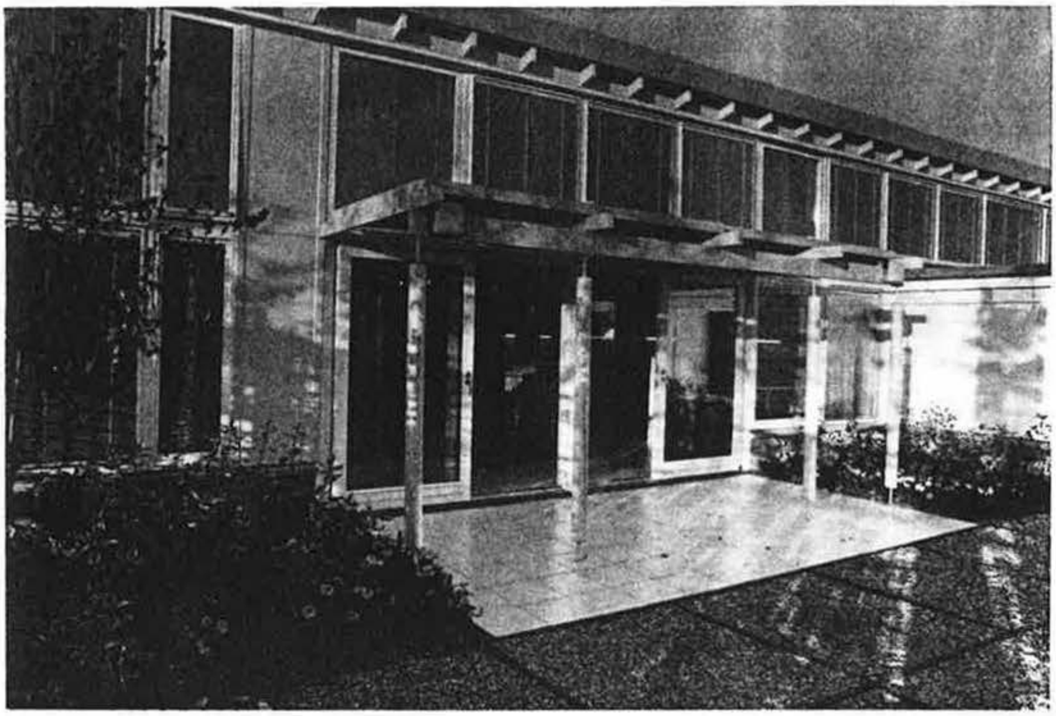

Figure 1 View of superglazed house from courtyard

SUNPATH[11] converts the measured solar data to the form required by SERI-RES, by using the inverse of the SERI-RES routine PSOLAR on the monitored global horizontal and south vertical insolations, to calculate direct normal radiation.

*2.2 Assembling an accurate building description file: Zones and heating*

The house is arranged as a passive solar 'living' zone and the more highly insulated and non-solar 'bedroom' zone. SERI-RES is a multi-zone model enabling the dwelling to be represented accurately in this respect. The zones have separate thermostats and timers to programme the heating demand periods. For example, the occupiers can heat the bedrooms to 19°C from 06.00 to 09.00 and 20.00 to 23.00, while the living zone may be heated to 20°C from 07.00 to 22.00. The system is responsive to solar and casual gains.

This arrangement can be modelled approximately in SERI-RES; a different heating regime (duration and temperature) can be scheduled for each zone but several problems arise:

- SERI-RES operates with environmental temperatures, whereas monitored room values are more nearly dry-bulb temperatures measured using thermistors in thermostat boxes. (Work with the simulation model Apache, on a different building, suggests that this is a significant problem.)
- Temperatures were logged at three points in the day zone (living room, kitchen-diner, and clerestory level) but in the bedroom zone, only one point was logged, in the main bedroom near the zone thermostat. Thermostatic radiator valves allow only the parts of the building in use to be fully heated; thus unoccupied bedrooms will be at reduced—and unknown—temperatures. The predicted heating loads will be those

