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USER-PERFORMANCE SENSITIVITY OF SMALL SUNSPACES IN A SCOTTISH HOUSING CONTEXT.

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Abstract

The performance of unheated solar buffer zones (SBZs) or sunspaces in relatively high latitudes' locations has become increasingly controversial. Conceived as simultaneously saving energy and providing amenity, the latter characteristic has provided the user with the opportunity and/or aspiration to negate the former - by heating a sunspace during winter either directly, or by opening it up as an extended heated part of the dwelling.

Scotland has been host to passive solar projects promoting the use of small sunspaces where 'opening up' is a greater risk than directly heating. 'Opening-up' signals a change from 'indirect' to 'direct' solar gain with the heated volume partially extended. Within this context, this work examines the relevant aspects of a small sunspace as a passive solar technique by posing three questions from which answers are to be sought.

1. How useful and usable are the sunspaces ?
2. To what extent are occupants' interventions affecting energy saving ?
3. What is the energy 'worth' of the two sunspaces ?

The vehicle for this work is the CEC Solar Energy Demonstration Project at Easthall, Glasgow, where 36 thermally sub-standard flats built in the 1960s have been retrofitted with each flat having two sunspaces on opposite facades to tackle the issue of random orientation, and a common stairwell functioning as a shared thermal buffer space. The author's close acquaintanceship with a relatively large sample of occupants over a monitoring period of two years, taken in conjunction with data from questionnaires, interviews, diaries and personal observations, has enabled a substantive 'cause and effect' analysis.

The findings confirm the likelihood of user intervention negating optimum performance, especially in spring and autumn, and in association with particular household types and characteristics. Nevertheless, the mean space heating load was approximately 30% lower than it would have been for the equivalent dwelling adjusted to the same internal temperature and ventilation rate, but without the front and rear sunspaces; and winter performance vindicates the role of sunspaces in providing good air quality at a relatively low running cost.

The work sets aside the issue of life-cycle, pay-back analysis since, in general terms, this is dependent firstly on how much of the cost of sunspaces is written off as necessary floor area or improved amenity, and secondly on variable costs of a complementary energy-efficient package. However, on the assumption that these factors may be favourable, the work concludes with broad design recommendations based on the research findings; in particular recognising the dominance of the 'heat recovery' rather than 'solar' mode of operation of sunspaces.

ACKNOWLEDGEMENTS

This doctoral thesis is undertaken at the Mackintosh School of Architecture (Department of Architecture of Glasgow School of Art and associated institution of the University of Glasgow) between 1991- 1995. My main debt is therefore to my supervisor Dr Colin Porteous for teaching me the art and craft of research and providing valuable guidance that enabled me to complete this research work.

I am also indebted to many for their support and encouragement in bringing this research project to completion. Many thanks go to the Glasgow School of Art and the Mackintosh School of Architecture team for their technical support;

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Last but not least, I could not have tackled such a complex problem without first hand experience of the people living in thermally sub-standard housing. The solar retrofit project at Easthall represents only four per cent of the council housing stock within the Easthall Housing Estate. However the project demonstrates that passive solar features in the form of sunspaces can provide a relatively high rate of ventilation within the context of affordable warmth as well as energy efficiency.

USER-PERFORMANCE SENSITIVITY OF SMALL SUNSPACES IN A SCOTTISH HOUSING CONTEXT.

CHAPTER 6. FOUR CASE STUDIES.

CHAPTER 7. CONCLUSIONS.

APPENDIXES (1, 3, 4 AND 6 CORRESPONDING TO CHAPTER NUMBERS)

APPENDIX 1

APPENDIX 3

APPENDIX 4

APPENDIX 6

Nomenclature

D	number of days in specified period, e.g. calendar month	(days)
$DD^{Tb1\ or\ 2}$	mean daily degree day load for period, for zone 1 or 2	(Kdays)
H	specific heat loss to unheated boundaries, replacing expression $\Sigma A.U + 0.33.n.V$ (boundaries signify connections to outside & unheated buffer zones)	(W/K)
H^*	specific heat loss to outside, including buffer space resistance (s)	(W/K)
H1	specific heat loss from zone 1 to boundaries other than zone 2	(W/K)
H2	specific heat loss from zone 2 to boundaries other than zone 1	(W/K)
H^b ($H^{b1/2}$)	specific heat loss from heated zone to sunspace (suffix to denote zone)	(W/K)
H^s ($H^{s1/2}$)	specific heat loss from sunspace to outside (suffix to denote sunspace)	(W/K)
i	incident angle (between line normal to surface and solar beam)	(°)
n^b	rate of air change per hour, e.g. between heated zones and sunspaces	(/hr)
n^e	effective rate of air change per hour, e.g. between heated zones and outside air	(/hr)
n^p	rate of air change per hour, e.g. between heated zone and each perimeter condition, including n^b	(/hr)
n^r	real rate of air change per hour, e.g. between heated zones and bounding zones including sunspaces	(/hr)
n^s	rate of air change per hour, e.g. between sunspaces and outside air	(/hr)
q^h	rate of heat output from heating system	(W)
q^i	rate of incidental or casual gains to heated zones	(W)
q^{is}	rate of incidental or casual gain to sunspace	(W)
q^s	rate of useful transmitted solar gain (insolation) to heated zones	(W)
q^{s*}	ditto q^s, derived from models with and without transparent glass	(W)
q^{ss}	rate of transmitted solar gain (insolation) to sunspace	(W)
q^{is}	rate of incidental gain to sunspace	(W)
q^{hs}	rate of heated interior loss to sunspace - i.e. free gain to sunspace	(W)
Qh	space heating load (purchased fuel energy) for specified period	(kWh)
Qi	incidental or casual heat gains to heated zones for period	(kWh)
Qs	useful transmitted solar gains to heated zones for periods	(kWh)
Tb	internal base temperature, replacing expression $Tai - (q^i + q^s)/H$	(°C)
Tb1 (**Tb2**)	internal base temperature for zone 1 (living) and 2 (rest of house)	(°C)
Ti ($Ti^{1/2}$)	mean daily inside air temperature (suffix to denote zone)	(°C)
Ti^p	ditto **Ti**, part of a heated zone adjacent to a particular perimeter condition (e.g. BR1 and glazed veranda, rather than zone 2 and veranda)	(°C)
To	mean daily ambient (outside) dry bulb air temperature	(°C)
T^p	ditto To, for specific perimeter condition (e.g. veranda, stairwell, etc.)	(°C)
Ts	mean daily sunspace air temperature	(°C)
U	thermal transmittance coefficient (U-value)	(W/m^{2}K)

$\mathbf{U^p}$	ditto **U**, between heated zone and each perimeter condition	(W/m^{2}K)
$\mathbf{V}$	Volume of the heated zone	(m^3)
$\mathbf{V^s}$	Volume of the sunspace	(m^3)
$\mathbf{\Sigma A.U}$	summed product of thermal transmittances & corresponding areas	(W/K)
$\mathbf{\Sigma A.U^b}$	summed product of thermal transmittances & corresponding areas between heated zones and sunspaces	(W/K)
$\mathbf{\Sigma A.U^p}$	summed product of thermal transmittances & corresponding areas between heated zones and each perimeter condition	(W/K)
$\mathbf{\Sigma A.U^s}$	summed product of thermal transmittances & corresponding areas between sunspaces and outside	(W/K)
$\mathbf{\Delta T}$	difference in temperature between two volumes	(K)

SOURCES OF ILLUSTRATIONS

Figure i.1	Butti K. and Perlins J. 1980 p.179.
Figure i.2	Butti K. and Perlins J. 1980 p.182.
Figure i.3	Bartholomew D.M.L. 1985 p.151.
Figure 1.1	Hawkes D. 1987 p.55.
Figure 1.2	Clegg P. Littler J. et. al., 1985 p.9 and 17.
Figure 1.3	Minogue P.J. 1987 p.211 and 213.
Figure 1.4	DG XII: CEC 1987 p.4 and 5.
Figure 1.5	Raven D. 1985 p.53.
Figure 1.6	Porteous C. 1990 p.167.
Figure 1.7	Seligman C. et. al. 1977/78 p.13.
Figure 1.8	Bourdeau L. 1988 p.168 and 169.
Figure 2.2	Fielding M. Undated back cover.
Figure 2.3	CAS Architects Ltd., Glasgow, Undated booklet, p.10, 11 and 15.
Figure 2.4	Ditto, p.5.
Figure 2.5	Ditto, p.15.
Figure 2.6	CAS Architects Ltd., Glagsow, 1991 drwg. no. L(--)01.
Figure 2.7	Ditto, drwg. no. A(27)15.
Figure 2.8	As in Figure 2.3, back cover.
Figure 3.2	As in Figure 2.2, p.8.
Figure 4.1	As in Figure 2.6, drwg. no. L(--)01.

All tables in Appendixes 4.1 - 4.4 are extracted from 'Passive Solar Retrofit of Thermally Substandard Housing at Easthall, Glasgow. Final Report - Results of the Monitoring Programme 1992 - 4.' Porteous C. 1995 p.p. 32 - 44. Copies available through MEARU, 177 Renfrew Street, GLASGOW, G3 6RQ.

(Others are illustrated by author)

INTRODUCTION

i.1 20TH CENTURY CONCERN IN SOLAR BUILDING DESIGN

'Many people desire a south front to their house, and roads having a general direction east and west are desirable from this point of view if the buildings can be arranged and planned accordingly. Houses with a south aspect need a greater frontage as all the best rooms should be on the south side.' (Unwin, 1909)[1]

In America in 1912, William Atkinson[2] published 'Orientation of Buildings or Planning for Sunlight' which was regarded as a landmark in passive solar architecture. Although Atkinson regarded solar buildings primarily as means of improving health, he also highlighted thermal benefits through a remarkable series of experiments using test cells (Figure i.1) and sun boxes. Atkinson reported that despite freezing weather outdoors, "a temperature of 100°F and over has been frequently attained within this building..[sun box].....entirely from the warmth of the sun's rays...........every dwelling may be converted into a sun box !" by glazing in the south facing wall and properly insulating all the other outside walls.

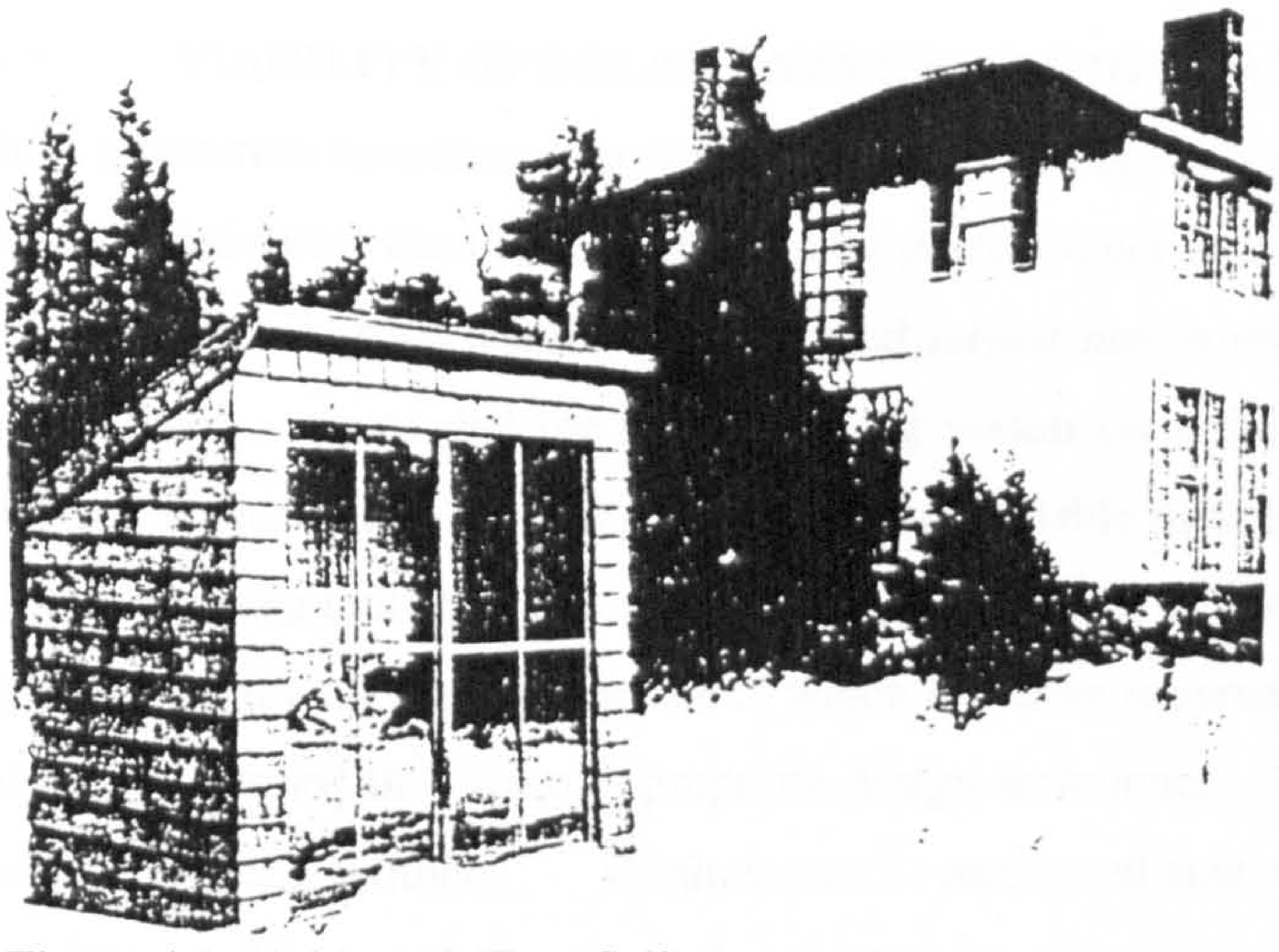

Figure i.1 Atkinson's Test Cell

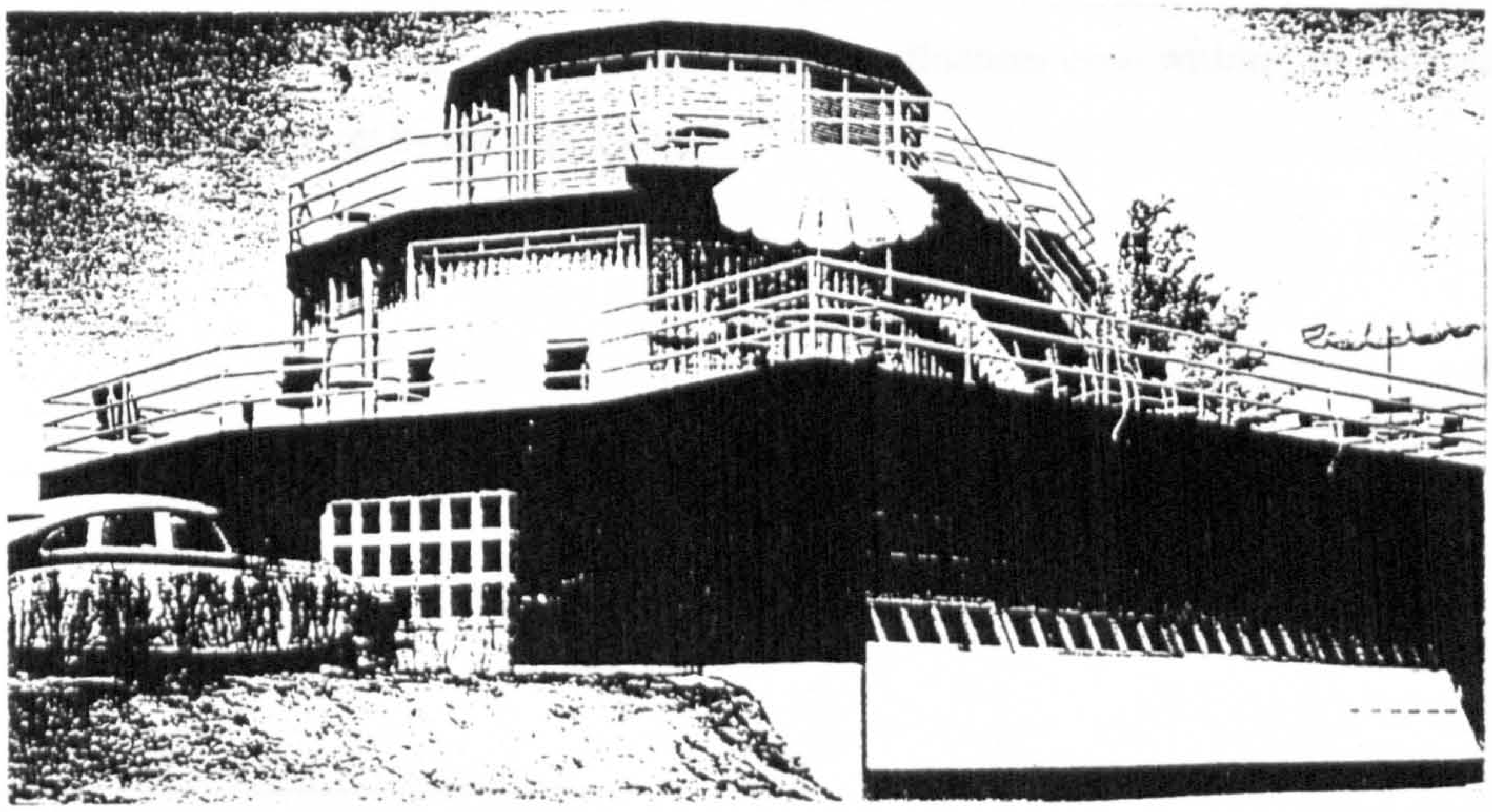

Figure i.2 G.F. Keck's First Solar Home.

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[1] UNWIN R. TOWN PLANNING IN PRACTICE London T. Fisher Unwin 1909.

[2] ATKINSON W. THE ORIENTATION OF BUILDINGS OR PLANNING FOR SUNLIGHT New York: Wiley 1912.

However in America, Atkinson's work did not arouse much interest. It was in Europe, in particular, Germany under the bandwagon of the Modern Movement that a number of schemes, mainly block of flats, with solar energy features were built. In the UK, the Royal Institute of British Architects[3] published sun paths diagrams almost two decades after Atkinson's publication and according to Butti and Perlin[4], the first 'solar home' (Figure i.2) of modern times was built by G.F. Keck at Chicago in 1940; while in the UK, the Curtis house built in 1956 is generally regarded as the first solar building, followed by the construction of St. Mary's School at Wallesey in 1961. The development of passive solar energy really took off after the year of oil crisis in 1973 and received a further boost in 1979. Although oil prices fell again during the 1980s, growing awareness of other environmental problems, notably 'Global Warming', has kept proposals for exploiting solar energy firmly on the agenda. Extensive research and development has been carried by the Commission of European Communities - Directorate General XVII, UK - Energy Technology Support Unit (ETSU) and Building Research Energy Conservation Support Unit (BRECSU), etc. hoping to find a commercial solution to this increasing energy problem.

i.2 VIABILITY OF SOLAR ENERGY AT HIGH LATITUDES

It is a common misconception that solar energy is mainly for the sunnier countries at low latitudes where water heating and direct electricity generation by photovoltaics and other means are viable propositions. In Scotland, where domestic space heating is the second largest non-renewable energy consumer after industry, analysis by MacGregor[5] argues that the longer heating season (as defined by Degree days) generally experienced in high-latitude countries allows a better utilisation of available solar energy in dwellings even though solar radiation falls with increasing latitude. Also, the reduction of solar radiation is much less marked on steeply tilted or vertical planes than on a horizontal surface in which the latter is commonly used for radiation measurement. Therefore, it may be argued that given appropriate design techniques, solar displaced fuel for space heating can increase with increasing latitude. Bartholomew[6] confirmed that this was certainly true of some passive solar house models. For example, a single aspect terraced house type with an atrium-type sunspace (Figure i.3) was predicted to save more fuel in Lerwick than the same model located in Kew; whereas the reverse was true of a more traditional 'direct gain' model. An agenda for exploring and exploiting passive solar techniques in high latitude locations, recognising specific climatic influences even within the relatively confined boundaries of the UK, was therefore set by the mid 1980s.