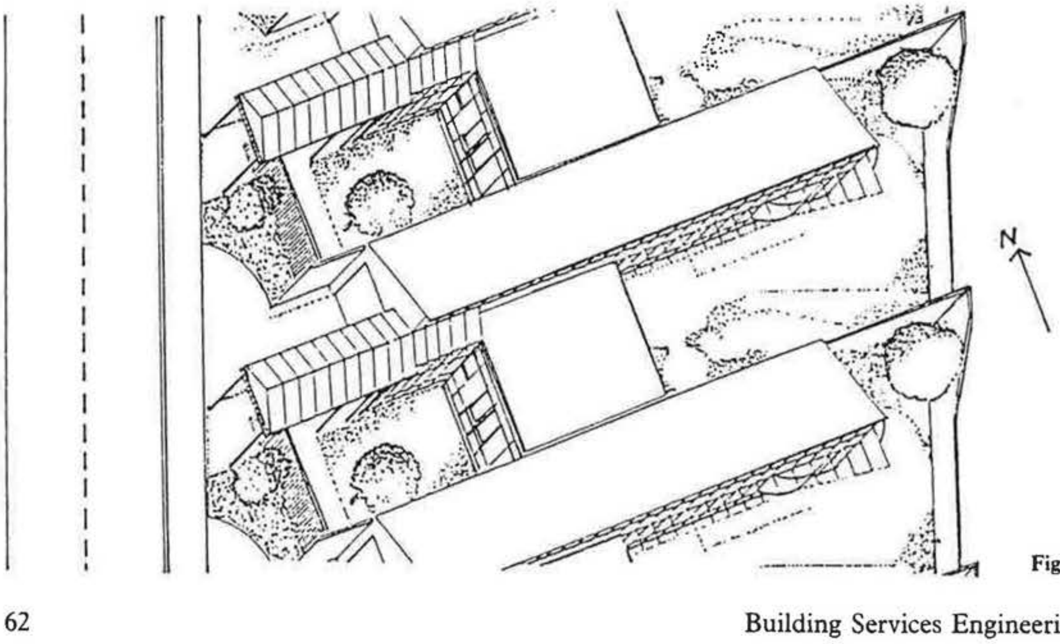


Figure 2 Privacy generated by layout

**Table 1** Casual gain calculation

| Mode of casual gain | Basis of calculation |
|---|---|
| Measured electricity use | 100% of electricity for appliances and lighting |
| Domestic hot water (DHW) | 35% of the DHW heating |
| Boiler casing loss | 5% of total boiler output for DHW and space heat |
| Occupants | 1.9 kWh/day per working couple |

required to heat the whole zone to the same temperature as the master bedroom.

- In the superglazed houses the HRV system can be used to transfer solar and casual gains in the living zone to the bedroom zone. Room-to-room air movement is not modelled accurately by SERI-RES, and since monitoring showed that the HRV was only used intermittently in the house under consideration, no allowance was made for interzone air flow.
- Version 1.2 of SERI-RES assumes that any heat loss from the house should be accounted for as long as the house is at $\leq 21°C$, but that heat loss is not useful when temperatures are $>21°C$. However, occupants may desire temperatures higher than 21°C, in which case the predicted loss will be less than that measured. In the present case the occupants very rarely set thermostats above 21°C.

### *2.3 Scheduling space heating*

Unfortunately many occupants use thermostats as on–off switches, and a proper representation of the temperatures achieved in a house would require hourly values of observed room temperatures, entered as schedules for the model to use as set points.

A year of hourly recorded room temperatures and heating demand data from the actual houses needs to be reduced for input to SERI-RES, since the number of schedules permitted, although large, is not large enough. To retain accuracy in predicting needs, this reduction process must result in a recognisable 'thumbnail sketch' of the detailed original. The hourly temperatures were split into monthly sections with each month represented by four schedules in total: weekdays and weekends for the living zone and a similar pair for the bedroom zone.

### *2.4 Casual gains*

Casual gains were also ascribed four schedules. For each month the gains were calculated as shown in Table 1. Occupancy pattern was estimated from the number of occupants, whether employed or not, and by interview.

### *2.5 Infiltration*

Infiltration varies with wind speed and direction, with inside/outside temperature difference and occupants' use of windows and doors. Such variations can be scheduled in SERI-RES. However, continuous measurements of infiltration rate were not made and the *short-term* variations are not known. $SF_6$ tracer gas decay measurements and blower door tests were made of the infiltration rate with all the windows and doors closed, and fireplace dampers shut. The superglazed houses were designed to be well sealed, but the background ventilation rate was 0.23 air changes per hour ($ac\,h^{-1}$), which compares badly with the value of $<0.05\ ac\,h^{-1}$ in the superinsulated houses monitored by PCL[12]. With the HRV turned on, the rate rises to $0.7\ ac\,h^{-1}$. The measured on/off times of the HRV were used to weight these values giving a mean value of $0.42\ ac\,h^{-1}$.

### *2.6 Walls*

The *U*-values calculated by SERI-RES are given in Table 2.

### *2.7 Ground floor heat loss*

Heat flow in SERI-RES can be coupled to ground, or to ambient via a thickness of earth representing a typical heat flow path length. Neither method accurately represents floor heat loss, where some heat flows to ground, some at the edges is to ambient via an unknown thickness of earth, and some is conducted laterally through the concrete floor slab to the adjacent walls, and then to ambient. (Ruyssevelt[12] comments on values of floor heat loss recorded in the PCL superinsulated houses.)

The complex issue of ground floor heat loss is modelled here by splitting the floor for each zone into sections:

- a middle section (where all heat flow is to ground via 1 m of earth);
- an edge section (made up of a 1 m wide band inside the external perimeter of the floor slab), where all heat flow is taken as being to ambient via 0.5 m of earth
- a subterranean wall section (where heat loss is to ambient via 0.1 m of earth).