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[3] RIBA JOINT COMMITTEE THE ORIENTATION OF BUILDINGS RIBA Journal 10 September 1932.

[4] BUTTI K. AND PERLINS J. A GOLDEN TREAD London, Marion Boyars Publishers Ltd., p 183, 1980.

[5] MacGREGOR W.K. WHY NORTH IS BEST FOR SOLAR HEATING OF BUILDINGS Sun at Work in Britain UK-ISES No. 20 - March 1985 p.p. 49 - 55.

[6] BARTHOLOMEW D.M.L. POSSIBILITIES FROM PASSIVE SOLAR HOUSE DESIGN IN SCOTLAND The International Journal of Ambient Energy Vol. 6 no. 3 July 1985 p.p. 147 - 158.

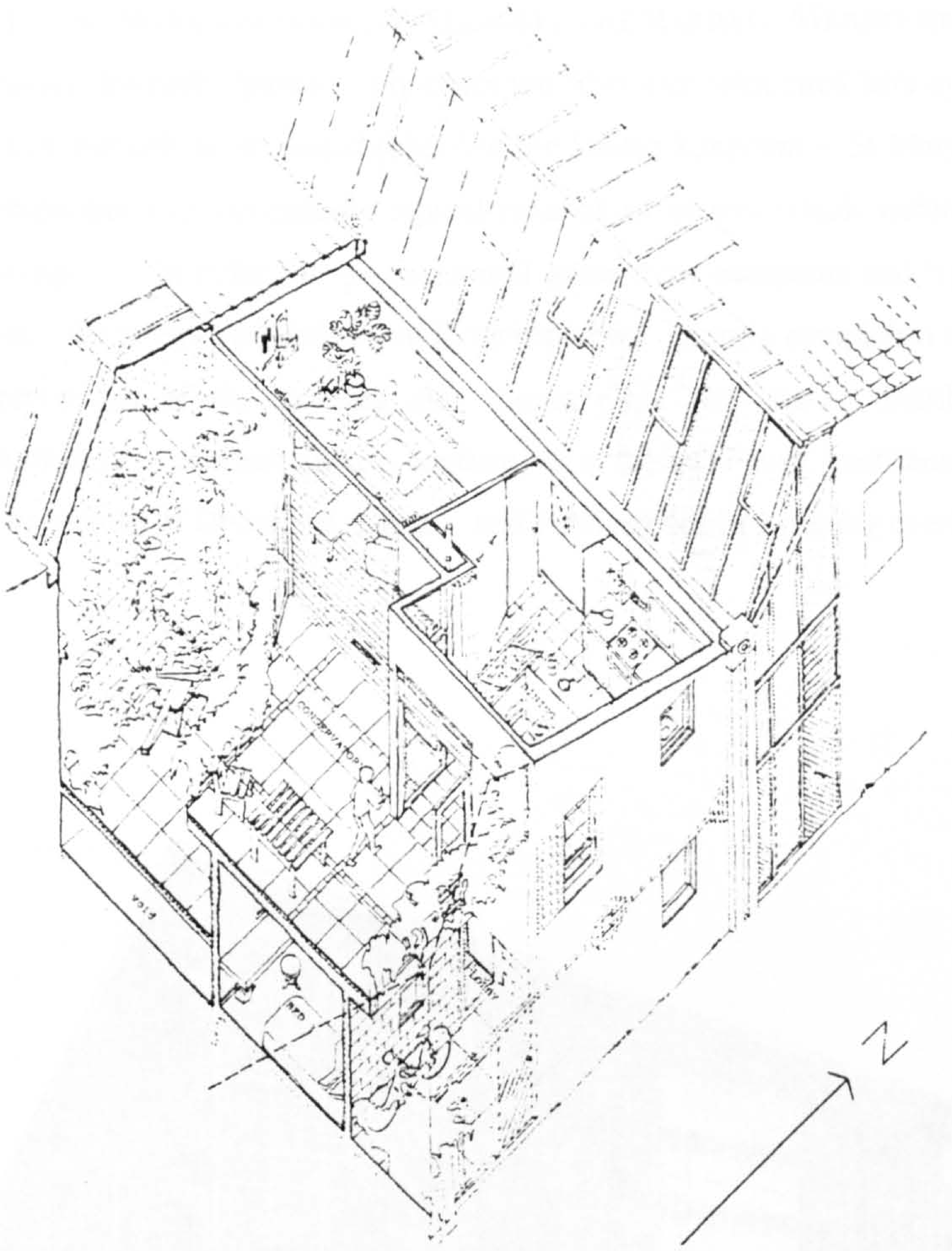

Figure i.3 Atrium-Type Sunspace Terrace House, reported by Bartholomew 1984.

Another broad debate, relevant to the context of this work, lies between a purely 'energy-efficiency' lobby and an 'energy-efficiency plus amenity' lobby. The path of the former - essentially engineering in outlook - lies with highly insulated, tightly sealed shells with mechanically controlled ventilation; while the latter - essentially architectural in outlook - leads to more highly glazed shells which are more responsive to occupant intervention, and make use of passive solar techniques to control both fabric and ventilation loss.

This work focuses on a particular strategy which belongs to the latter lobby - that of small sunspaces. It also tests its worth against a particular consumer-led demand in Scotland, that of the large proportion of existing thermally sub-standard housing stock in the public sector. One outcome of this demand has been a part CEC funded Solar Energy Demonstration Project on the periphery of Glasgow and this is the primary vehicle for the thesis.

However, as a contextual preface to detailed assessment of the performance of this project, it is worth identifying relevant aspects of both the existing problem which is driving the demand or need, as well as strategic performance indicators arising from earlier case studies in the United Kingdom and Ireland.

CHAPTER 1: SCOTTISH DEMAND IN THE CONTEXT OF RELEVANT CASE STUDIES.

1.1 SIGNIFICANT PASSIVE SOLAR EXAMPLES IN ENGLAND AND IRELAND

1.1.1 ST MARY'S SCHOOL, WALLASEY, THE WIRRAL, MERSEYSIDE - 1961 (53°4'N)

Although this early 'pioneer' pre-dates the other examples cited here by more than two decades, experience from the first partially solar heated school in the United Kingdom - St Marys School, Wallasey (Figure 1.1) - raises an important and increasingly topical issue of air quality which architects have to address when designing solar buildings. In order for the incidental gains from occupants and lighting together with solar gain to balance losses, the rate of ventilation had to be kept low, causing complaints of odour and poor air quality. The single aspect design of the building also causes glare and uneven distribution of daylight within the classroom. Nevertheless, research data[1] confirms that the solar wall contributed to the heating requirement even in the winter months of December, January and February whilst avoiding overheating in summer.

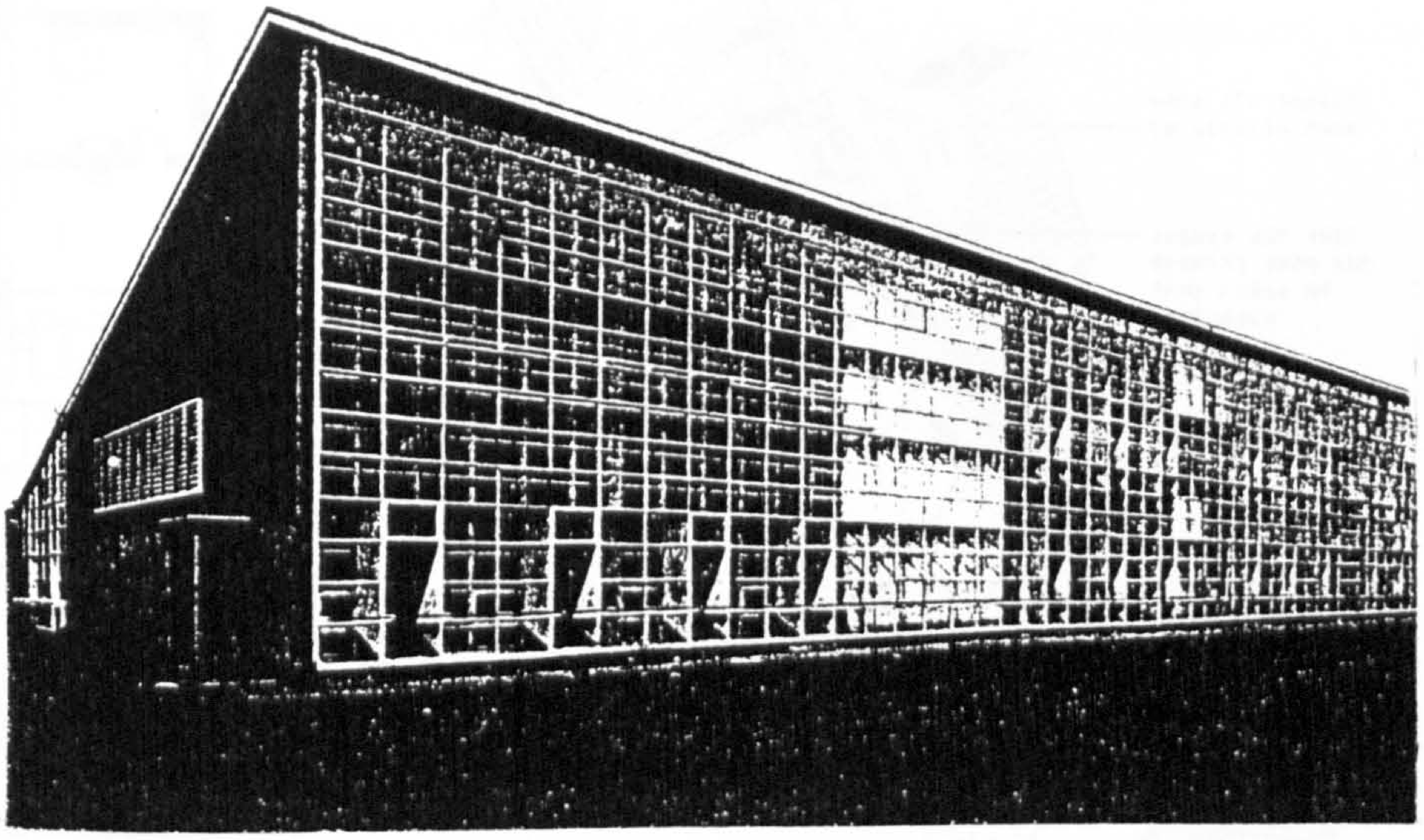

Figure 1.1 St. Marys School, Wallasey.

The design embodied a direct solar gain system, a dual skin solar wall 600mm deep and 8m high with limited openable apertures, within a well insulated envelope (averaging a low U-value of 0.24 W/m²K). Had the dual-skin glazing system incorporated a satisfactory absorber, e.g. heat absorbing glass louvres, then in addition to providing direct solar gain to the interior, it could also have preheated air for ventilation. This would have permitted relatively high 'real' rates of air change but lower 'effective' rates. The 'effective' rate ($\mathbf{n^e}$) which takes into account of the pre-heating effects of the sunspace is taken as the rate relative to the inside-outside temperature differential in a simple heat balance equation as in Appendix 1.1.

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[1] HAWKES D. ENERGY REVISIT WALLASEY SCHOOL: PIONEER OF SOLAR DESIGN. Architects Journal p.p. 55 - 59 6 May '87.

1.1.2 Woodbridge Cottage, Ubley, Bristol, 1983 - 51°4'N

The design of Woodbridge Cottage might appear to bear little relationship with Wallasey School. Here, a 'black attic' air collector is used to distribute pre-warmed air to the interior of the house, where load-bearing constructional elements provide most of the thermal storage mass. However, the net result is very similar to the enhanced Wallasey scenario (i.e. with absorbers inside the glazed buffer space). Solar gain is input both directly through windows and indirectly through the attic collector, and the latter again enables a relatively high 'real' rate of air change for a low 'effective' rate.

The roofspace collector of Woodbridge Cottage (Figure 1.2) was constructed by insulating part of the attic space and glazing the southerly roof slope with twinwall polycarbonate sheeting. Monitoring data between October 1983 and July 1984[2] confirmed the collector performed very well though its cost-effectiveness was reduced by unexpected increases in capital costs and unusually high internal gains. Although not made explicit in the analysis, it may be assumed that a large proportion of the 2,438 kWh energy saving is manifested in the form of ventilation preheat.

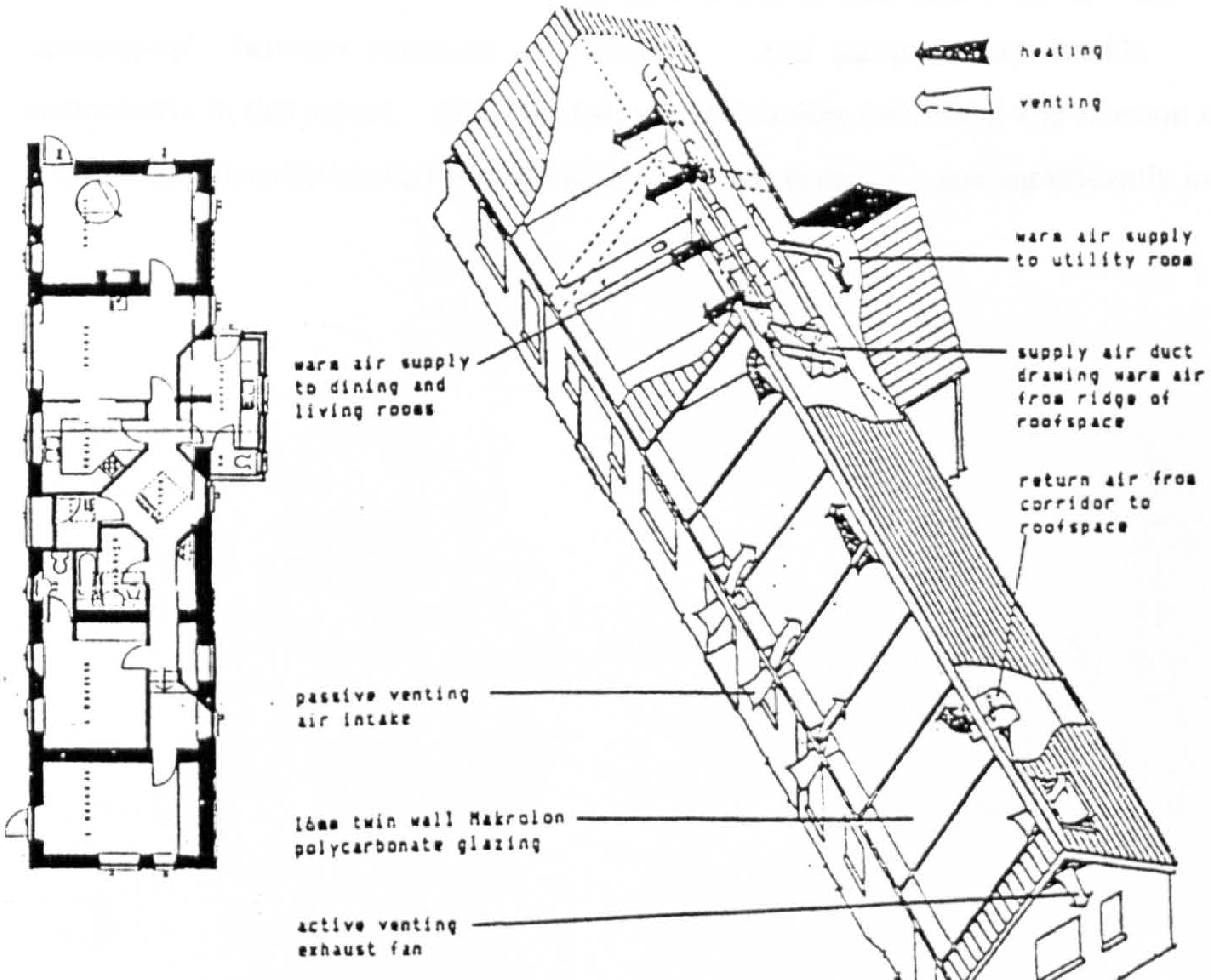

Figure 1.2 Woodbridge Cottage.

The report concludes that given the house was insulated to such a high standard including triple glazing, further energy saving as a result of passive solar measures was less cost effective. However, the conclusion requires closer examination since ventilation preheat is potentially a worthwhile technique in a high-insulation scenario, in much the same way as a mechanical heat recovery system.

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[2] CLEGG P. , LITTLER J. , MARTIN C. , NEWCOMB C. , PRIOR J. , RUYSSEVELT P. WOODBRIDGE COTTAGE ROOF SPACE SOLAR COLLECTOR Final Report for the Energy Technology Support Unit by Energy Design Group Feb. 1985

1.1.3 CARRIGEEN PARK, CLONMEL, IRELAND - 1985 (52°3'N)

This is a further progression from the previous two case studies - a school with a regular daily input of incidental gains but where solar ventilation preheat appears under-exploited, and a one-off house where solar ventilation preheat appears under-acknowledged - to repetitive local authority housing on a tight budget. Here the main passive solar device functions both as an energy saver and as a useful amenity (a place to sit, dry clothes, etc.). Solar gain to the Clonmel sunspaces (Figure 1.3) may be transferred to the heated interior in two ways - firstly by means of the solid 215mm brick dividing wall (lowering its effective U-value and hence slowing losses if not actually transferring heat to the interior in the Trombe-wall mode); and secondly by convection or ventilation preheat. A natural thermal loop is possible by means of the 'solar chimney' at the upper part of the sunspace to bedrooms, down via stairs at the north side, back into main living room and dining/kitchen and back to lower part of sunspace.

Results suggest that the latter mode was the most promising and that a well insulated dividing wall may have been a better tactic. The other issue raised here is that of user intervention, particularly relative to the extent of 'opening-up' between sunspace and interior, and sunspace and outside. Monitoring results[3] appear inconclusive in this aspect. However this variable is very influential and relevant to the scope of this work, since it can simultaneously convert an indirect gain system to direct, and significantly increase the volume to be heated.

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[3] MINOGUE P.J. HOUSING AT CLONMEL, IRELAND Batiment International Building Research & Practice. The International Council of Building Research Studies and Documentation. p.p. 210 - 214 July/August 1987.

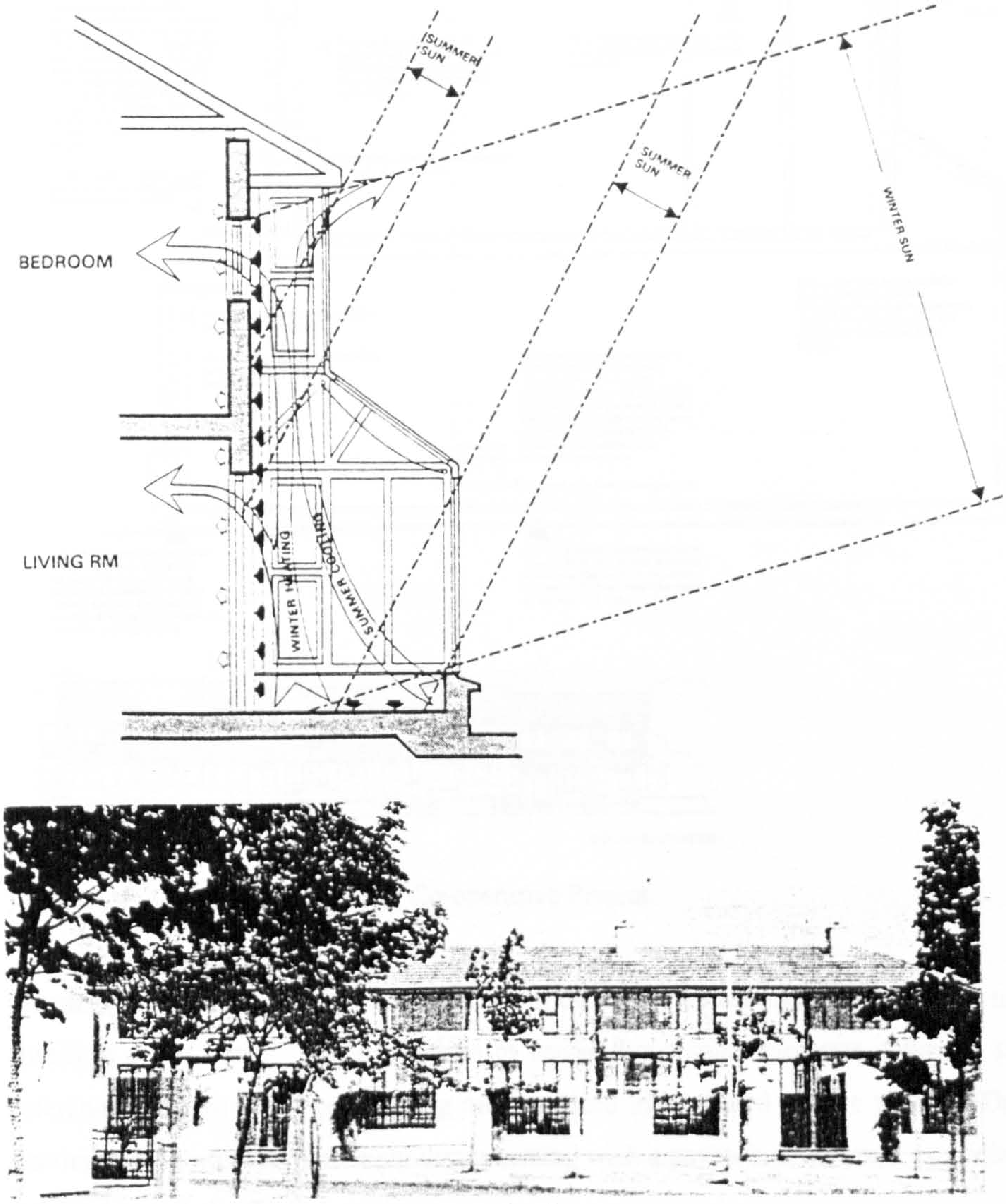
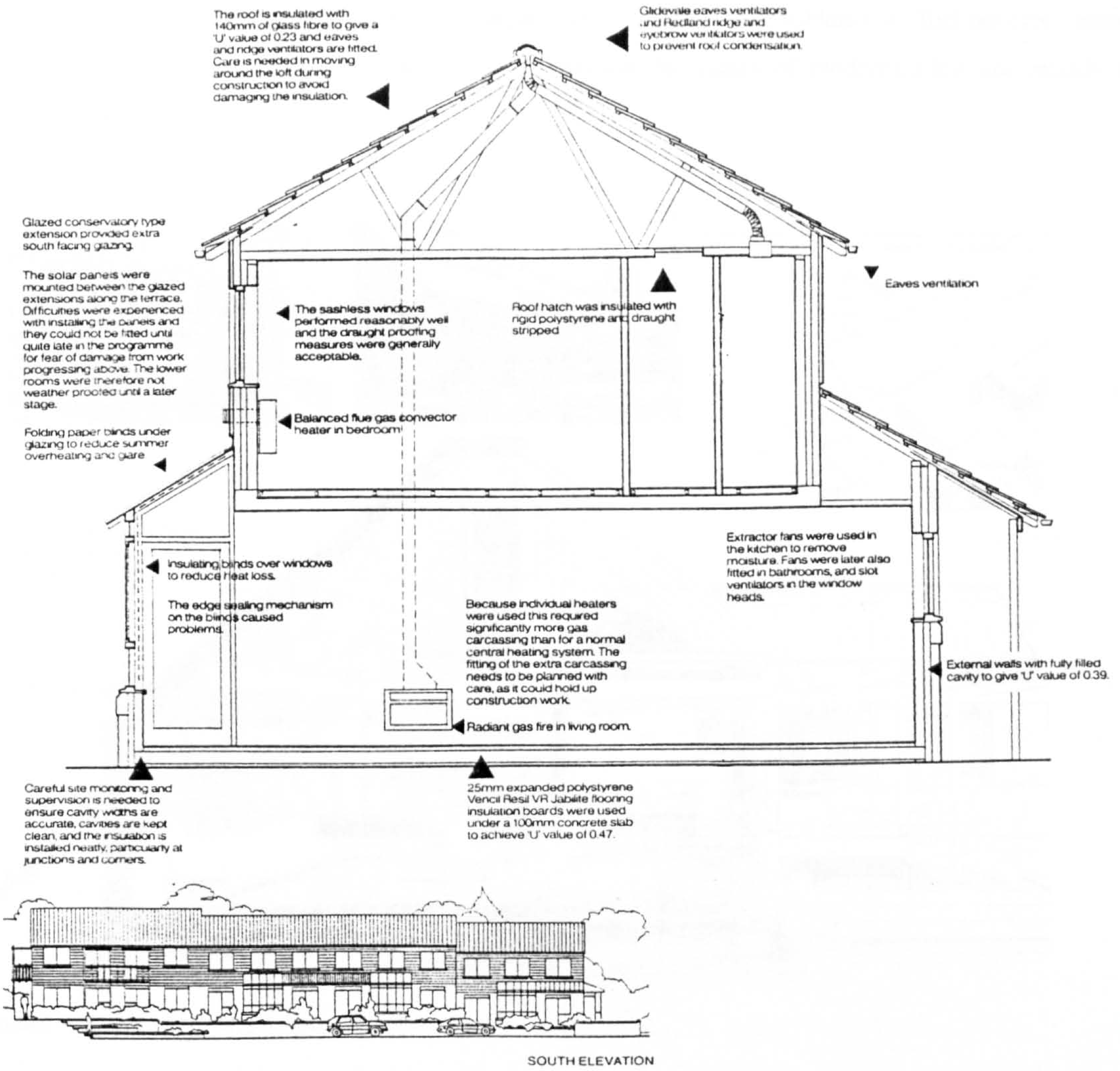


Figure 1.3 Carrigeen Park, Clonmel, Ireland.

1.1.4 Giffard Park Housing Co-operative Project, Milton Keynes - 1983 (52°1'N)

This scheme is included since its passive solar component resembles an 'opened-up' version of a sunspace. There is an apparent sunspace at the south end of the living room, with both vertical and roof glazing and with a solid floor to function as a thermal store. But the lack of dividing screen or wall means that it is simply a highly glazed direct gain system. There is also an active solar element - gravity-fed solar hot water panels for a selection of solar houses. The project (Figure 1.4), which consists of thirty-six flats and houses arranged in four identical two storey terraces on a rectangular site alongside the Grand Union Canal in Milton Keynes, was monitored from September 1983 to February 1986.


The roof is insulated with 140mm of glass fibre to give a 'U' value of 0.23 and eaves and ridge ventilators are fitted. Care is needed in moving around the loft during construction to avoid damaging the insulation.

Glidevale eaves ventilators and Redland ridge and eyebrow ventilators were used to prevent roof condensation.

Glazed conservatory type extension provided extra south facing glazing.

The solar panels were mounted between the glazed extensions along the terrace. Difficulties were experienced with installing the panels and they could not be fitted until quite late in the programme for fear of damage from work progressing above. The lower rooms were therefore not weather proofed until a later stage.

The sashless windows performed reasonably well and the draught proofing measures were generally acceptable.

Roof hatch was insulated with rigid polystyrene and draught stripped

Balanced flue gas convector heater in bedroom

Folding paper blinds under glazing to reduce summer overheating and glare

Insulating blinds over windows to reduce heat loss.

The edge sealing mechanism on the blinds caused problems.

Because individual heaters were used this required significantly more gas carcassing than for a normal central heating system. The fitting of the extra carcassing needs to be planned with care, as it could hold up construction work.

Radiant gas fire in living room.

Extractor fans were used in the kitchen to remove moisture. Fans were later also fitted in bathrooms, and slot ventilators in the window heads.

External walls with fully filled cavity to give 'U' value of 0.39.

Careful site monitoring and supervision is needed to ensure cavity widths are accurate, cavities are kept clean, and the insulation is installed neatly, particularly at junctions and corners.

25mm expanded polystyrene Vencil Resil VR Jabilite flooring insulation boards were used under a 100mm concrete slab to achieve 'U' value of 0.47.

Figure 1.4 Giffard park Housing Co-operative Project.

Results[4] revealed a boost of 25% solar contribution to the heating load compared to an average United Kingdom dwelling. However, the proportion of useful direct solar gain was unknown since there was no equivalent reference house with reduced glazing area replaced by insulated opaque wall. The performance of solar water heating system was also extremely disappointing with a payback period well exceeding the expected lifetime of the system due to its ineffectiveness.

1.1.5 NETHERSPRING CO-OPERATIVE, SELF-BUILD HOUSES, SHEFFIELD - - 1983 (53°4'N)

This is a further example of passive solar intent in the form of large sunspaces, air collectors within these spaces and variable insulation between sunspaces and heated volume. The techniques were a development from the SHED project (Figure 1.5) at the University of Sheffield by Green[5]. Although little performance data is available, the demand-led co-operative and self-build nature of the project clearly placed high amenity homes within reach of those normally in the tenanted public sector. It seems to illustrate in principle, provided an appropriate financing/enabling structure is in place, that sunspaces are not unaffordable luxuries in a mass housing context.

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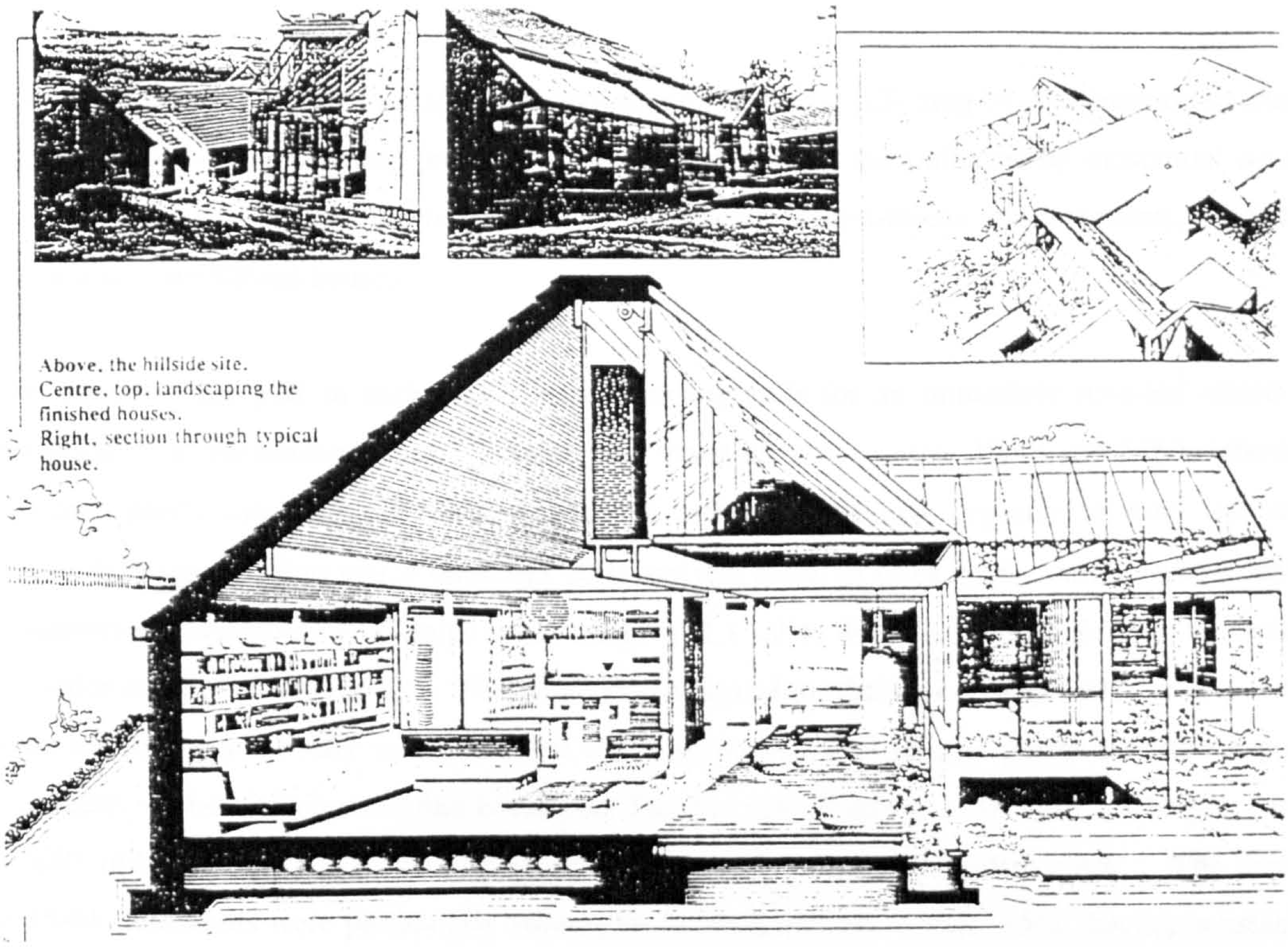
[4] DIRECTORATE GENERAL XII: COMMISSION OF THE EUROPEAN COMMUNITIES PROJECT MONITOR - GIFFARD PARK HOUSING CO-OPERATIVE PROJECT, MILTON KEYNES, UK. Issue 1 - June 1987 8 pages.

[5] RAVEN D. GREEN ENERGY RIBA Journal, Oct. 1985 p.p. 53-55.

This contention has great relevance in the Scottish context, where the problems of 'fuel poverty' associated with existing stock are acute and proposals which go beyond the issues of modernisation are readily targeted as unaffordable and unrealistic.



Above, the hillside site.
Centre, top, landscaping the finished houses.
Right, section through typical house.

Figure 1.5 Netherspring Project.

1.2 FUEL POVERTY - GENERATING A DEMAND FOR PASSIVE SOLAR SOLUTIONS

Fuel poverty[6] is simply defined as the inability to afford adequate warmth in the home and was first identified as a distinct issue of public concern following the oil crisis in 1973-4. The plight of fuel poverty is well documented by Boardman[7]. The findings of a survey carried out in 1988 reveal a median household in the UK spent 5.1% on fuel. However, the proportion of total expenditure on fuel varied widely from 11.5 % for the poorest quartile to 3.5% for the richest. A family in the lowest income quartile spent more than twice the median as proportion of income. Even amongst low-income households, the proportion spent on fuel[8] varies considerably:

- Pensioners 14.4%
- Single parents 15.8%

The problem of fuel poverty stemmed from three main causes, namely:

- increase in the real fuel price (steeper price rises in electricity than gas);
- loss of income in real and absolute terms;
- inadequate building standards.

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[6] LEWIS FUEL POVERTY CAN BE STOPPED National Right to Fuel Campaign, Bradford 1982.
[7] BOARDMAN B. FUEL POVERTY: FROM COLD HOMES TO AFFORDABLE WARMTH......Belhaven Press: London 1991.
[8] SOCIAL TRENDS (ANNUALLY) 1990 Central Statistical Office, HMSO. The year quoted in the reference is the year of the year, rather than the year of publication.

In 1985, Glasgow District Council (GDC) undertook a physical survey[9] of the condition of 15,700 dwellings (9% of the total housing stock) in the city. The survey highlighted the extent of measured disrepair in the City's housing stock. Alerted to the danger of housing disrepair and lack of amenity being regarded as solely physical problems, Glasgow District Council also carried out a parallel social survey.

The survey found that GDC had some 46,000 dwellings (28%) affecting by condensation in which 14,000 (8%) had a substantial condensation problem. The housing stock most affected by substantial condensation are the early post-war tenements, the inter-war semi-detached four-in-a-blocks and tenements, and the early post-war low rise non-traditional houses.

The extent of disrepair in such public sector housing calls for an immediate state-led action to arrest further deterioration of the housing stock. Among the worst affected are the 1950s and 1960s tenements, which are generally poorly insulated and often in locations with above average exposure to wind and rain. They are primarily in three or four storey buildings with concrete block or brick cavity walls, which have a high thermal transmittance co-efficient or U-value in the range of 1.1 - 2.4 W/m^2K; and single-glazed, steel framed windows - U-value norm of 6.0 W/m^2K. They were also designed for the era of cheap fuel, initially with coal fires in all main rooms, and laterally with coal fires in living rooms, and electric power sockets for portable appliances elsewhere. These tenements often house poor families with children. In 1985, Glasgow District Council had 48,600 of such properties which formed the largest single group in Glasgow' stock. The survey found that the 1945-64 tenements were particularly vulnerable to condensation, with 35% having substantial condensation problem. Easthall is a typical housing estate of this era and is amongst the worst affected. Irrespective of tenure, the 1950s and 1960s tenements were more vulnerable to condensation than tower blocks and deck access developments. It is the combined effect of low disposable income, excessive heat loss, lack of economic and responsive heating and ventilation, the last particularly with respect to drying clothes, which provides a 'condensation cocktail'.

The plight of fuel poverty is naturally concentrated in the low-income groups which are spending a higher proportion of their disposal income on fuel due to these thermally defective characteristics. Typical measures taken by many local authorities to rectify these problems are often piecemeal - for example, draught-proofing and elementary loft insulation programmes; and may also incorporate other objectives such as employment/training. Other more radical programmes, such as window replacement and internal/external wall insulation, may or may not be associated with installation of heating systems. So typically, an 'improvement' may result in a somewhat lower rate of air change (due to draught-proofing and/or new windows), but the relative humidity still frequently rises above 70%, particularly in parts of the dwelling which are thermally isolated from the living room. Most Scottish housing stock also suffers from impractically small kitchens with lack of adequate facility to dry clothes indoors, and tenements typically have other particular characteristics which are currently negative,

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[9] GLASGOW DISTRICT COUNCIL HOUSE CONDITION SURVEY 1985 - Volume Five Condensation and Dampness May 1989.

but could be positive - e.g. dank common stair 'closes', and balconies or verandas which are currently under-used due to the unfavourable climate or poor orientation.

Out of this bleak scenario, in tandem with a more flexible approach to the financing of regeneration of houses, a range of more radical solutions are now emerging as follows:

- the first option is to demolish relatively recent stock and rebuild - generally with a funding structure which draws on the private sector;
- the second option is selective demolition or height reduction, often leading to loss of verandas and conversion to main-door terraced form;
- the third option is to retain the basic form, but to institute a complete thermal up-grading package which includes the entrance close and verandas, and possibly also to add on features which cannot be accommodated within the existing shell.

The third option is cheaper per housing unit than the first two, and offers scope for the kind of passive solar interventions examined in this work, namely the Solar Energy Demonstration Project at Easthall. Of course, it cannot compete in a simple cost comparison bases with a fourth option, which is to 'make do and mend' with minimum possible thermal upgrading within the existing shell. But such a fourth option tends to leave unresolved issues, for example, lack of utility provision and storage space, and hence future maintenance burdens.

Problems of dampness due to condensation are not entirely confined to older stock. Although 1980s housing could not be said to fall into the general 'fuel poverty' category, cold-bridging and lack of controlled ventilation can still result in persistent condensation and mould growth[10]. So it is relevant to refer to a new-build passive solar case study in Scotland, and nearly 5°N latitude further north than the most northerly of the United Kingdom and Irish examples cited above.