**Table 2** *U*-values calculated by SERI-RES

| Building element | Construction | $U(W\,m^{-2}\,K^{-1})$ |
|---|---|---|
| Exterior walls | 100 mm ISOfoam or polystyrene insulation | 0.24 |
| Window frames | Timber | 1.20 |
| Roofs | 160 mm glass fibre insulation | 0.21 |
| Floor | Concrete floated on 100 mm polystyrene foam | 0.29 |

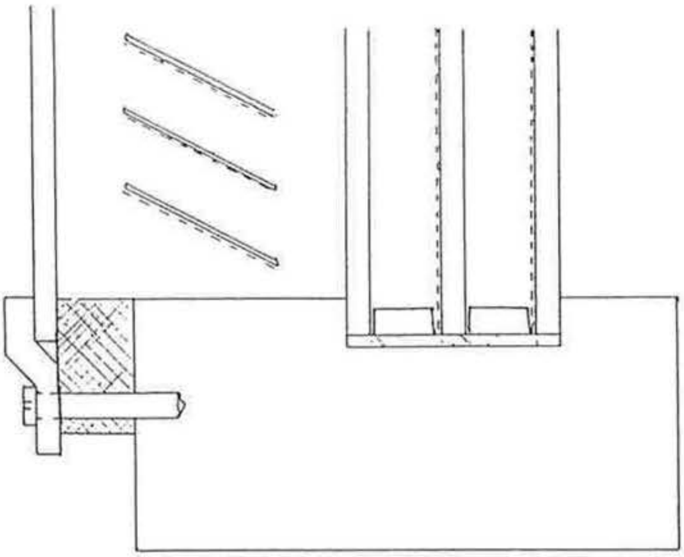

**Figure 3** Construction of superglazed windows comprising a sealed triple-glazed unit with two Interpane IPLUS Neutral soft low-*e* coatings and 12 mm cavities filled with argon gas, a low-*e* louvred blind and a fourth outer pane. All components are housed in a Nor-Dan timber frame.

The bedroom floor is sunk 300 mm below the living floor level to increase solar access to the living zone; this results in non-negligible heat loss through the bedroom zone wall below earth level. The ground temperature can be scheduled in SERI-RES, but as no underfloor ground temperature data are available for the site, the SERI-RES default value of 10°C was used.

### 2.8 *Windows, glazing and solar gains*

The fixed superglazing is made of four layers of glass, two with low-emissivity coatings. Two of the spaces were filled with inert gas (argon). Figure 3 illustrates the arrangement in a timber frame. Opening windows and sliding doors lacking the fourth appliqué pane on the outside. More details can be found in Reference 10.

Experimentally derived *U*-values and shading coefficients were used to model the glazing. Both parameters can be scheduled in SERI-RES to allow for insulating blinds and curtains, and for the seasonal changes which occur in shading coefficient due to high sun angles or blinds in summer. In the courtyard houses the bedrooms create a projection which shades the living room glazing at certain times of day, and the overshadowing routines in SERI-RES were used to model the loss of solar gain. Table 3 summarises the *U* and *UA* values for the house.

**Table 3** Fabric insulation and infiltration values

| Building element/ Parameter | Value |
|---|---|
| Walls | 0.24 W $m^{-2}$ $K^{-1}$ |
| Roofs | 0.21 W $m^{-2}$ $K^{-1}$ |
| Floor | 0.29 W $m^{-2}$ $K^{-1}$ |
| Glazing and frames | 1.1 W $m^{-2}$ $K^{-1}$ |
| Glazing shading coefficient | 0.48 |
| Mean infiltration | 0.45 ac $h^{-1}$ |

### 2.9 *Other inputs*

Several parameters, ground reflection, solar-to-air ratio and solar loss fraction, offer some problems to the SERI-RES user. Ground reflection was assumed to have the high value of 0.2, since the external courtyard near the glazing has reflective white ceramic tiles. The rest of the courtyard is covered in light gravel.

The solar loss represents the fraction of solar radiation in a zone which is reflected out through the windows. The fraction depends on room geometry, solar geometry, nature of internal surfaces and glazing area. The value suggested in the SERI-RES users' manual is 5%, but experimental work by the Energy Monitoring Company (EMC)[13] in passive solar test rooms, and modelling by P Haves[1], suggest that this is an underestimate for passive solar designs with large window areas. For an off-white room with mid-grey carpet and glazing area equal to 40% of the floor area a solar loss fraction of 15% is suggested by these authors. This configuration corresponds closely to the living zone of the superglazed house, and 15% was used in the simulation. For the bedroom zone with its small windows a value of 5% is used.

The solar-to-air ratio is the fraction of solar radiation absorbed by lightweight objects and thus immediately available to heat the room air. It was taken to be 0.2. EMC, in their test cell investigations into the SERI-RES input parameters, found that they could not estimate the solar-to-air ratio with any confidence, but did determine that the sensitivity of the model to this parameter was very low[14].

## 3 Monthly comparison of SERI-RES predictions with monitored data

In this section, SERI-RES predictions are compared with measured values of:

- heating demand
- room temperatures
- effective solar aperture
- building heat loss.

Figure 4 shows the monthly comparison between SERI-RES predicted space heating and the measured space heating.