1.3 STILEPARK NEW-BUILD HOUSING PROJECT, STORNOWAY, ISLE OF LEWIS - '84 (58°2'N)

Undoubtedly, new-build passive solar energy has distinct advantages over retrofit. Orientation can be optimised and passive techniques aligned with essential components of the plan/construction. Concurrently with the theoretical modelling by Bartholomew[11], the first Scottish new-build passive solar housing was near to completion in the Western Isles of Scotland (Figure 1.6).

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[10] PORTEOUS C. VISUAL SURVEY (25th 1989) THERMAL ANALYSIS - 11/13 BURGH HALL STREET, PARTICK, GLASGOW. February 1989. Unpublished, copies available through MEARU, 177 Renfrew Street, GLASGOW, Scotland.

[11] BARTHOLOMEW D.M.L. POSSIBILITIES FROM PASSIVE SOLAR HOUSE DESIGN IN SCOTLAND THE INTERNATIONAL JOURNAL OF AMBIENT ENERGY Vol. 6 No. 3 p.p. 147 - 158 July 1985.

Figure 1.6 Stornoway New Build Housing Project.

The project aims to demonstrate the potential for passive solar systems at high latitudes where lower direct solar radiation, but higher diffuse radiation still offers a significant energy saving for twenty-two single person flats built in two and three storey blocks. Each flat has its own sunspace in the form of a double glazed entry porch abutted by a shared communal stairwell which is integrated with an air collector and thermal rock store. A single glazed screen with hit and miss ventilator at high level was used to partition the living room and sunspaces. From rudimentary questionnaires, the uses of sunspaces and, in particular, the use of the dividing screen between buffer zone and living room are unclear. More importantly, the aspirations leading to the opening or closing of the screen are unknown.

Nevertheless, work by Porteous[12] based partly on predictive analysis and partly on measured fuel consumption together with weather data, reveals the following findings:

- the sunspace strategy favours relatively high temperature demand regimes (i.e. by the user) corresponding to a relatively low specific heat loss value (outwith the user's control) as in the ground floor intermediate location;
- inappropriate uses of damper and overnight charge control may result in inadequate heating to meet a resident's demand, hence resulting in the use of auxiliary heating appliances, i.e. bottle gas or electric convector;
- higher infiltration rates due to high winds might be the cause of higher than predicted space heating loads (highest gusting values in January and December 1986);

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[12] PORTEOUS C. PERFORMANCE CHARACTERISTICS OF SOLAR BUFFER ZONES FOR SCOTTISH HOUSING PhD Thesis University of Strathclyde Chapter 2 p.p. 17 - 51 Oct. 1990.

- slow responsiveness of storage heaters may cause over-consumption by overheating or the use of auxiliary heating in a rapidly changing autumn weather.

Porteous[13] also infers an interesting aspect - a resident's subjective need for warmth. In two particular sunny but cold months, February '86 and March '87, measured heating consumption is significantly below of that predicted. This may be as a result of subjective well-being and experienced physical comfort - sitting in direct warmth from the sun while room air temperature remains relatively cool. Conversely, a visible and responsive radiant heating source may fulfil the subjective need particularly in a wet, windy climate. The research supports the need to have a better understanding of the motives behind resident interactions with the sunspace. It also indicates a need for more reliable measured data with respect to the potential performance of sunspaces without the erratic variables due to the intervention on the part of the occupants. The latter has at least been possible in Scotland due to the presence of one of the European PASSYS[14] test sites in Glasgow.

1.4 PASSYS IN SCOTLAND

Demonstration projects, test cell experiments and computer simulations form parts of the programme funded by the Directorate General for Science Research & Development, Commission of the European Communities. The PASSYS programme of DG XII of the European Commission involves the research institutions of several member states who monitor specific passive solar test components. One objective of the United Kingdom team at the University of Strathclyde was to examine the influence of the conservatory in different operational modes with a view to assessing the relative benefits for potential energy saving in practical applications. The conservatory operates firstly as a buffer zone and secondly as a source for ventilation pre-heat.

The findings[15] of the PASSYS test cell at the University of Strathclyde indicate that solar ventilation preheat mode has potential in saving energy by pre-heating ventilation air. Although the experimental results reveal that for an overcast day during a heating season, with a low level of solar radiation, solar ventilation pre-heat gives little or no benefit at all; for a sunnier day, some benefits may be achieved provided that the thermal capacity of the conservatory is significant, or the radiative heat losses reduced, say by insulated panels. This is essentially when the conservatory is operating at a free float mode without any occupants' interventions.

1.5 PREVIOUS RESEARCH ON THE INFLUENCE OF OCCUPANTS

Research into occupancy-related factors and how dwellings are used, and the subsequent effects on heating needs has been rather general in nature; and reliable data on how occupants interact with ventilation and heating controls seems to be relatively sparse. However, the influence of occupants on fuel consumption was certainly recognised in relatively early research work. Two national surveys were carried out in 1951/52 and 1955[16] in an attempt to quantify fuel consumption of dwellings in England and Wales and to study some of the factors affecting consumption. Early monitoring work by the Building Research Establishment (BRE) on 20 similar

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[13] PORTEOUS C. ibid. Chapter 2.5 p.p. 41 - 50 Oct. 1990

[14] VAN DIJK H.A.L., ANTINUCCI M. TEST METHODOLOGIES FINAL REPORT, PASSYS PHASE I, 1986 - 1989 Official Publication of the European Communities, Luxembourg, EUR - 13122, 208 pages 1990.

[15] BAKER P., GUY A., STRACHAN P. PERFORMANCE ASSESSMENT OF A CONSERVATORY IN SOLAR VENTILATION PRE-HEAT MODE Proceedings of the NORTH SUN '92- Solar Energy at High Latitudes p.p. 132 - 136 September 1992.

[16] GRAY P.G. DOMESTIC HEATING - AN INQUIRY FOR THE BUILDING RESEARCH STATION IN 1955. Central Office of Information, SS237, 1955.

dwellings with different heating systems at Abbots Langley[17] suggested variations were partly due to the heating systems and partly to occupant requirements.

The findings at Abbots Langley specifically concerning window opening will be referenced in subsequent chapters and are of particular value, along with other later work (see also Section 4.1.5) in setting a level of expectation with respect to such intervention by the occupants. Indeed coming to terms with what is normal and reasonable behaviour for users given a particular system, in this case a house with sunspaces and manually openable windows, doors, louvres and vents, appears to be the crux of evaluation. Housing enablers should simply not expect an almost 'closed-window' regime throughout a heating season and this is not 'custom and practice'.

Further work[18] carried out by the BRE, Scottish Laboratory, on the effects of insulation in a large number of local authority dwellings with similar calculated heat loss confirmed a wide range of fuel consumption for space heating as well as total delivered energy. In well-insulated dwellings, the 10% highest users consumed 2.5 times more energy for space heating than the 10% lowest users. In the poorly insulated dwellings, the difference was 6.5 times which was reported to be partly due to socio-economic factors as well as the level of fabric loss.

The unpredictability of energy consumption was mirrored on the other side of the Atlantic in USA where an extensive study on the influence of occupants was carried out in the Twin River Project as part of a major research into energy demand of the town.

THE TWIN RIVER PROJECT, USA, 1948 - 1950.

The two-year study confirms the occupants did play an influential part with respect to the energy demanded. The study of 205 similar dwellings reported by Seligman et. al.[19] confirms findings as follows:

- where there had been a change of occupants, energy consumption of the new occupants could not be predicted from the old. The effect of different occupants on weekly fuel consumption of the same house is illustrated in Figure 1.7. The graph does show the dependence of energy consumption on external temperature to be similar in both cases.
- the variance in space heating energy consumption among the dwellings remained the same as before the dwellings had been thermally improved by 20% to 25%.
- the rank order in relation to energy consumption did not change after thermal improvements.

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[17] WESTON J.C. HEATING RESEARCH IN OCCUPIED HOUSES. Journal of the Institute of Heating and Ventilating Engineers, V19, n143, p.p. 47 - 108, 1951/2.

[18] CORNISH J.P. THE EFFECT OF THERMAL INSULATION ON ENERGY CONSUMPTION IN HOUSES. Proceedings of the 1976 Symposium of the International Council for Building Research studies and Documentation (CIB), Building Research Establishment, The Construction Press p.p. 459 - 466.

[19] SELIGMAN C. DARLEY J.M., BECKER L.J. BEHAVIOURAL APPROACHES TO RESIDENTIAL ENERGY CONSERVATION. Energy and Building, V1, p.p. 325 - 337, 1977/78.

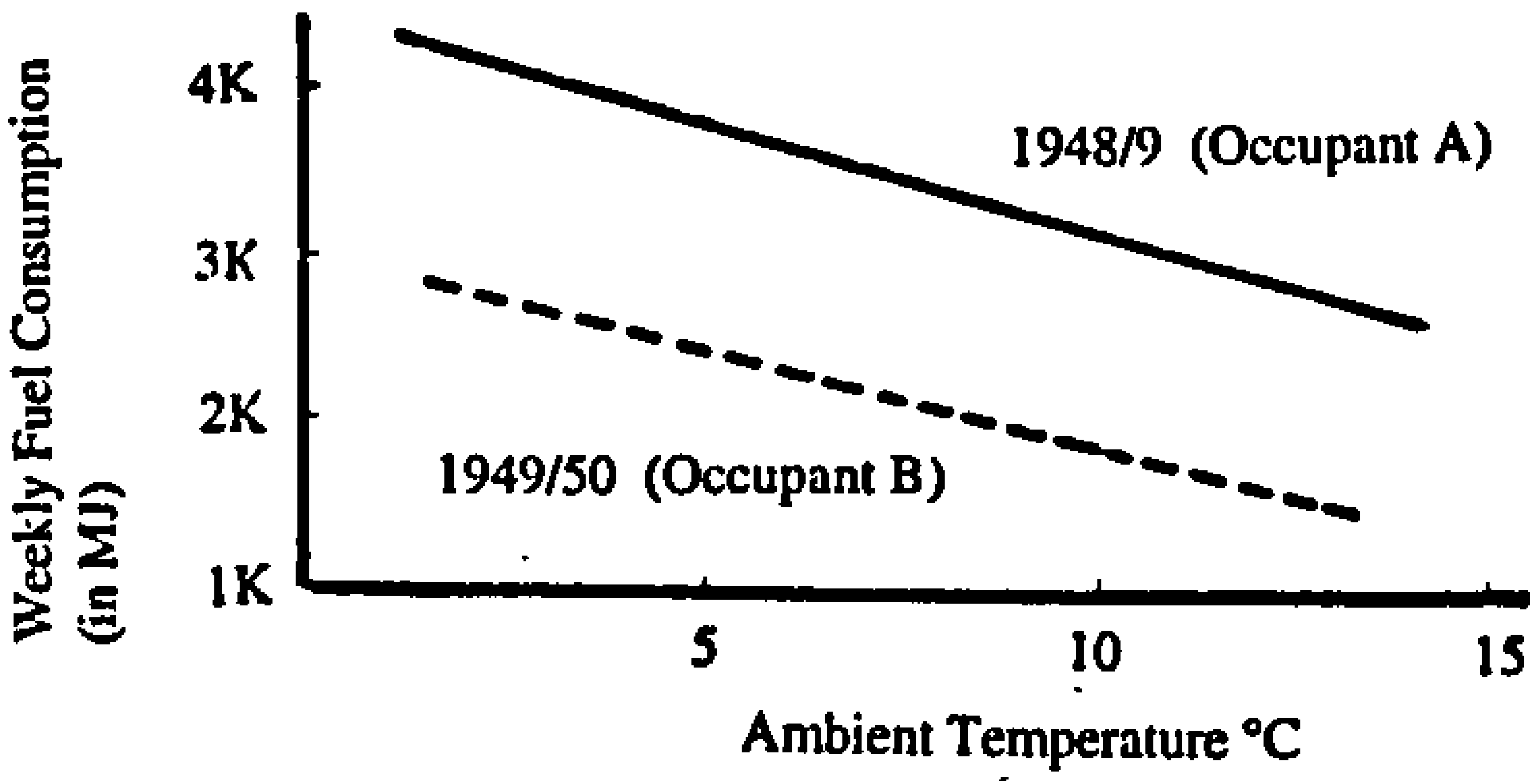

Figure 1.7 Effects of Different Occupants on Fuel Consumption.
(Source: Seligaman C. et.al. 1977/78))

The study concluded that two-thirds of the variation, unexplained by obvious physical factors, was caused by occupant-related factors. Half of the variation caused by occupant-related factors was due to changes in occupant behaviour over time, and the other half was due to permanent behaviour.

The Twin River Project confirms energy consumption is indeed strongly influenced by the occupants' behaviour and interactions with ventilation and heating controls. However, the extent of influence was not clear and, to a large extent, not easy to identify. Compatible research work in France - the Le Balcons de Velchee project reported by Bourdeau[20] - provides a degree of insight with respect to the occupants' behaviour influencing energy consumption for space heating in a passive solar project which employs small sunspaces similar to those at Easthall.

THE LE BALCONS DE VELCHEE PROJECT, FRANCE, 1984.

This project was researched almost a decade ago and, it has its direct relevance to the CEC Easthall project in terms of similar passive solar features, and in that the study focuses on how people use their sunspaces. The work studied a group of 186 rental flats in six two-to-eight storeys high blocks, as in Figure 1.8 (overleaf), built at Malzeville, near Nancy, Eastern France. The field study was conducted partly using a questionnaire to assess satisfaction, especially concerning use of the sunspace, partly by observation of the use of the shading system, and partly by measurements in some of the sunspaces and living rooms as well as fuel consumption.

The questionnaire attracted a response rate of 51% (93 out of the 183 households responded). The findings confirm that the sunspace was not much perceived as a thermal feature by the occupants - only 9% spoke of the heat provided by the sunspace as an advantage. However, the provision of sunspace was well received as an additional amenity to the occupants with an overwhelming 71% satisfied, within which 20% were very satisfied. Despite the lack of perception with respect to thermal function, monitoring results confirm that the behaviour of occupants has by no means cancelled energy savings provided by the addition of a sunspace to a given facade design. However, although this project focuses on the use of the sunspace and its shading system, the methodology which relies mainly on data from questionnaires, observations by the author, and rudimentary fuel consumption and thermal comfort measurements may mask the underlying reasons of how and why the occupant interact in such a way with their shading devices as well as ventilation and heating controls.

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[20] BOURDEAU L. HOW PEOPLE USE THEIR SUNSPACES. Building Research and Practice, The Journal of CIB, Volume 16, Number 3, 1988 p.p. 167 - 171.

The project has not explored the influence and interaction of family structure, daily patterns of occupancy and habits in terms of heating and aspirations and/or needs. According to the findings of the Twin River project described previously, this dynamic can lead to a two-thirds variation in energy consumption. The deficiency of the French project in terms of understanding of the occupant-related factors and the interactions of the occupants with ventilation and heating controls suggests that further research in this area is much needed. This work aims to give a feel for how the occupants in the Easthall project operate heating and ventilation controls, and where possible the motives leading to such actions, by correlating various characteristics of the occupants with space heating consumption, and with particular regard to use of the sunspaces and the various means of controlling ventilation.

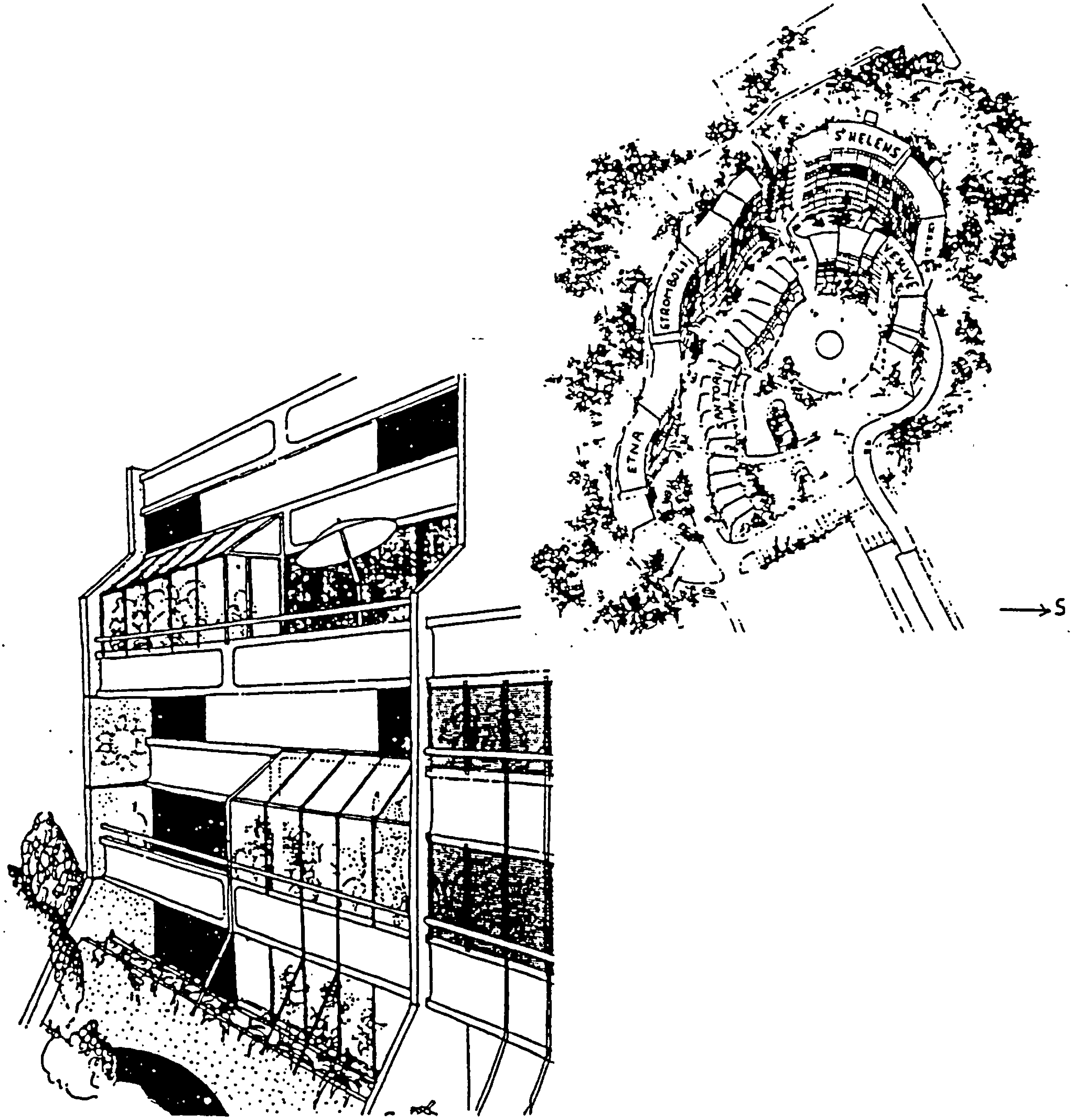

Figure 1.8 The Le Balcons De Velchee Project, France.

Despite some gaps, Bourdeau's attempt in quantifying the energy penalty with respect to shading devices, ventilation and heating controls is of much interest and relevance to this project. Occupants are classified into 'standard' and 'non-standard' behaviour in accordance with how the occupant uses the sunspace. Standard behaviour refers to occupants who always kept the blinds in the up position during the day (blinds down at night), and the sunspaces openings and French windows always closed, thus achieving the maximum energy savings. Table 1.1 summarises the energy penalty relative to a predicted 'standard' saving of 26% for the non-standard behaviour on heating needs.