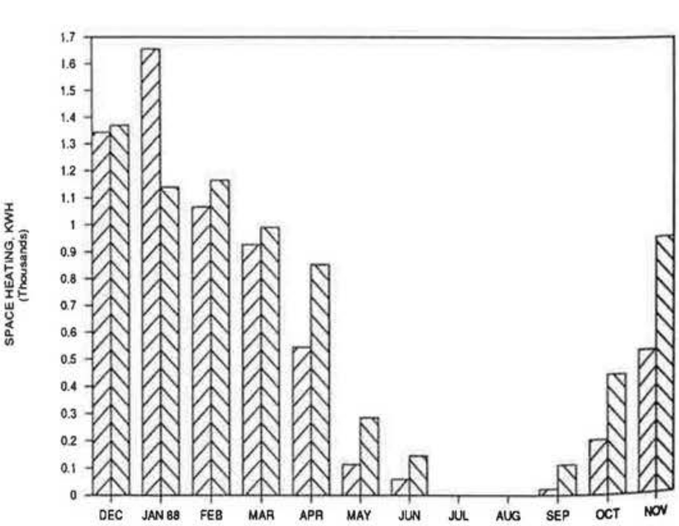


**Figure 4** House 2 (superglazed): Monthly SERI-RES prediction versus measured data for space heating

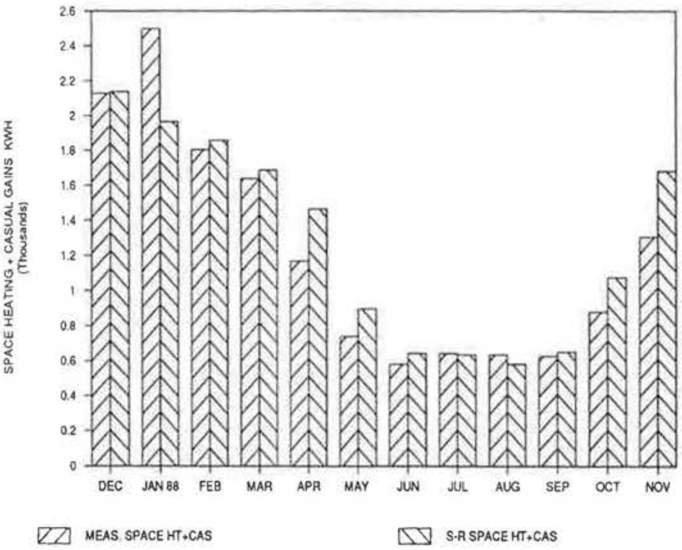


**Figure 5** House 2 (superglazed): Monthly SERI-RES prediction versus measured data for casual gains + space heating

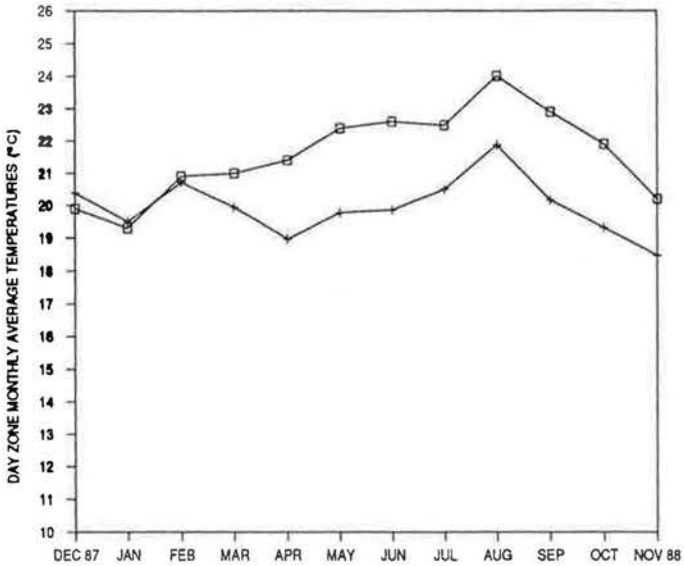


**Figure 7** Monthly SERI-RES predicted day zone temperatures (+) versus measurements (□)

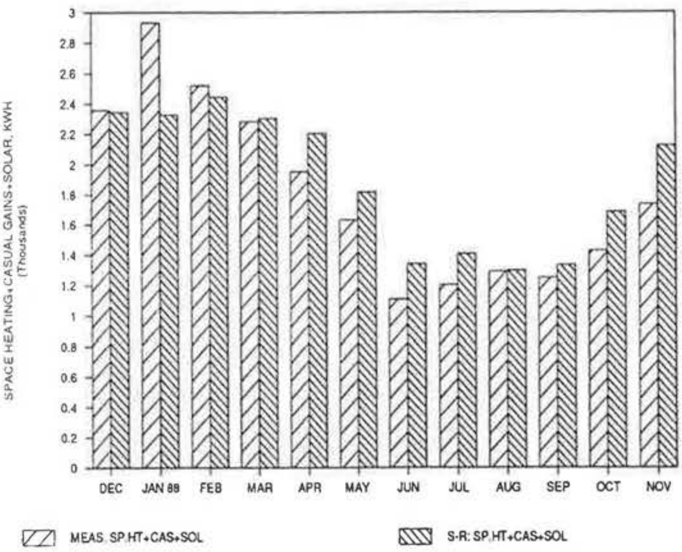


**Figure 6** House 2 (superglazed): Monthly SERI-RES prediction versus measured data for casual gains + space heating + solar gains

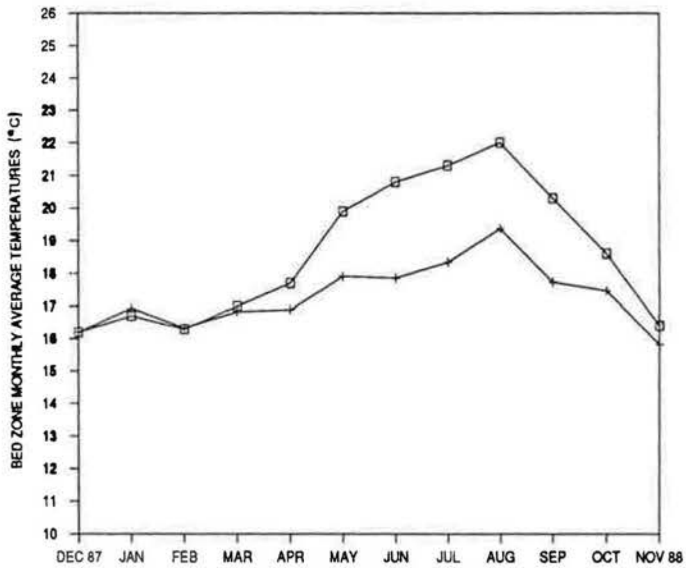


**Figure 8** Monthly SERI-RES predicted bedroom temperatures (+) versus measurements (□)

Figure 5 shows the monthly comparison between SERI-RES predicted space heating plus casual gains and the measured space heating plus estimated casual gains. Figure 6 shows the monthly comparison between SERI-RES predicted space heating plus casual gains plus solar gains and the measured space heating plus casual gains plus solar gains. From inspection of Figure 5 it can be seen that agreement is close for all months except January 88, April 88 and November 88. In January, SERI-RES underpredicts by 22%, and in April and November SERI-RES overpredicts by 25% and 29% respectively. Inspection of Figure 7 (day zone) and Figure 8 (bedrooms) shows that SERI-RES is also underpredicting the zone temperatures during these periods and in the summer months.

Siviour[15] introduced the concept of effective aperture $A_{eff}$ to reflect the importance of useful solar gain (that is, gains which do not cause overheating), shading by window reveals the blinds, and the shading coefficient of the ensemble of glazed elements. He showed that $A_{eff}$ could be obtained by regression of heating load plus casual gains against incident solar energy. The concept was investigated further by Everett[16]. SERI-RES version 1.2 tracks the useful solar gains and useful casual gains, and when using such a detailed model for design purposes, the concept of useful gain has proved immensely efficacious.

$A_{eff}$ is the area of unobstructed single glazing which would afford the same useful solar gain as that observed through windows with obstructions and lower shading coefficients. Figure 9 compares SERI-RES predicted monthly useful solar gains with those calculated from the effective solar aperture parameter $A_{eff}$ resulting from regression analysis of the October to April data. $A_{eff}$ is strictly only valid for the heating season and is an average for that period; in reality it would vary continuously with solar altitude, and the changing usefulness of solar gains through the year. The effective apertures are determined from SERI-RES pre-

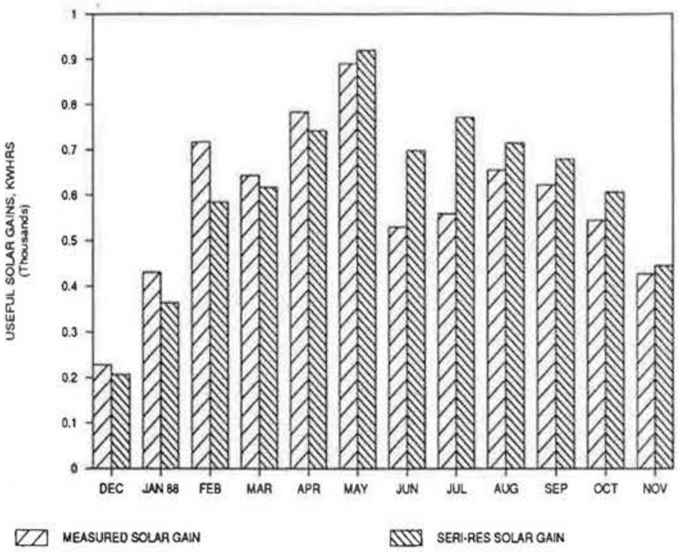


**Figure 9** Monthly SERI-RES predicted solar gains compared with those calculated from measured data and regression analysis

dictions of useful solar gain, by using the measured shading coefficient to calculate the area of single 4 mm glass which would provide the same useful gain.