	Energy Penalty	Saving
Standard behaviour	±0%	26%
Heating of the sunspace	+41%	15.3%
Opening-up of sunspace onto heated volume (extended heated. volume)	+18 - 37%	21.3 - 16.4%
Outer sunspace windows always kept open (vent. sunspace & opening up)	+31%	17.9%
Outer sunspace windows always kept ajar	+20%	20.8%
Inside roller blinds of the sunspace always in the down position	+8%	23.9%

Table 1.1 Energy Penalties of the Bourdeau's Project for Non-Standard Behaviour Occupants. (Last column denotes energy saving compared to an identical model with no sunspace).

Bourdeau concluded that the behaviour of the occupants has by no means cancelled the energy savings provided by the addition of a sunspace to a given facade. Bourdeau illustrated that since the 'standard' behaviour occupant corresponded to a 26% saving (compared to a dwelling without sunspaces), the reduction in saving due to 'non-standard' behaviour in ventilation and heating controls was limited on average to a fifth of the anticipated savings. Therefore, in addition to the amenity value, sunspace may still provide energy saving of 20% for 'non-standard' behaviour occupants, when compared to the same dwellings without sunspace. On this optimistic note, attention is again focused on the CEC project.

1.6 CONCLUDING COMMENT

Research data from the PASSYS experiment, backed up with case studies such as that in Stornoway and Le Balcons De Velchee, on the uses of sunspaces for solar ventilation pre-heat and climatic buffering suggests that an energy saving in winter months is achievable whereas monitoring projects like Carrigeen Park suggest that the use of sunspaces is highly user-sensitive. Energy consumption up to two-third variation has been reported in the Twin River project in the USA. This work sets out to investigate user performance sensitivity of small sunspaces in the context of energy-efficient retrofitted houses. The intention is to explore the viability of a much more flexible approach to ventilation rates than is normal, with the objective of promoting better air quality while not compromising fuel expenditure.

CHAPTER 2 EASTHALL SOLAR ENERGY DEMONSTRATION PROJECT PROCUREMENT.

2.1 PROJECT BACKGROUND

The Solar Energy Demonstration Project is in the Easthall council estate in the Easterhouse District of Glasgow as shown in Figure 2.1. The 3-storey tenemental blocks (flats accessed by common staircases), dating from the late 1950s and early 1960s, are built partly cavity brickwork and partly in non-traditional composite concrete block adapted from a former proprietary system[1]. The latter are particularly difficult to keep warm because of the high heat loss co-efficient, and all of the thirty-six solar retrofitted dwellings are of this type.

Each composite 'Wilson' block comprises a slender inner and outer leaf held together with 3 concrete encased steel ties, resulting in extensive 'peppered' cold bridging. The block as originally designed was intended to include sawdust/cement battens cast on to the inner leaf to which plasterboard would be fixed - i.e. a dry-lining over a second cavity. This construction was tested by the Building in the early 1950s[2] and found to have a U-value of 1.7 W/m²K. Unfortunately at Easthall, the dry-lining was replaced by plaster directly applied to the inner face of the blocks. By implication, deducting for the thermal resistance of the 'plasterboard + cavity' and adding for gypsum plasters. The U-value at Easthall is of the order of 2.7 W/m²K. This corresponds to a value of 2.43 calculated using the CIBS[3] method. Not only was this well above the maximum value of 1.7 W/m²K introduced in 1963[4], but lack of control joints combined with the slenderness of the outer skin resulted in loss of mortar from vertical joints. The wall was therefore vulnerable to both moisture penetration from the outside as well as surface condensation on the inside.

The uniqueness of this project lies in the participatory role played by the residents, who took all the important initiatives in attempting to identify and overcome the problems associated with the design and construction of their homes. This had important bearings how the demonstration project was conceived and procured.

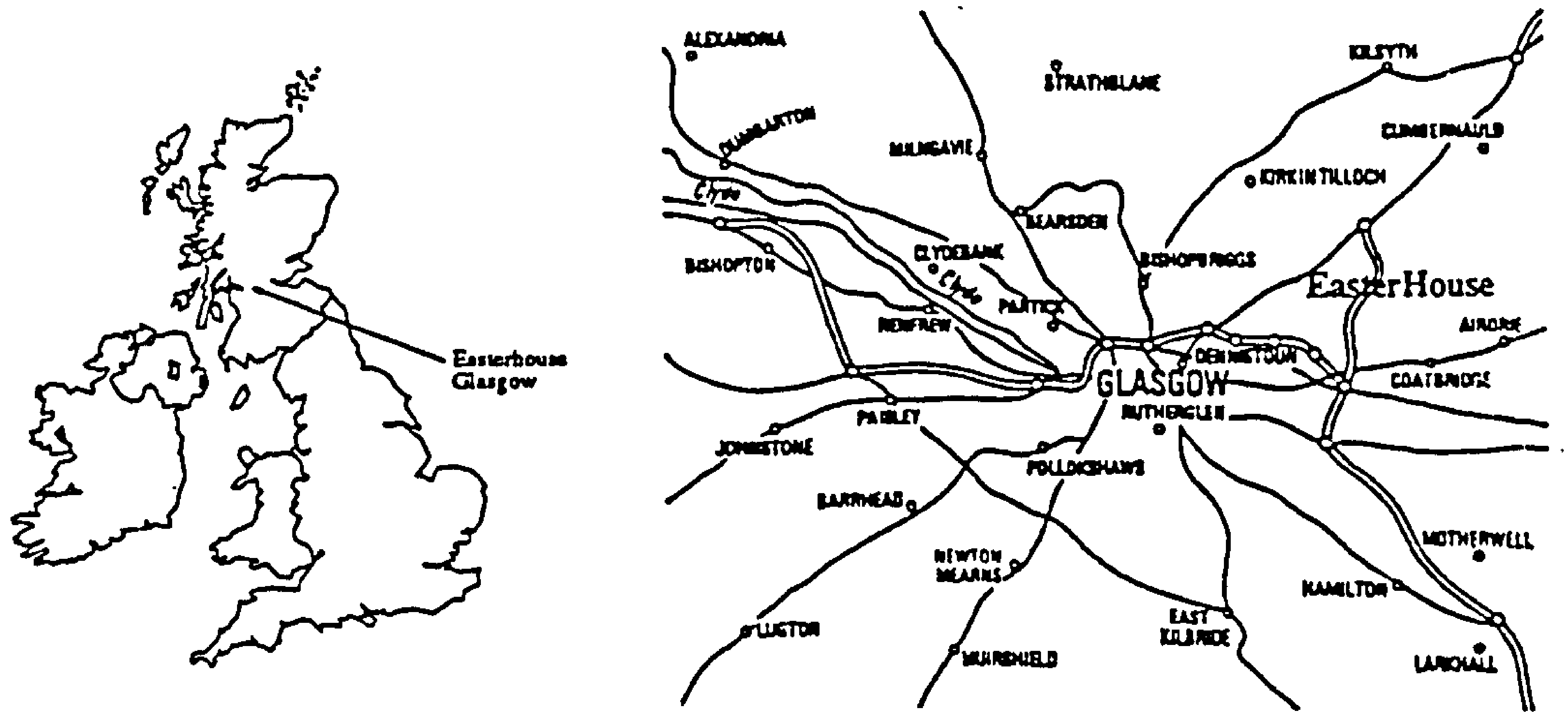

Figure 2.1 Easterhouse Location

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[1] SCOTTISH OFFICE BUILDING DIRECTORATE A GUIDE TO NON-TRADITIONAL AND TEMPORARY HOUSING IN SCOTLAND 1923 - 1955. p.p. 161 - 162 and 207 - 209 1987.

[2] PRATT A.W. HEAT TRANSMISSION IN BUILDINGS Department of Construction and Environmental Health University of Aston in Birmingham Published by John Wiley and Sons p. 252 1981.

[3] CIBS GUIDE A3: THERMAL PROPERTIES OF BUILDING STRUCTURES p.p. A3 9-13 1981.

[4] STATUTORY INSTRUMENTS THE BUILDING STANDARDS (SCOTLAND) REGULATIONS 1963 No. 986 (S125) HMSO London 1963.

2.2 THE STARTING POINT

Poor living conditions became a major concern of local residents relatively soon after they were first occupied. Easthall Residents Association (ERA), an autonomous action group, was formed in 1973 by the residents with the aim of promoting residents' interest and welfare within the estate. Excessive expenditure on heating and frequent re-decoration costs had caused financial difficulties on the part of many residents, apart from living in a thermally uncomfortable and unhealthy environment. In 1982, a survey of housing conditions of almost 2,000 houses as part of the 'Anti-dampness Campaign' in Easterhouse confirmed dampness and 'fuel poverty' as their main priority. This subsequently led to the setting up of the 'Dampness Group' in 1984. In the same year, ERA joined the Technical Services Agency (TSA), a user-controlled Community Technical Aid Centre which had just become operational throughout the Strathclyde Region with the aim of fulfilling unmet technical needs in the tenanted sector.

TSA was formed in 1983 and registered under the Friendly Societies Act with major funding from the European Social Fund's Urban Programme as well as carrying out fee-earning works. TSA's user-controlled structure enabled ERA to take part in its management as well as commissioning more detailed house condition surveys and energy audits within the estate. Two reports[5] were produced by TSA within a period of two years (1985 - 6). One of the alarming findings was that conventional repairs already carried out had made no difference to the incidence of dampness, and had therefore brought little perceived benefit to the residents.

The landlord of the Easthall Estate is Glasgow City Council (formerly Glasgow District Council) and the estate is managed by their City Housing Department. The conventional policy of the Department towards hard-to-heat dwellings with a high incidence of condensation was to carry out remedial work such as dry-lining particularly vulnerable surfaces in rooms which were difficult to heat regularly, improving/increasing ventilation by installing extract fans/mechanical ventilators and eradicating mould and fungus by applying fungal washes. Such measures were reactive and did not address the overall lack of insulation, or the lack of an economic means of whole-house heating, or in this low-temperature context, the provision of an adequate facility for drying clothes indoors.

2.3 THE TURNING POINT

The latter part of the 1980s can be described as the turning point of the ERA campaign in combating dampness and thermally sub-standard living conditions. Armed with technical advice provided by TSA, ERA was also scrutinising the link between sub-standard housing and its consequences such as dampness, mould and ill-health. For example, temperature monitoring had confirmed that inside surface temperatures in thermally remote bedrooms were often only 1 - 2 °C above ambient temperature.

Research findings from a field survey in Edinburgh by Hunt and others[6] of the Research Unit in Health and Behavioural Change at Edinburgh University supported an association between damp housing and children's health. Acting upon TSA's advice, ERA decided to take part in a larger survey carried out in 1988. The

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[5] TECHNICAL SERVICES AGENCY LTD. THERMAL/DAMPNESS FABRIC SURVEY 35 pages July 1985 / MONITORING APPRAISAL 1985/86 20 pages March 1986 - Both reports are for EASTHALL RESIDENTS ASSC and copies available through MEARU, 177 Renfrew Street, GLASGOW, Scotland G3 6RQ.

[6] HUNT S.M., LEWIS C. et. al. DAMP HOUSING, MOULD GROWTH AND HEALTH STATUS. Part 1 and 2. Research Unit on Health and Behavioural Change. Undated.

survey[7] which studied 597 households in public housing in Edinburgh, Glasgow and London confirmed the earlier findings of a significant, if lesser, association between adult health (which the previous survey had not identified) as well as that of children and dampness in housing. On-going study in linking ill-health and thermally inadequate housing is continuing.

2.4 THE 'SPARKING' POINT

The Scottish Solar Energy Group in conjunction with the West of Scotland Energy Working Group were interested in sponsoring an ideas competition to upgrade sub-standard housing in Scotland. Subsequently, due to commonality of purpose and already established links, TSA became the third sponsor, and ERA, as an active member of TSA, volunteered to host the competition as a 3-day design workshop at Easthall. Financial assistance was also made available by the landlord - Glasgow District Council - through the Greater Easterhouse Initiative, an agency set up to re-vitalise the economy of the district.

2.4.1 HEATFEST COMPETITION

The weekend idea's competition took place at Easthall in January 1987 with seven multi-disciplinary teams comprising architects, quantity surveyors, engineers, housing managers, representatives from other resident's groups and architectural students. The participation of the end-users, namely the residents in the design team undoubtedly reflected the vital role played by ERA. This was summarised by Helen Martin[8], subsequently ERA Chairperson:

> *"....... all the professional people in the past had been responsible for creating these living conditions would be sitting round a table with residents .... and coming up with ideas for solving that problem. The residents were part of the team so that their voice would be heard, and it was probably one of the first competitions where the residents actually did have a voice in making decisions as to how things should be done."*

The brief for the Heatfest objectives[9] included:

1. Modify the building fabric in order to reconcile the space heating load for all flat locations to thermal comfort within an affordable expenditure band - taken to be an average house temperature of 18°C within an upper cost limit of £5 per annual week at 1987 fuel prices. In conjunction with insulation measures, consideration should be given to reduction transmission losses using passive solar techniques.
2. Provide a well distributed heating capacity, the criteria being the unit cost in relation to (1), responsiveness and quality/comfort.
3. Devise a natural/mechanical ventilation system which is simple to control and economically promotes adequate rates of air change to negate adverse effects of normal pollutants and condensation risk. Put simply the aim is for healthy ventilation without draught nuisance and within an energy conscious framework - for example, solar pre-heating of ventilation air may be an appropriate option.

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[7] MARTIN C.J., PLATT S.D., HUNT S.M. HOUSING CONDITIONS AND ILL HEALTH British Medical Journal, Vol. 294, p.p. 1125 - 1127, 2 May 1987.
PLATT S.D., MARTIN C.J. et. al. DAMP HOUSING, MOULD GROWTH AND SYMPTOMATIC HEALTH STATE. British Medical Journal, Vol. 298, p.p. 1673 - 1678, 24 June 1989.

[8] VAUGHAN N., JONES P., et al. ENERGY PERFORMANCE ASSESSMENTS: 9 EDDERTON PLACE Welsh School of Architecture (ESTU Report no. 1163/24 March 1992) p.p. 1-14.

[9] FIELDING M. HEATFEST - publicity pamphlet Mackintosh School of Architecture, Glasgow undated p. 3.

4. Suggest modest planning improvements where these relate to energy efficiency and moisture production, e.g. internal clothes drying provision.
5. Suggest improvements externally with emphasis on energy saving potential.

Table 2.1 compares the predicted energy costs for the HEATFEST improved house with the existing costs[10]. These costs are for the house with the worst conditions, i.e. ground floor, gable end. (in 1988 prices)

	HEATFEST running costs	Existing worst case	UK average
Electricity Consumption	(£ per annual week)		
Space heating	2.90	16.78	
Water heating	0.92	2.50	
Cooking	0.50	1.15	
Lighting & service charge	2.07	2.07	
Total	6.50	22.50	9 - 10

Table 2.1 November - January Space Heating Cost.

2.4.2 COMPETITION RESULTS

The result of the competition was not announced until March 1987 after a panel of adjudicators in conjunction with four evaluation groups representing residents, landlord, public sector and community architects and energy experts had assessed all seven entries.

The winning entry (Figure 2.2) features a glazed-in veranda to the front, a device used by several teams. The small space, 3 m wide by 1.2 m deep, buffers the master bedroom and part of the living room, and also provides a source of pre-warmed fresh air . The folding door to the master bedroom enables extension of this room during the summer months. A feature unique to the winning entry was a glazed conservatory extension on the opposite facade to the veranda, buffering the kitchen and bathroom.

Similar to the glazed veranda, this reduces transmission losses and provides a source of pre-warmed air, this time primarily dedicated to the kitchen. Since direct access to an outside wall was eliminated to both kitchen and bathroom, each required mechanical ventilation. In order to make this work optimally with the two passive solar features, continuously operating fans were proposed. By creating a slightly negative pressure within the house, and assuming the main window to the living room remained closed, air would tend to be drawn in via the glazed veranda and conservatory. It was recognised from the outset that the 'thermal buffer/ventilation pre-heat' attributes of the veranda and conservatory were beneficial spin-offs of their main function, which was additional, albeit unheated floor space. In particular the conservatory provided invaluable space for 'wet-utility' activities which could not be reasonably accommodated in the small kitchen together with space for eating. This requirement was tenant-led and although it might appear extravagant in the 1980s context of constraint in terms of resourcing housing improvements, it simply conformed to the strategy set out by the Scottish Office as far back as 1944[11] as well as to item 4 in the brief. The open verandas were originally built as a needed amenity, but in

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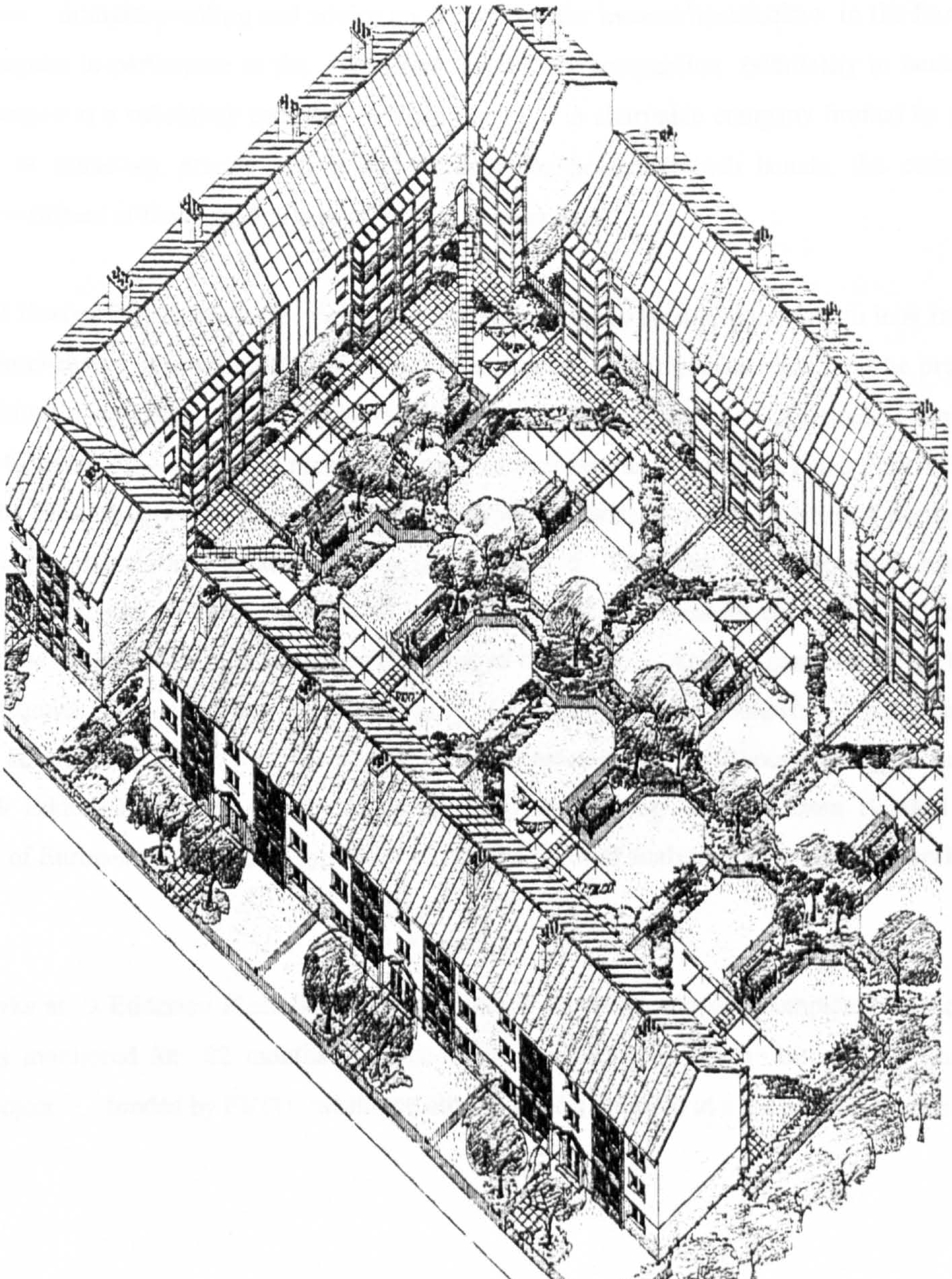
[10] FIELDING M. ibid. undated, p. 9.