The two estimates $A_{eff}$ agree with the expected discrepancy in the summer months of May, June, July, where the $A_{eff}$ calculation is not valid. Table 4 shows the annual total inputs to House 2. More relevant comparisons can be made using the totals for the heating season, during which period the predicted temperatures are in better agreement with actual temperatures and the $A_{eff}$ parameter is valid. This comparison is made in Table 5. For the heating season there is very good agreement between SERI-RES predicted energy inputs and the measured energy inputs. Figure 10 shows the monthly comparison between building heat loss predicted by SERI-RES and that calculated from the measured global heat loss coefficient and the sum of the inside–outside temperature differences. Agreement is fair for all but the summer months. The yearly total building loss is predicted by SERI-RES to be 22 888 kWh, and that calculated from measurement, to be 22 548 ± 2 438 kWh. The more meaningful heating season comparison is: from SERI-RES 18 873 kWh, and from measurement 18 848 ± 2 038 kWh.

**Table 4** Annual totals for heat input to superglazed house 2: Useful solar gains, Space heating (Space heating + Casual gains), (Space heating + Casual + Solar gains)

| Parameter | Annual total heat input (kWh) | |
|---|---|---|
| | Measured | SERI-RES |
| Useful solar gains | 7026 ± 759 | 7344 |
| Space heating | 6466 | 7457 |
| Space heating + Casual gains | 14652 ± 819 | 15275 |
| Space heating + Casual + Solar gains | 21678 ± 1578 | 22619 |

**Table 5** Heating season (September–May) totals for heat input to superglazed house 2: Useful solar gains, Space heating (Space heating + Casual gains), (Space heating + Casual + Solar gains)

| Parameter | Annual total heat input (kWh) | |
|---|---|---|
| | Measured | SERI-RES |
| Useful solar gains | 5285 ± 571 | 5163 |
| Space heating | 6407 | 7313 |
| Space heating + Casual gains | 12794 ± 639 | 13416 |
| Space heating + Casual + Solar gains | 18079 ± 1210 | 18579 |

## 4 ENERGY DESIGNER

The second model compared with measured data, ENERGY DESIGNER, is based on a procedure developed by Anderson and Uglow at the Building Research Establishment from extensive field trials and monitored data[2]. There is a series of models, BREDEM (Building Research Establishment Domestic Energy Models) for different applications as shown in Table 6. Each model develops basic equations as required for specific applications. ENERGY DESIGNER[3] has undergone improvements in its ability to handle solar gains, the effects of controls on heating requirements and calculation of ventilation rates. It remains, however, a non-dynamic model, unable to account accurately for heat flux in and out of thermal mass.

### *4.1 Energy cost index*

Comparisons of energy costs between different houses is made more difficult by standing charges which vary from utility to utility, and by floor areas which give an unreasonable advantage to larger houses. To avoid this distortion the energy cost index ECI was defined in terms of the extra fuel costs above a minimum requirement. The minimum requirement $£E_{min}$ was taken as the cost of electrically heating a small one person flat.

$$\text{ECI} = S\,(\text{TOT} - £E_{min})/\text{TFA}$$

where TOT is the total annual fuel cost including standing and maintenance charges, TFA is the total floor area and $S$ is a scaling factor to give a good low-energy house an ECI of 100.

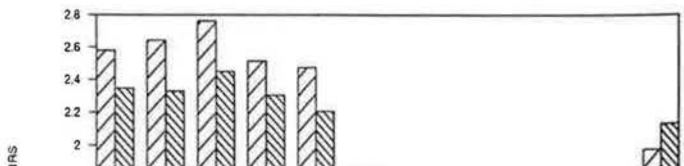


**Figure 10** Monthly comparison between building heat loss predicted by SERI-RES and that calculated from the measured house $UA$ (heat loss coefficient) and $\Sigma\Delta T$ (the sum of the inside–outside temperature differences)

**Table 6** BREDEM models

| Name | Application |
|---|---|
| ENERGY DESIGNER | Design of low-energy houses |
| ENERGY AUDITOR | Thorough energy audits of existing dwellings |
| ENERGY TARGETER | Assessment of insulation and heating system options for large housing stocks |
| ENERGY ASSESSOR | Rapid energy audits by surveyors, estate agents and contractors |
| ENERGY CALCULATOR | Rapid assessment of energy running costs of existing or projected dwellings |

## 5 Comparing measured data with DESIGNER predictions

This section details comparisons between the DESIGNER energy predictions for the house as built with the monitored data from the superglazed house.

### *5.1 Realistic building description of the superglazed house for DESIGNER*

Annual degree–days to the base 15.5°C were calculated for the site as 2330. This value was used in DESIGNER. The number of bed spaces was chosen as three, so that the program uses an occupancy of two (the same number of occupants as in house 2) for calculating casual gains and domestic hot water requirements. (In DESIGNER number of occupants = $\frac{2}{3}$ × no. of bed spaces, to the nearest integer.) Parameters affecting the air change rate of the modelled house were specified to force agreement with the infiltration and ventilation rate measurements performed in the house.

DESIGNER V1.65 does not allow the user to specify advanced glazing systems; in particular the transmittance must be ≥50%, and only one type of glazing can be specified, with a static $U$-value. The approach taken to find the average area-weighted glazing $U$-value $U$ for the whole house from:

$$A_t U_t + A_q U_q = U(A_t + A_q)$$

where $A_t$ and $U_t$ are the area and $U$-value of the triple glazed windows and $A_q$, $U_q$ are the area and $U$-value of the quadruple glazed windows. The glazing area and $U$-value were adjusted to allow use of the minimum solar transmittance of 0.5. A glazing area $A_f$ was specified such that:

$$0.5\,A_f = AT$$

where $A$ is the glazing area, $A_t + A_q$, $T$ is the measured average solar transmittance, and similarly the average $U$-value of the glazing, $U$ was given by:

$$U_f A_f = UA$$

External values of wall, roof and floor areas were used, and their $U$-values were those calculated in SERI-RES. Space heating and domestic hot water systems were specified as realistically as possible from the options provided by the program.

### *5.2 Results of comparison for superglazed house 2: 'As built'*

Table 7 shows the comparison for December 1987 to November 1988, including ventilation loss. Table 7 suggests that there is a significant discrepancy between monitored space heating energy output from the boiler compared with that predicted by DESIGNER. However, a comparison of useful casual gains excluding solar gains, plus space heating shows better agreement between prediction and measurement to within the error band associated with the measured useful casual gains. The useful casual gains were calculated from the casual gain summation discussed previously, multiplied by the factor of 0.8 used in DESIGNER to allow for non-useful casual gain.

Comparison of the average temperatures for each zone is not

**Table 7** Comparison of designer predictions with annual monitored data: Superglazed courtyard house (House 2)

| Parameter | Source | |
|---|---|---|
| | Monitored data | DESIGNER |
| Building specific heat loss coefficient (W $K^{-1}$) | 265 ± 35 | 221 |
| Effective air change rate (ac $h^{-1}$) | ~0.45 | 0.4 |
| Space heating (kWh)<br>(System efficiency) | 6 374<br>(~76%) | 8 044<br>(76%) |
| Solar gains (useful) (kWh) | 7 045 ± 805 | 5 840 |
| Casual gains (useful) (kWh) | 6 808 ± 680 | 5 519 |
| Average day zone temp. (°C) | 21.6 | 19.1 |
| Average bed zone temp. (°C) | 18.6 | 16.7 |
| DHW requirements (kWh)<br>(System efficiency) | 3 876<br>(80%) | 2 888<br>(72%) |
| Space heat + Casual gains (useful) (kWh) | 13 182 ± 680 | 13 563 |
| Space heat + Casual + Solar gains (useful) (kWh) | 20 227 ± 1 485 | 19 403 |

Table 8 Comparison of monitored data with DESIGNER and SERI-RES predictions: Superglazed courtyard house (House 2)

| Parameter | Source | | | | |
|---|---|---|---|---|---|
| | Monitored data | | DESIGNER prediction | SERI-RES prediction | |
| Building specific heat loss coefficient (W $K^{-1}$) | 265 ± 35 | | 221 | 257 to ambient +22 to ground | |
| Effective air change rate (ac $h^{-1}$) | ~0.45 | | 0.4 | 0.45 (input) | |
| Period of comparison | Year | Heating season | Year | Year | Heating season |
| Space heating (kWh) (System efficiency (%)) | 6 466 (~75) | 6 407 | 8 044 (76) | 7 457 | 7 312 |
| Solar gains (Useful) (kWh) | 7 026 ±759 | 5 285 ±571 | 5 840 | 7 344 | 5 163 |
| Casual gains (Useful) (kWh) | 8 186 ±819 | 6 567 ±639 | 5 519 | 7 818 | 6 103 |
| Average zone 1 temperature (°C) | 21.6 | 21.1 | 19.1 | 19.9 | 19.7 |
| Average zone 2 temperature (°C) | 18.6 | 17.7 | 16.7 | 17.3 | 16.9 |
| DHW requirements (kWh) (System efficiency (%)) | 3 876 (80) | — | 2 888 (72) | — | — |
| Space heat + Casual gains (Useful) (kWh) | 14 652 ±819 | 12 794 ±639 | 13 563 | 15 275 | 13 416 |
| Space heat + Casual + Solar gains (Useful) (kWh) | 21 678 ±1 578 | 18 079 ±1 210 | 19 403 | 22 619 | 18 579 |

so favourable, with DESIGNER estimates falling short by 2.5°C (living zone) and 1.9°C (bedroom zone). Solar gain seems to be underpredicted by DESIGNER, accounting for the low temperatures in the living zone, which is highly glazed. The value for useful solar gains predicted by DESIGNER is 5840 kWh/year which includes non-useful solar gains in the summer. The value calculated from $A_{eff}$ and the measured insolation (as described above) in the heating season is 5285 kWh/year. Useful solar gain can be estimated from $A_{eff}$ and insolation with less accuracy in the summer as 780 kWh giving a total of 6065 kWh/year. This value has been used in Table 8 to calculate the total monitored heat input to the house for comparison with that calculated by DESIGNER. Discrepancy in the domestic hot water requirements is unsurprising as DESIGNER's estimate is an average, based on occupancy, taken from field observations in a variety of dwellings.