[11] SCOTTISH HOUSING ADVISORY COMMITTEE PLANNING OUR NEW HOMES - report by the Scottish Housing Advisory Committee on the Design, Planning and Furnishing of New Homes His Majesty's Stationery Office p. 24 1944.

practice little used due to the nature of the Scottish climate. Glazing them in provided, for a relatively modest outlay, much greater scope for use (homework/play/music den, etc.) as well as a solar 'loggia'.

So having justified the investment in glazing-in the veranda at the front, as well as building on a utility room at the back, as necessary planning improvements, the bonus was that they also fulfilled a passive solar role, with at least one space benefiting from available sunshine during part of the day even though existing blocks were randomly oriented.



Axonometric of Proposed Backcourt Arrangement
(drawn by Willy Munro)

Figure 2.2 'Heatfest' Winning Entry

2.4.3 THE PILOT SCHEME

The enthusiasm of all participants in finding a viable solution to solve the housing problem had kept the momentum continued. A voluntary design team was set up to develop the winning scheme into a detailed design, incorporating some appropriate ideas from other schemes. The detailed design (Figure 2.3 overleaf) later became the blueprint for the refurbishment of six flats at 9 Edderton Place, and subsequently the prototype, in terms of passive solar strategy, of the larger Solar Energy Demonstration Project of 36 houses.

The persistence of the team persuaded Glasgow District Council to make funds available for a pilot scheme at 9 Edderton Place through an agency, Heatwise, which had been operating a thermal improvement programme (loft insulation, draught-proofing and advice on energy for low income households) in the Easterhouse area and had sent delegates to participate in the "Heatfest" conference/competition (similarity in names a coincidence). Heatwise Glasgow is a subsidiary company of Wise Group - a charitable company limited by guarantee. The Group aims at attracting private and public funding for projects which benefit the community and train unemployed members of the community to carry out the works.

The Jobs and Energy Project funded by the Urban Aid was set up by Heatwise in 1987 to look into the possibilities of more comprehensive improvements to housing in the Easterhouse Initiative areas. The project was managed by a committee of delegates from five resident groups in Easterhouse and the Joint Committee of Greater Easterhouse Council. A sub-committee was formed to oversee the 9 Edderton Place Pilot Scheme. This was chaired by the ERA chairperson with representatives from Heatwise and other interested parties representing the interests of both landlord and tenants. The latter included TSA and their associated community business, Community Architecture Scotland (CAS), who were appointed architects for the Jobs and Energy prototype and subsequently the 36 houses which constitute the focus of this work. Another committee was formed with much the same personnel, but chaired by a representative of Glasgow District Council's Department of Architectural and Related Services (DARS) with the task of technical assessment. Although set up in relation to the pilot project at 9 Edderton Place, it also served to assess the primary outcome from Heatfest - the bid to the Commission of European Community by ERA - since the thermal analysis was common to both (see Section 2.5 below).

Building works at 9 Edderton Place began in the summer of 1989 and was completed in the spring of 1990. One flat was monitored for 22 months (March 1990 - December 1991) through an Energy Performance Appraisal Project[12], funded by ESTU while the other 5 were monitored at a lesser level by Heatwise[13].

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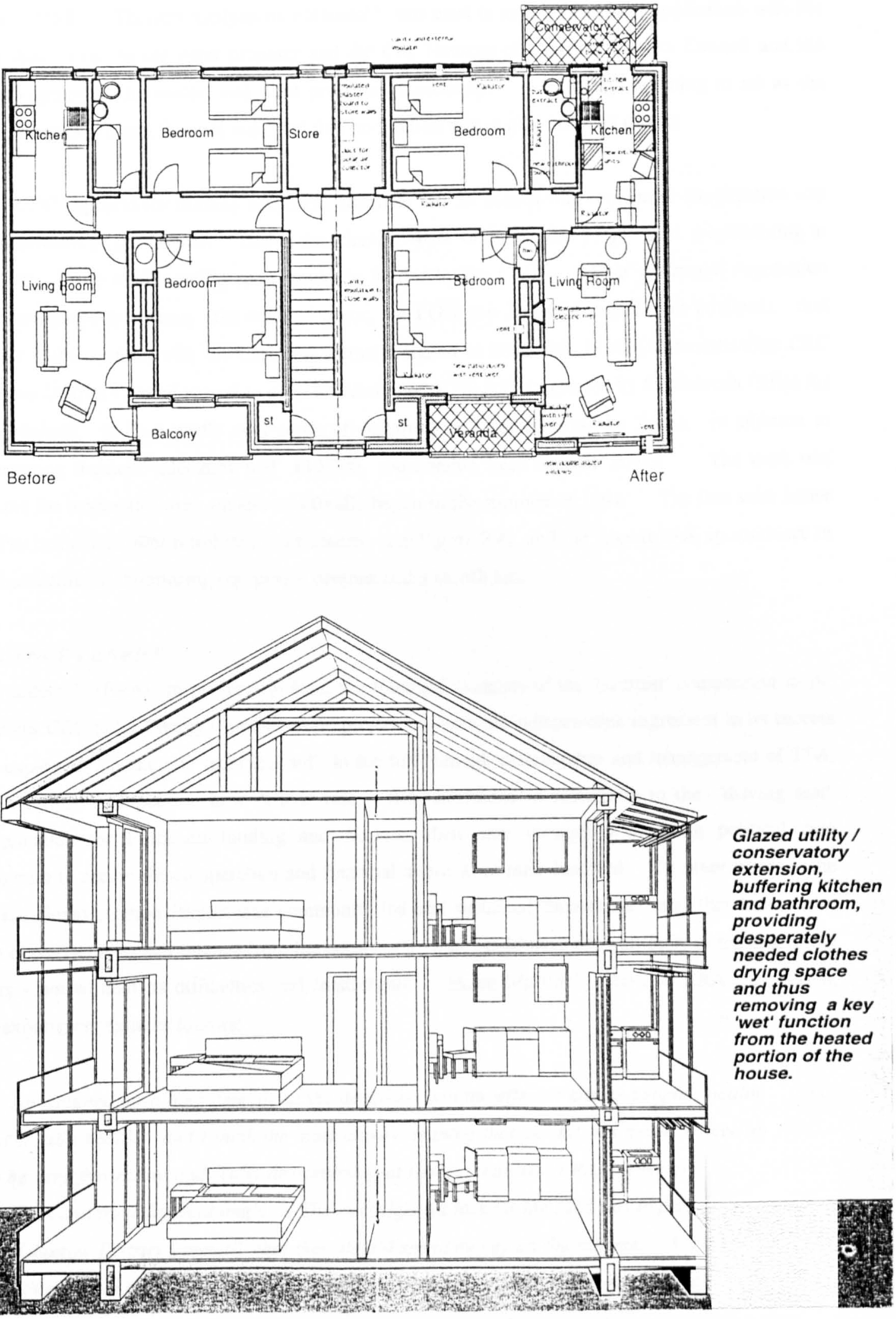
[12] VAUGHAN N., JONES P., et al. ibid. p.p. 3.1 - 3.18 March 1992.

[13] HEATWISE GLASGOW WARM, DRY AND AFFORDABLE TO HEAT - An Interim Report on the Monitoring of the Easthall Project: March 1990 - May 1991. 22 pages April 1992. Copies available through Heatwise Glasgow, 8 Elliot Place, GLASGOW G3 9EP.



Glazed Veranda to the front of the house to enhance an existing amenity as a 'winter garden'. As well as eliminating 'cold bridges', this enables introduction of prewarmed ventilation air via the living room and bedroom. Patio doors to the bedroom permits extension of the room area into this space during the summer months.

Glazed utility / conservatory extension, buffering kitchen and bathroom, providing desperately needed clothes drying space and thus removing a key 'wet' function from the heated portion of the house.

Figure 2.3 Proposed Floor Plan and Section Through Flats.

2.5 BEYOND THE PILOT PROJECT

In response to the Heatfest adjudicators' recommendations to pursue a grant-aided Passive Solar Demonstration Project, the parallel application with respect to the EEC (subsequently known as CEC) Demonstration Project was lodged in April 1988. Thermal analysis by Porteous[14] was used to support the CEC application with the Easthall residents Association as the main proposer and the City Housing of Glasgow District Council and the Technical Services Agency as the second and third proposer respectively. Although agreeing to act as the second proposer, Glasgow District Council indicated that no funding was in place for this project.

In January 1989, CEC approval for funding assistance adequate for 36 houses was confirmed (application was made for the refurbishment of 102 houses). Under the scheme, 40% of the eligible project cost (representing in this case about 30% of the total building cost) would be funded by the CEC. After protracted negotiation between Easthall Residents Association, the main proposer, and Glasgow District Council (the landlord), and the second proposer, the contract with the CEC was formally signed in November 1990 (22 months after CEC approval). Glasgow District Council agreed to extra borrowing of £750,000 (approved by the Scottish Office for energy efficiency projects, at least partly as a result of sustained political lobbying by ERA), in addition to £370,000 from existing financial allocation and £10,000 sponsorship from Scottish Power. The work was subsequently put out for tender and work on site was finally begun in the summer of 1991. The first solar house was completed (For before and after retrofitted solar houses, see Figure 2.4) and the tenants took up residence in March 1992. Installation of monitoring equipment commenced a month later.

2.6 EXPERIENCE LEARNT

The role of the residents (ERA) in proceeding from the freehand sketches of the 'Heatfest' competition to the realisation of a major CEC Solar Energy Demonstration project has been an indispensable ingredient in its success story. Having exploited 'community technical aid' to the full through membership and management of TSA, and hosted the 'Heatfest' competition in a 'client' role, they succeeded in remaining in the 'driving seat', fronting the application for European funding and working their way through a daunting political cum bureaucratic quagmire to secure the co-operation and financial approval of their landlord. In other words, the procurement of the Demonstration Project was community led and sustained throughout, and this has in turn enabled a degree of co-operation and interest from the occupants, that would have been unlikely in the absence of its unique history - not without its difficulties and frustrations. Helen Martin[15], now as ERA chairperson, summarised the experience learnt as follows:

> *"We have campaigned for a long time about the dampness and the effect it has on people's health, in particular kid's health, and I think the most important thing that we did was never to give up .... it can be very frustrating and really demoralising at times ... but we (ERA) never give in and always go back and try a different angle .... The most difficult task for the ERA was to persuade the landlord (Glasgow District Council) that they should spend money on the scheme. We have to come up with evidence that action was needed together with a workable, well-considered scheme*

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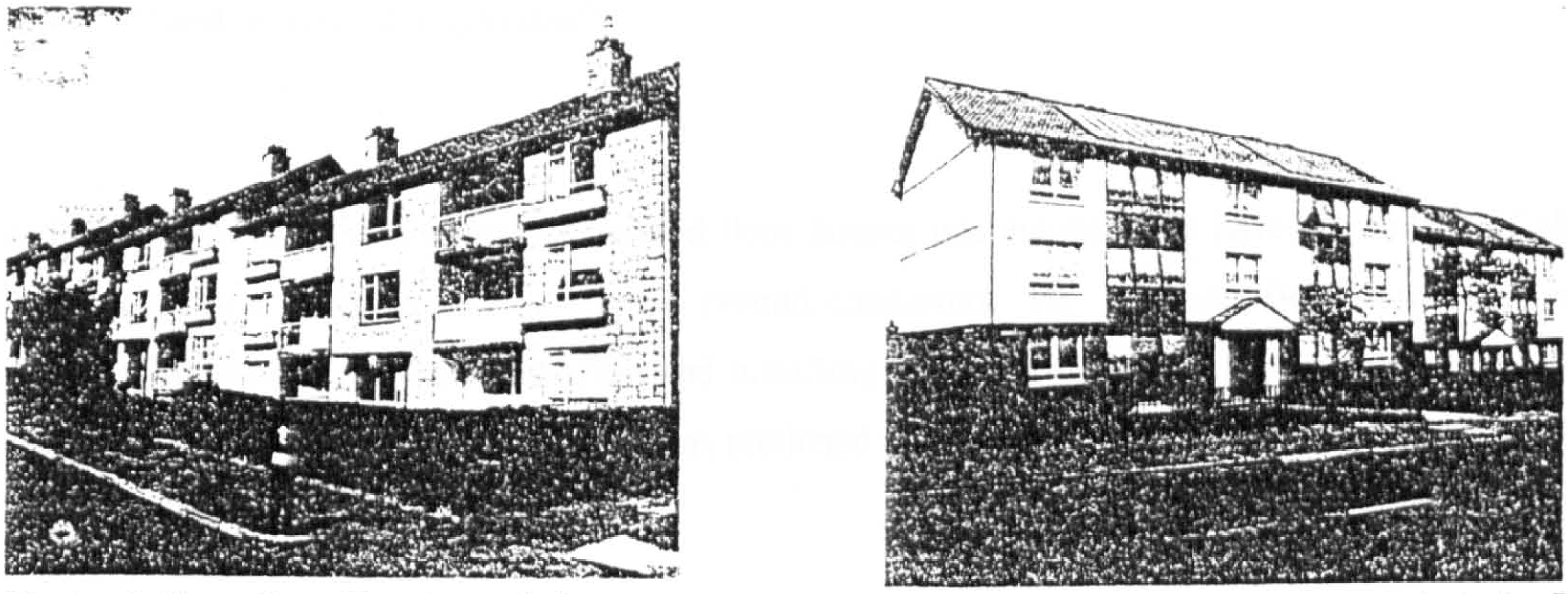
[14] PORTEOUS C.D.A. RETROFIT OF THERMALLY SUB-STANDARD HOUSING IN GLASGOW AS A CEC PASSIVE SOLAR DEMONSTRATION PROJECT Mackintosh School of Architecture, Unpublished, p.p. 12 - 64 April 1988.

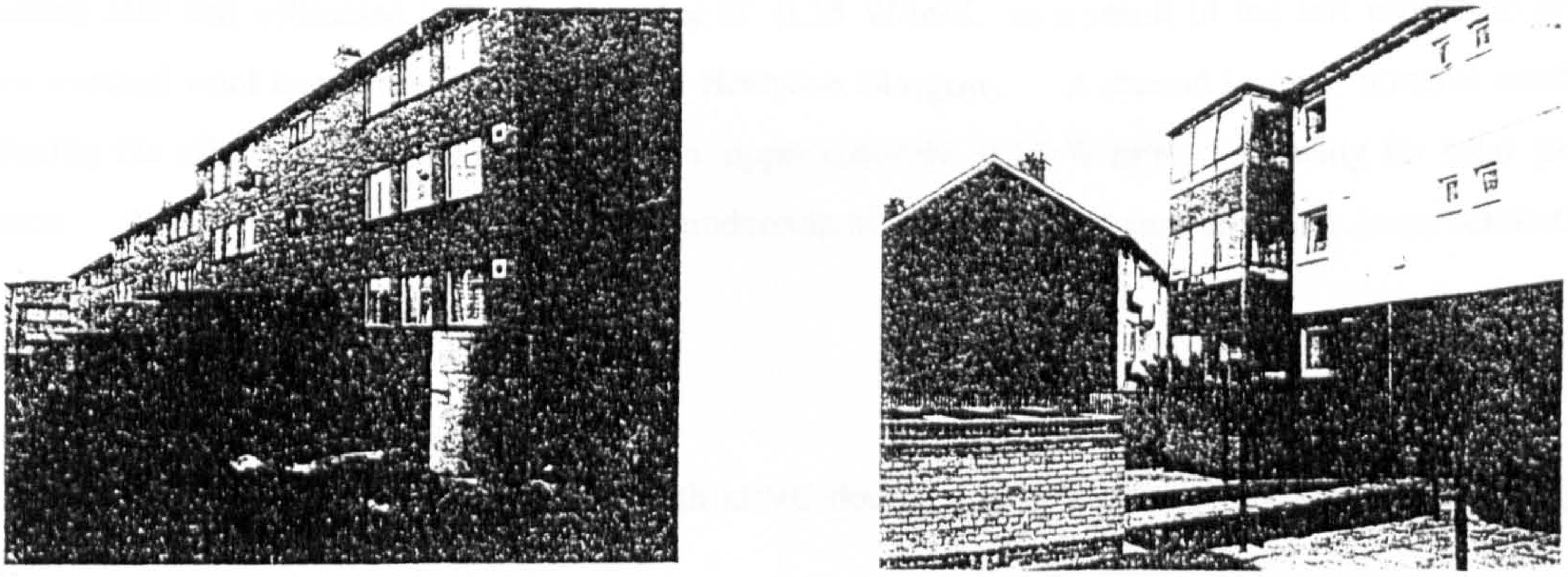
[15] VAUGHAN N., JONES P., et al. ibid. March 1992 p.p. 1-16.

(solution) and a large share of the funds .... We have learnt to argue (our case) articulately and lobby councillors and officers ... and most importantly, collaborate with a wide range of resident groups and technical experts."



Glenburnie Place - Front Elevation as Before.

Wardie Road - Front Elevation (S-E facing) after Retrofit.



Wardie Road - Rear Elevation as Before.

Wardie Road - Rear Elevation (N-W facing) after Retrofit.

Figure 2.4 Before and After Retrofitted Solar Houses.

2.7 DESIGN STRATEGIES

The detailed design strategy described by Porteous[16] embodies three elements; namely, insulation, ventilation and heating:

2.7.1 DESIGN STRATEGY 1: INSULATION

Energy efficiency by means of insulation is an integral part of the project, underscoring the passive solar components.

EXTERNAL AND PARTY WALL

The strategy starts off in energy conservation by reducing fabric loss by means of insulating all the external walls. External wall insulation and cavity-filled insulation are used to achieve a near 'super-insulation' standard for external wall U-values of 0.24 W/m²K. The external insulation overcomes the 'cold-bridge' deficiency of the Wilson Block, and also eliminates water penetration. A relatively small additional expenditure on fibreglass

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[16] PORTEOUS C.D.A. RETROFIT OF THERMALLY SUB-STANDARD HOUSING IN GLASGOW AS A CEC PASSIVE SOLAR DEMONSTRATION PROJECT. Mackintosh School of Architecture, Glasgow, United Kingdom, Unpublished April 1988.

cavity insulation is then justified, since the cold-bridging of the ties has been blocked by the external insulation, and the extra 100mm can now contribute to a significantly lower U-value. The cavity party wall between the staircase and houses are also filled with Pilkington glass wool insulation, whereas the single skin solid wall between the storage area (locally known as 'cellar') was dry-lined. A detailed specification for the various wall constructions is listed in Table 2.1 (overleaf).

FLOORS

The suspended timber floor of the original ground floor houses was estimated to have a U-values of almost 1.0 W/m²K taking account exposure of site, typical ground conditions, etc. Some floorboards were raised and mineral wool insulation put in whilst re-wiring and installing central heating. Most of the original floorboards were untouched. A U-value of 0.37 W/m²K was predicted when fitted with underlay and carpet, and 0.42 in the kitchens and bathrooms.

LOFT

The existing roof was estimated to have a U-value of 0.35 W/m²K as a result of the loft insulation programme (100 mm mineral wool insulation) carried out by Heatwise Glasgow. A second layer of mineral wool has been laid reducing the effective U-value still further to approximately 0.15 W/m²K, allowing for solar gains to the attic space. Plastic ventilators are fixed to the underside of the soffit to ensure adequate cross ventilation in the loft.