### *5.3 Comparison of DESIGNER predictions for courtyard superglazed house: 'From plans'*

The energy cost index from the simulation in this paper is 92, which is much worse than the ECI prediction of 72 calculated from the plans and before building commenced. There are several possible reasons:

(*a*) The glazing *U*-value originally used was 0.8 W $m^{-2}$ $K^{-1}$, which is an accurate centre-of-pane value for the quadruple windows but takes no account of spacer and frame effects which degrade the *U*-value to 0.9. In addition, for reasons of weight, the opening windows are only triple glazed with a *U*-value of 1.1 W $m^{-2}$ $K^{-1}$.

(*b*) The solar transmittance of the low emissivity coatings was overestimated.

(*c*) Discussion with various users of DESIGNER highlights some confusion as to whether the floor area should be:

— the area bounded by the external surface of the perimeter walls;

— the area bounded by the internal surface of the perimeter walls;

— the average of these two figures (i.e. the area bounded by an imaginary surface halfway between the internal and external surfaces of the perimeter walls)—this is the area used in the 'as built' simulation and is the one recommended in the user manual;

— the sum of the areas of each room (i.e. the usable area of the building).

(There are similar problems when specifying the areas of walls and roof.)

The ECI changes from 89.6 to 97.3 by adjustment of the floor area with a constant house volume. Estimates of the heat input to the house change by 4.0 GJ, from 56.5 GJ to 60.5 GJ if the house volume is adjusted. The degree–day figure used in the present simulation arose from the site weather data. It was 2330 degree–days, which is lower than the last 20-year average degree–day figure for the area, 2500, which was assumed in the ECI calculation from the plans. The ECI predicted by DESIGNER varies with the degree–day figure

**Table 9** Comparison of monitored data with DESIGNER and SERI-RES predictions: Double glazed courtyard house (House 5)

| Parameter | Source | | | | |
|---|---|---|---|---|---|
| | Monitored data | | DESIGNER prediction | SERI-RES prediction | |
| Building specific heat loss coefficient (W $K^{-1}$) | 311 ± 29 | | 289 | 316 to ambient +22 to ground | |
| Effective air change rate (ac $h^{-1}$) | 0.8 (estimate) | | 0.69 | 0.8 (input) | |
| Period of comparison | Year | Heating season | Year | Year | Heating season |
| Space heating (kWh) (System efficiency (%)) | 14 373 (~75) | 14 122 | 13 386 (~76) | 14 368 | 14 062 |
| Solar gains (Useful) (kWh) | 5 516 ±742 | 3 927 ±511 | 4 906 | 7 064 | 4 670 |
| Casual Gains (Useful) (kWh) | 5 760 ±576 | 4 690 ±469 | 5 424 | 6 096 | 4 986 |
| Average zone 1 temperature (°C) | 20.5 | 20.3 | 18.7 | 19.1 | 19.3 |
| Average zone 2 temperature (°C) | 20.0 | 19.8 | 17.0 | 18.9 | 19.2 |
| DHW requirements (kWh) (System efficiency (%)) | 1 712 (80) | — | 2 892 (71) | — | — |
| Space heat + Casual gains (Useful) (kWh) | 20 133 ±576 | 18 808 ±469 | 18 810 | 20 464 | 19 048 |
| Space heat + Casual + Solar gains (Useful) (kWh) | 25 694 ±1 318 | 22 735 ±980 | 23 716 | 27 528 | 23 718 |

so that the same house built in a harsher climate scores a worse (higher) ECI.

## 6 Summary: Measured data versus DESIGNER and SERI-RES predictions

As a result of this study the following conclusions can be reached regarding the two programs under investigation. For the superglazed house, Table 9 shows the comparison of monitored data with DESIGNER and SERI-RES predictions. For the double-glazed house, Table 10 shows comparison of monitored data with DESIGNER and SERI-RES predictions. The courtyard house has a reduced area of *double* glazing, and extract fans instead of heat recovery ventilation.

For double-glazed house 5, measured heating season figures are in very good agreement with the SERI-RES predictions. Most DESIGNER predictions agree very well for the technologically more conventional version of the courtyard house design, with its reduced passive solar and low energy features. Solar gains are underpredicted slightly but, as already discussed, the method of calculating the actual solar gains will result in an overestimate for whole-year calculations (the method is only valid for the heating season). Predicted and measured space heating plus casual gains (not including solar gains) agree within the error bands associated with the measured data, as do the space heating plus solar and casual gains (i.e. total heat into the house), predicted and measured. The predicted average internal temperatures are too low by 1.8 and 3°C for the living and bedroom zones respectively. The domestic hot water requirements are predicted wrongly—this time overestimated—for the same reasons as discussed in the superglazed case. Predicted performance from both the dynamic SERI-RES model and the non-dynamic DESIGNER agree very well with the monitored data over the extended periods of comparison (a full year or heating season).

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