WINDOWS

All windows to the heated zones are replaced with uPVC double glazed windows (U-value estimated to be 3.05 W/m²K).

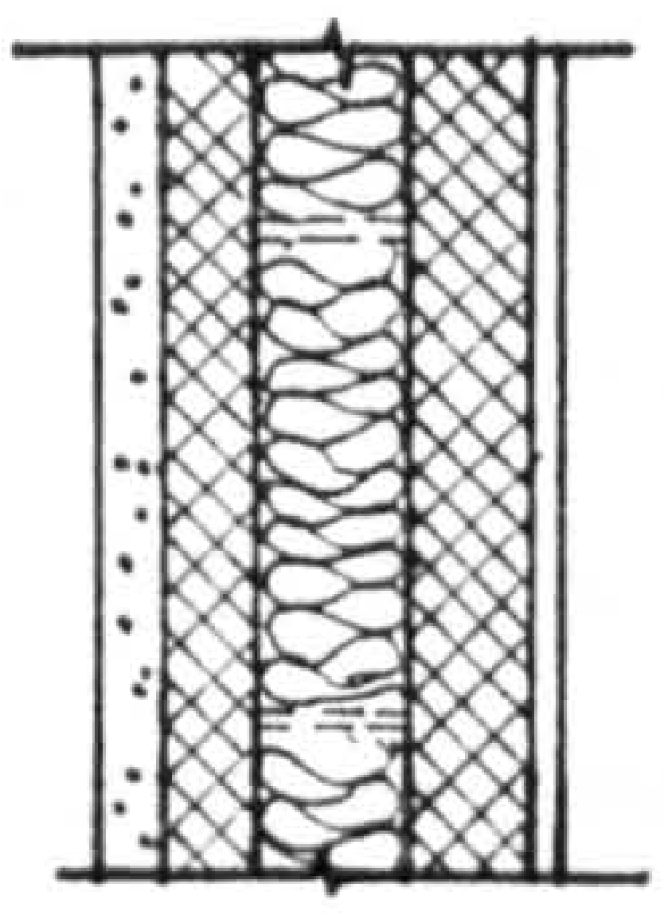
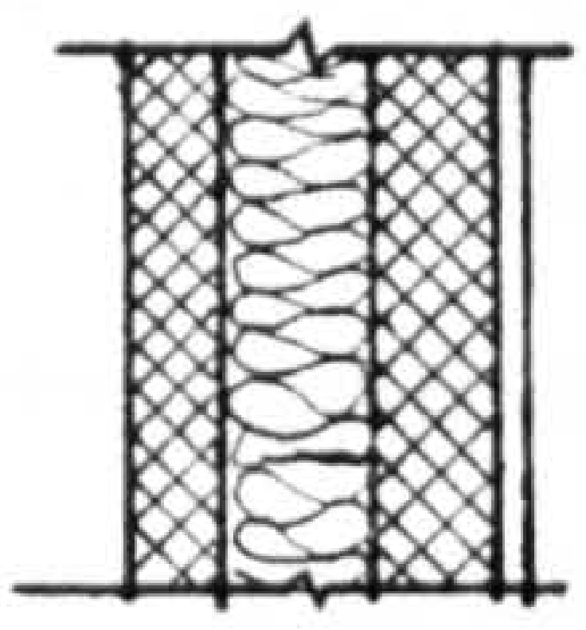
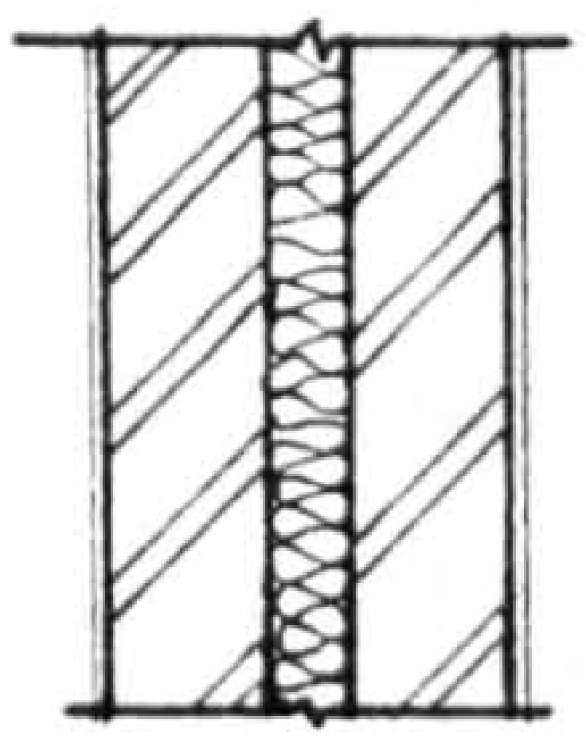
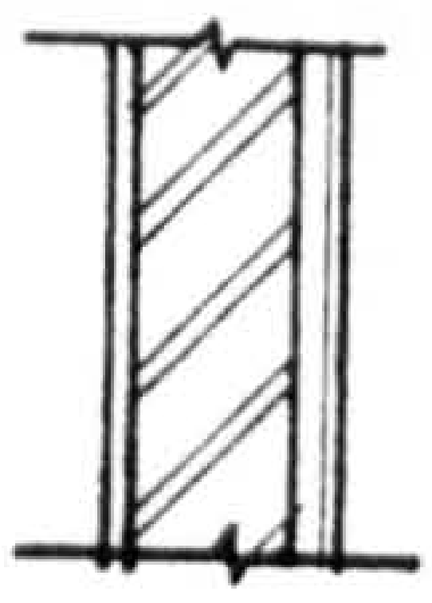
	**External walls** (outside to inside). • Outer air/surface. • MR Polymer Systems - 30 mm foamed polisocyanurate insulation, 8 mm polymer cement render. • Existing outer leaf concrete 'Wilson' block. • 100 mm Pilkington glass wool insulation. • Existing inner leaf concrete 'Wilson' block. • Existing plastering • Inner air/surface.	Predicted U-value (W/m^{2}K) 0.24
	**Walls between bedroom 1 & veranda, kitchen and conservatory** (outside to inside). • Outer air/surface. • Existing outer leaf concrete 'Wilson' block. • 100 mm Pilkington glass wool insulation. • Existing inner leaf concrete 'Wilson' block. • Existing plastering • Inner air/surface.	0.39
	**Stair party wall.** • air/surface. • plastering • Existing brickwork. • 50 mm Pilkington glass wool insulation. • Existing brickwork. • plastering • air/surface.	0.54
	**Dry-lined wall between bedroom 2 and store room.** • air/surface - inside. • plastering • Existing brickwork. • 9.5 mm plasterboard with 25 mm expanded polystyrene. • air/surface.	0.73

Table 2.1 Insulation Specifications and Predicted U-values of Composite Wall Constructions.

2.7.2 DESIGN STRATEGY 2: VENTILATION

EXTRACTION/VENTILATION IN THE 'WET' ZONE

After curtailing the fabric loss to such a low level, the rate of ventilation loss has to be controlled, but not to jeopardise air quality and risk mould growth. As indicated in Chapter 2, a controlled rate of extraction was introduced by continuously extracting air mechanically from both 'wet' zones - kitchen and bathroom.

The Passivent Intelligent Assisted System powered by a 150W extract fan in the loft is designed to run throughout the day extracting air from the kitchens of all six houses via a common vertical duct. The rate of extraction is between 30 and 75 m^3/hour regulated by a diaphragm - automatically opening when humidity rises. A manual override allows residents to open the vent fully, i.e. whilst cooking. Openable glass louvers and a single glazed door opening on to the conservatory extension enable residents to control air supply. The extract system of the bathroom is similar to the kitchen, but powered by a 40 W fan and without the manual override button. The decision to remove the fan's control switch from residents is to ensure adequate rate of extraction in the 'wet' zone where some corners, or 'cul-de-sacs' might still vulnerable to mould growth. This assures an air change range of 0.48 - 1.02 ac/hr for the kitchen and 0.82 - 2.04 ac/hr for the bathroom. It is of course the design intention that these fans help to control air flow from other parts of the house - i.e. from glazed spaces into heated rooms.

EXTRACTION/VENTILATION IN THE HEATED ZONE

Both bedrooms have permavents on walls (Bedroom 1 on chimney flue; Bedroom 2 on external wall) with air flow again controlled by humidity-sensitive diaphragm. The master bedroom has a double glazed sliding uPVC patio door with overhead hit and miss ventilators, opening on to the glazed-in veranda. The living room of electrically heated solar houses has the same humidity-sensitive permavent while gas-heated houses have a traditional permanent wall ventilator. Permanent ventilation is a statutory[17] requirement for gas-heated houses. The living room also has a single glazed door, with an overhead hit and miss ventilator open on to the veranda. Double-glazed steel pivoting windows in the conservatory extension and veranda all have permanent window-head trickle ventilators. The conservatory extension also has both hot and cold water plumbed to washing machine valves, power points and lighting. A wall vent is provided for the tumble dryer outlet and a clothes-drying 'pulley' is installed in the conservatory to ensure that as many 'wet' functions as possible are removed from the heated zones. Figure 2.5 illustrates the position of these ventilation devices. These constitute an important component of the design strategy, since their operation by the user will directly affect the thermal performance, particularly with respect to energy saved by admitting fresh air via buffer spaces. If the main dividing components are opened too far too frequently, the mixing of air will be such that the buffering effect will be lost, and the heated volume extended to include these spaces, so that passive solar gain can only function in 'direct mode'. The quantitative impact of such interventions on energy performance and the motives behind them constitute the most important aspects of the investigation in this work.

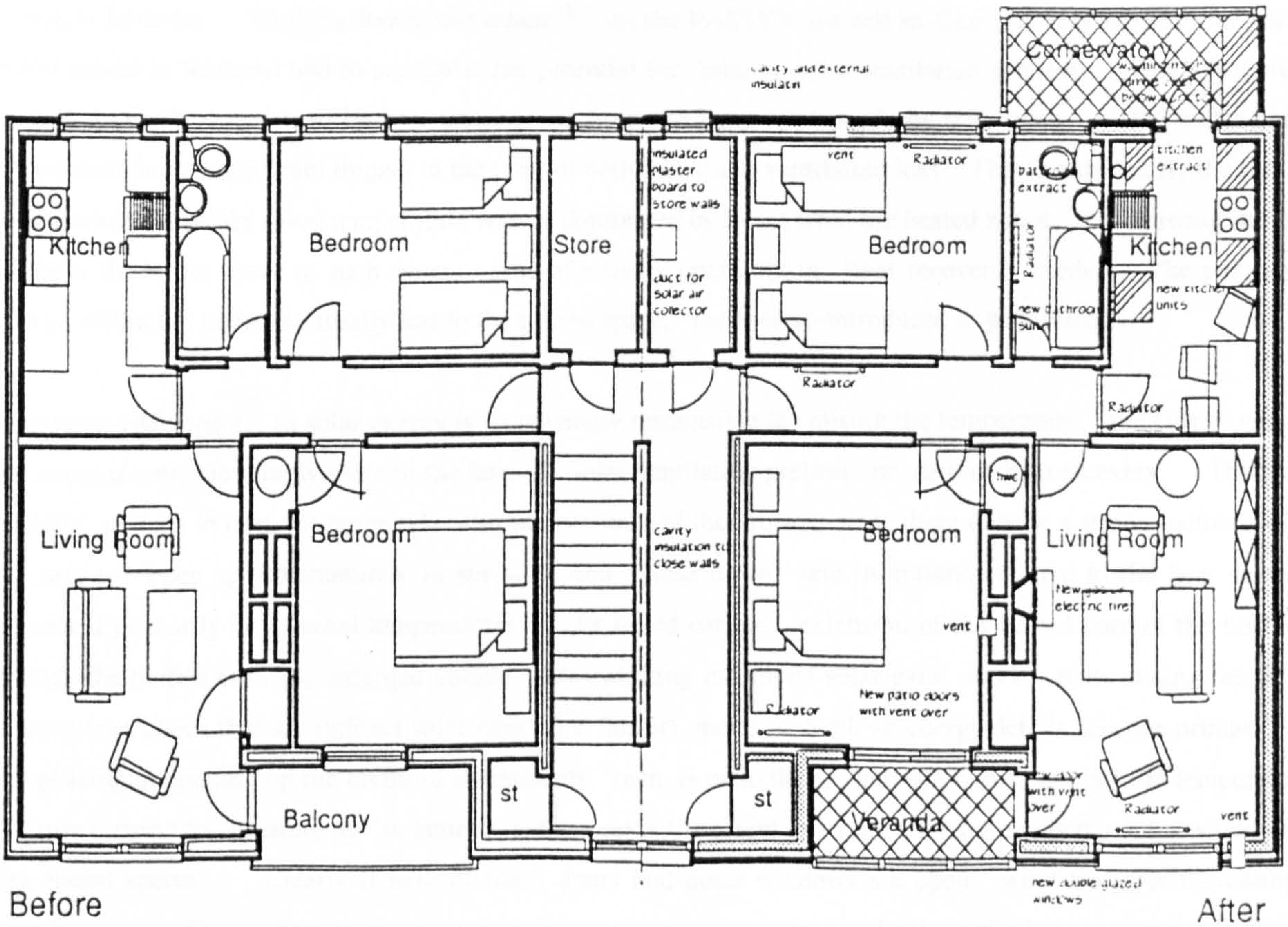


Figure 2.5 Position of Ventilation Devices.

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[17] STATUTORY INSTRUMENTS THE BUILDING STANDARDS (SCOTLAND) REGULATIONS 1990 No. 1596 (S169)- PART K - VENTILATION OF DWELLINGS. HMSO London 1990.

2.7.3 DESIGN STRATEGY 3: HEATING

A fast response heating system, i.e. gas-fired central heating system, with a gas fire plus back boiler in the living room and individual thermostatic valves on radiators, compliments the passive solar design as well as fulfilling the psychological appeal of a visible radiant appliance. As a matter of individual tenant's choice, the project ended up having 21 gas-heated houses and 15 electric-heated houses. Although more difficult to control optimally, the electric houses had the advantage of being easier to monitor accurately in terms of consumption.

In gas-heated houses, space heating is provided by a 3 kW gas fire with a 12.8 kW Baxi back boiler in the living room (boiler efficiency between 76 - 78%) with radiators in all heated rooms. The boiler at a factory set temperature of 70 - 75°C also provides hot water via a water cylinder located in a cupboard in Bedroom 1.

In electric-heated houses on 'white meter' tariff, space heating is provided by electric storage heaters in living room, kitchen, hallway and bathroom , a conventional 3 kW electric fire in the living room and one 2 kW electric convector (with timing device) in each of the bedrooms. Hot water is provided by an electric immersion heater. Details of the electric white meter tariffs are included in Chapter 4.

2.8 PASSIVE SOLAR DESIGN STRATEGY

Parallel work by Bartholomew, Baker and Porteous (discussed in Chapter 1) in each instance supports significant potential for glazed buffer spaces in improving the energy balance compared to direct gain solutions in northerly latitudes. Work by Baker and others[18] on the PASSYS test cell in Glasgow also supports the use of buffer spaces in Scotland and in particular the potential for 'passive solar ventilation preheat', given appropriate control. Partly determined by heat flowing out from the house and partly by solar gain, the buffer space temperature has a significant impact in the rates of both fabric and ventilation loss. This is particularly the case in winter when the buffer space temperature will be dominated by losses from the heated zones. By drawing in fresh air from the buffer space at such times, it is effectively operating in 'heat recovery' mode. The purchased energy within the house is initially lost to the glazed space, but then re-introduced as preheated air.

In autumn and spring, as solar energy is increasingly responsible for raising the temperature, the energy gain to the house is correspondingly more in the form of 'solar ventilation preheat' rather than heat recovery. These are 'volatile' periods in terms of the purely solar performance of the project, since there may be a strong inclination by the user to 'open up' prematurely in spring, and 'close down' late in autumn relative to the heat demand generated primarily by external temperatures. As stated earlier, extension of the heated core of the house to include the buffers with the enlarged volume now operating in 'direct solar gain' mode, risks raising the space heating load above that in 'indirect solar gain' (i.e. buffer) mode. Such an energy deficit depends primarily on the phasing of opening up the dividing components, such as patio door, and solar gain and outside temperature. A further aspect to 'opening up' in autumn and spring is the extent to which a tenant opens the outer windows of the glazed spaces. Clearly if both dividing doors and outer windows are open, wind becomes increasingly significant as a climatic parameter, in addition to ambient temperature and solar radiation. A point is clearly

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[18] BAKER P., GUY A., STRACHAN P. PERFORMANCE ASSESSMENT OF A CONSERVATORY IN SOLAR VENTILATION PRE-HEAT MODE. Proceedings of the North Sun '92 - Solar Energy At High Latitudes, Trondheim, Norway. September 1992 p.p. 132 - 137.

reached when the weather allows any amount of 'opening up' without this constituting a penalty in energy terms, and this may happen on fine days in autumn and spring as well as in summer.

The existing retrofitted houses are divided into two groups - the first group in Wardie Road with main frontage facing south-east & north-west and the second group in Glenburnie Place facing east & west (Figure 2.6). The provision of a glazed-in veranda at the front and conservatory extension at the rear is intended to tackle the issue of randomness in orientation within the Easthall Housing Estate. However, it is reasonable to anticipate that the glazed-in veranda will outperform the conservatory in Wardie Road, while there should be approximate parity in Glenburnie Place. Comparing respective south-east facing Wardie Road and west facing Glenburnie Place glazed-in veranda, climatic data[19] indicates that south-east solar gain is greater than that from the West. Similarly, the East facing conservatory at Glenburnie Place will receive more insolation than those facing north-west at Wardie Road.

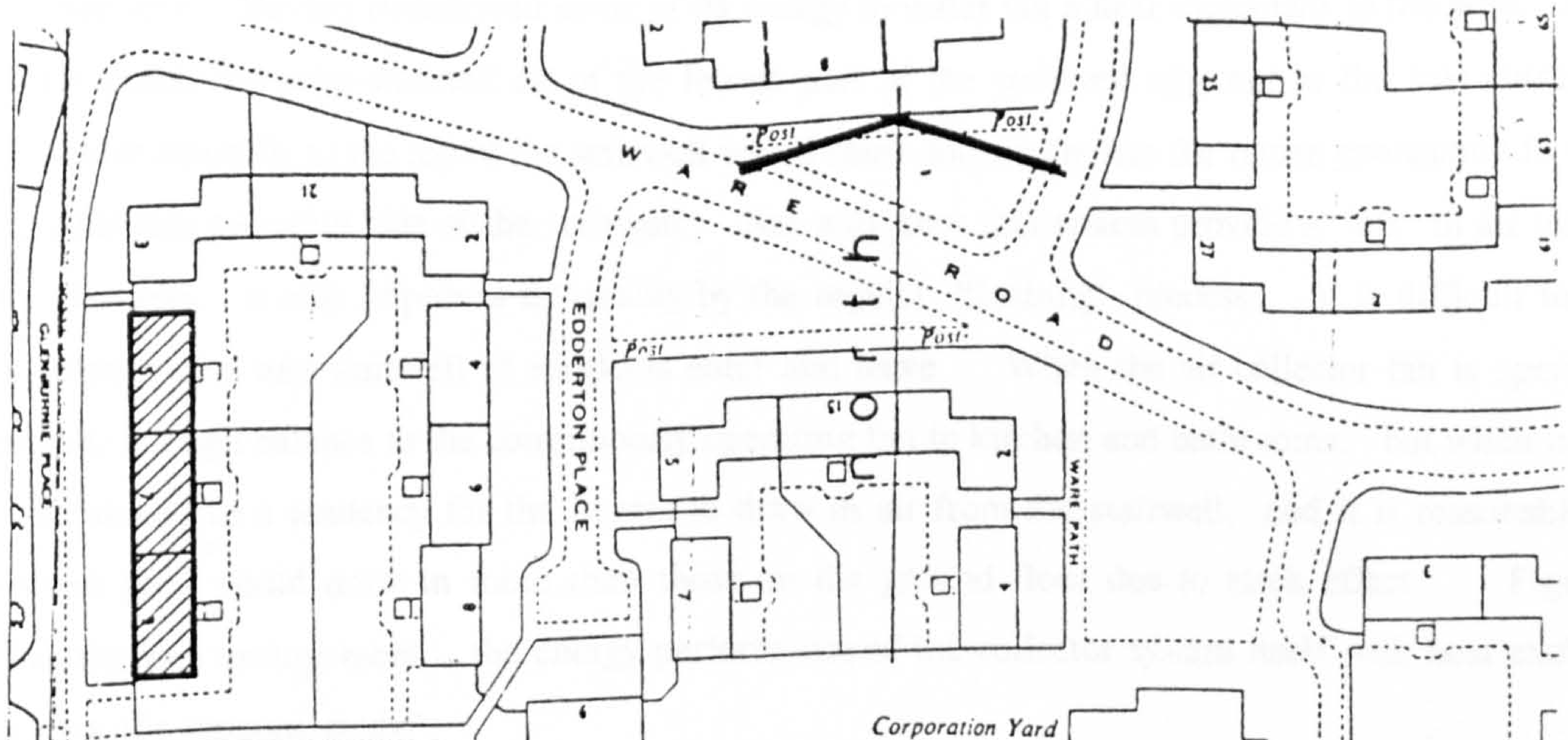

Figure 2.6 Location Plan of Solar Energy Demonstration Project.

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[19] PAGE J. (EDITED), LEBENS R. CLIMATE IN THE UNITED KINGDOM - A HANDBOOK OF SOLAR RADIATION, TEMPERATURE AND OTHER DATA FOR THIRTEEN PRINCIPAL CITIES AND TOWNS. p.p. 171 1986.

The external 'skin' of both verandas and conservatories is a combination of insulated panels and double glazed, centre pivot steel windows; while second floor conservatories are roofed by twin-polycarbonate sheet resulting in a slightly higher overall U-value than ground and first floor houses, but also potential for greater solar gain.

In addition to the two glazed buffer spaces to each house, a set of six houses shares a further partly glazed buffer space - the common entrance close and stairwell, including individual stores. Both external and cavity insulation were extended to the stairwell and two large double glazed uPVC windows were installed to the front of the building and two 450x450 mm of the same specification to the store rooms at the rear. New front and rear self-closing entrance doors were also installed to ensure maximum security and reduce excessive ventilation loss.

The performance of this shared buffer space is further enhanced by a semi-active or hybrid solar feature (not included in the earlier pilot project at Edderton Place). Purpose made roof-integrated air collectors, designed primarily to pre-heat water, and so not in that sense relevant to this work, include the stairwell as part of the thermal loop. Having transferred some of its energy to water via a heat exchanger in the attic, a duct within the stores expels the solar-warmed air at the lowest part of the stairwell adjacent to the rear entrance. This then circulates naturally to the top of the stairwell where short ducts complete the return connection to the bottom of the air collectors on either side of the stairwell. Not only does this system provide a 'lift' in air temperature within the stairwell, it also improves its quality by the regular 'flushing' process. It is difficult to predict air flow between houses and stairwell as residents enter and leave. When the air collector fan is operating, this may provide a rough balance to the continuously operating fan to kitchen and bathrooms; but when it is not operating, there should be a tendency for the houses to draw in air from the stairwell, and it is reasonable to assume that second floor would draw in more than those on the ground floor due to stack effect. Figure 2.7 and 2.8 illustrate this arrangement, the energy performance of the collector system itself with heat exchanger being the subject of a separate study.

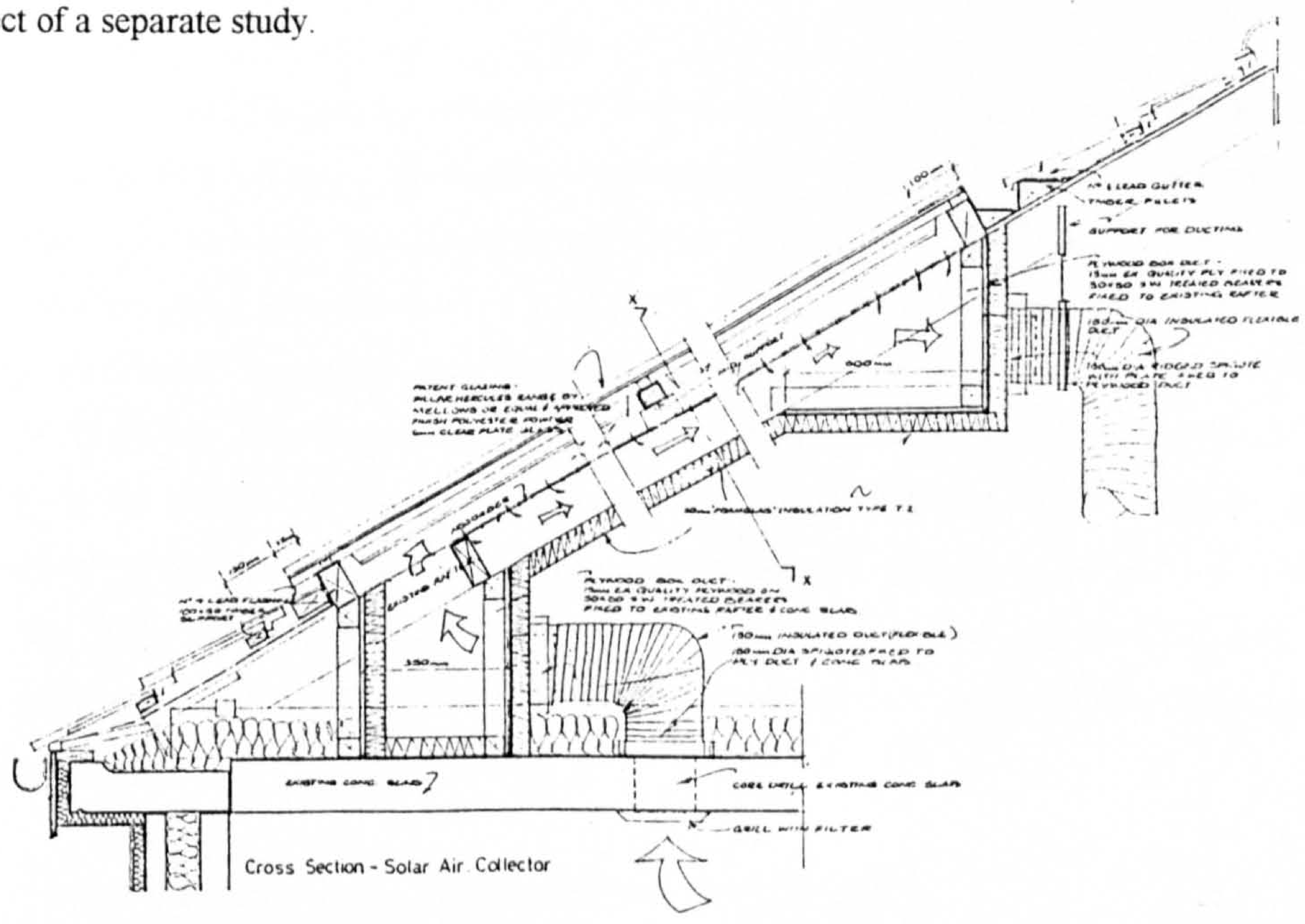

Figure 2.7 Section of Solar Roof Collector.

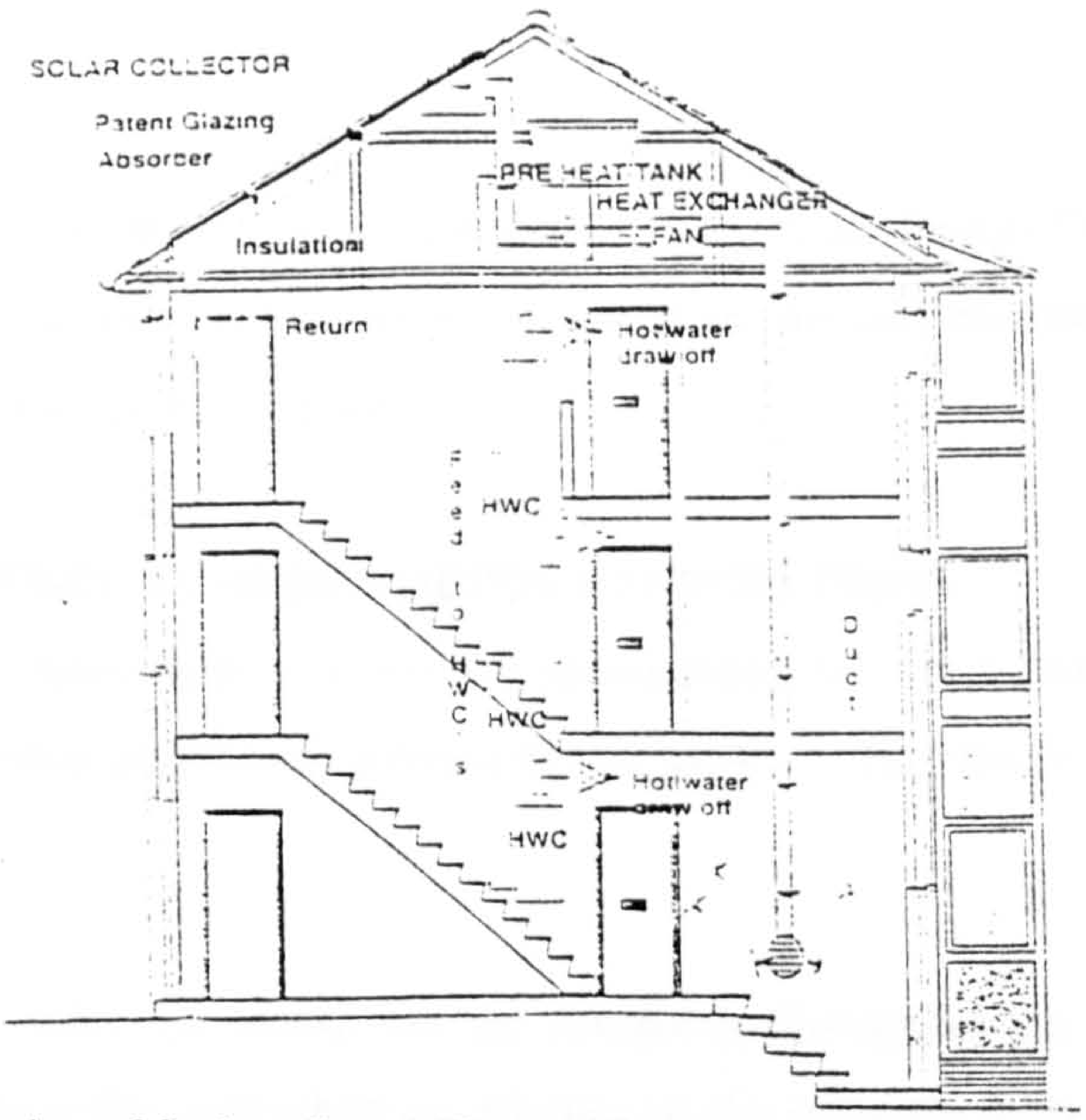

Figure 2.8 Section of Stairwell and Thermal Loop.

CHAPTER 3: RESEARCH METHODOLOGY.

INTRODUCTION

This chapter explains the research methodology of the Solar Energy Demonstration Project at Easthall in so far as it relates to the objectives of this thesis - i.e. to assess the performance sensitivity of small unheated glazed spaces relative to interventions by the users.

3.1 SUMMARY OF MONITORING EXPECTATIONS

As a preclude to this chapter, it is worth summarising in a more precise way what is expected in terms of output from the monitoring programme relative to this work. This can be done by posing questions to which answers are required.

Firstly, how useful and usable are the sunspaces throughout the heating season and to what extent is such usefulness and usability dependent on opening up the sunspace to the heated volume ? This can be answered very simply by relating air temperature and resultant temperature profiles in sunspaces and heated zone and illuminating these profiles with the help of the questionnaire - interview - diary - observations (qido) data, all in the context of the house as a whole.

Secondly, to what extent are the interventions/characteristics of the occupants having a negative effect on the potential energy saving of the sunspace ? This is a prelude to the third question, with increasing emphasis on the relationship between the ventilation regime and 'qido' data. In particular, it is of interest to know whether occupants respond instinctively to perceived weather. For example, will they tend to open up the sunspace on a cold, sunny day, or conversely, keep it closed on a mild, overcast day ?

Thirdly, having established the influence of interventions, what is the energy 'worth' of the two sunspaces ? This is a complex question. One method requires an equivalent model without the sunspaces, which has to be theoretical since there were only 'before' and 'solar-after' cases at Easthall. A second energy-efficient 'after' without the sunspaces would have been very useful. Also although some of the unknowns in the heat balance equation are directly measured and others may be calculated with varying degrees of confidence, the critical unknown of ventilation rate and its split between various routes is bound to be elusive, given the level of monitoring and the proposal to use steady-state heat balance methodology. Another method is to compare measured q^h (equation 1) with a theoretical $q^{h'}$ (equation 1) with n^e replaced by n^p (equation 3). In either case, the 'qido' data may be expected to have a valuable illuminating and checking role. All these questions imply a hypothesis that small unheated sunspaces can and do save energy in this particular public sector retrofit context.

3.2 MONITORING STRATEGY AND METHODOLOGY

Given a relatively large sample of thirty-six solar and two control houses, the monitoring strategy reflects a small available research budget and the critical components required in three steady state heat balance equations. The basis for using steady state analysis is that of BREDEM by Anderson et. al.[1] and SODEM, the version of BREDEM modified by Porteous[2] to allow for any number of unheated spaces in conjunction with the standard two heated zones - living room and the rest of the house.

The first equation addresses energy gain/loss to/from the heated zones and outside, both directly and via unheated buffer spaces:

$$\mathbf{q^h + q^s + q^i = (\Sigma\ A.U + 0.33n^e.V)\ (Ti - To)} \qquad \mathbf{(W)} \qquad \mathbf{(1)}$$

where $\mathbf{q^h}$ is the average 24 hour net space heating load to be met by electricity or gas (W);

$\mathbf{q^s}$ is the average 24 hour useful solar gain to heated zones (W);

$\mathbf{q^i}$ is the average 24 hour useful incidental gain to heated zones (W);

Σ A.U is the sum of respective areas of components multiplied by U-values between heated zones and outside (i.e. including sun/buffer spaces) (W/K);

$\mathbf{n^e}$ is the effective rate of air change between the inside and outside - i.e. taking into account the 'solar ventilation preheat' (hereafter termed 'SVP') effect of the sun/buffer spaces, so that it will be lower than the real rate of air change as long as there is a positive SVP effect (ac/hr);

V is the volume of the heated zones (m³);

Ti is the mean daily internal air temperature of the heated zones (°C);

and **To** is the mean daily outside air temperature (°C).

The second equation gives a focus to the front and rear sunspaces:

$$\mathbf{q^{ss} + q^{is} + q^{hs} = (\Sigma\ A.U^s + 0.33n^s.V^s)\ (Ts - To)} \qquad \mathbf{(W)} \qquad \mathbf{(2)}$$

where $\mathbf{q^{ss}}$ is the average 24 hour solar gain to the sun/buffer space (W);

$\mathbf{q^{is}}$ is the average 24 hour incidental gain to the sun/buffer space (W);

$\mathbf{q^{hs}}$ is the average 24 hour gain to the sun/buffer space from the heated zones (W);

$\mathbf{\Sigma\ A.U^s}$ is the sum of respective areas of components multiplied by U-values between sun/buffer spaces and outside (including other unheated spaces as in case of glazed veranda with adjacent store) (W/K);

$\mathbf{n^s}$ is the real rate of air change between sun/buffer and outside (ac/hr);

$\mathbf{V^s}$ is the volume of the sun/buffer space (m³);

Ts is the mean daily temperature of the sun/buffer space (°C);

and **To** is the mean daily outside air temperature (°C).

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[1] ANDERSON B.R., CLARK A.J., BALWIN R., MILLBANK N.O. BREDEM2: DOMESTIC ENERGY MODEL, BACKGROUND, PHILOSOPHY AND DESIGN, Building Research Establishment, 1984.

[2] PORTEOUS C.D.A. PERFORMANCE CHARACTERISTICS OF SOLAR BUFFER ZONES FOR SCOTTISH HOUSING. Ph.D. Thesis, University of Strathclyde, Glasgow, p.p. 3 - 16 October 1990.

Note that q^{hs} can be expanded as follows:

$$q^{hs} = (\Sigma\ A.U^{b} + 0.33n^{b}.V)\ (Ti - Ts) \qquad (W) \qquad (2')$$

where $\Sigma\ A.U^{b}$ is the sum of respective areas of components multiplied by U-values between heated zones and buffer spaces (W/K);

and n^{b} is the real rate of air change between heated zones and buffer spaces.

If the combined fabric and ventilation component in (2'), $(\Sigma\ A.U^{b} + 0.33n^{b}.V)$, is termed as H^{b} and the equivalent in (2), $(\Sigma\ A.U^{s} + 0.33n^{s}.V^{s})$ is termed as H^{s}, equation (2) may be written as:

$$q^{ss} + q^{is} + H^{b}\ (Ti - Ts) = H^{s}\ (Ts - To) \qquad (2a)$$

Re-organising the equation:

$$Ts = (q^{ss} + q^{is} + H^{b}.Ti + H^{s}.To) / (H^{s} + H^{b}) \qquad (2b)$$

And if two heated zones are used as in BREDEM:

$$Ts = (q^{ss} + q^{is} + H^{b1}.Ti^{1} + H^{b2}.Ti^{2} + H^{s}.To) / (H^{s} + H^{b1} + H^{b2}) \quad (2c)$$

where suffixes 1 and 2 refer to Zones 1 and 2.

The third equation relates the energy exchanges from/to the heated volume with each perimeter condition - i.e. directly to the outside, to the sunspaces, to the stores and to the stairwell:

$$q^{h} + q^{s} + q^{i} = \Sigma[(\Sigma A.U^{p} + 0.33n^{p}.V)\ (Ti^{p} - T^{p})] \quad (W) \qquad (3)$$

where U^{p} is the U-value between heated zone and each perimeter condition (W/m²K);

n^{p} is the real rate of air change between the heated zone and each perimeter condition (ac/hr) (including n^{b} in equation 2');

Ti^{p} is the mean daily internal air temperature of the heated zone adjacent to the particular perimeter condition;

T^{p} is the air temperature of each perimeter condition.

Note that T^{p} in buffer spaces may be greater than the internal base temperature in the relevant heated zone, found by $Tb = Ti - [(q^{s} + q^{i}) / (\Sigma A.U + 0.33n^{c}.V)]$ from equation 1, and this negative value will displace the space heating load until there is no longer a positive Degree-Day difference between inside base temperature and outside temperature. It should also be noted that Degree-Day temperature differences are modified in accordance with the standard Meteorological Office method[3].

In equation (1 - 3) the main unknowns are the rates of air change n^e, n^s, n^b and n^p. Some of the other components are directly measured, e.g. temperatures by data-logger and disaggregated energy uses by split-meters in electric-heated solar houses. This first tier of data is more reliable than subsequent tiers, although the method of recording fuel consumption relied on manual reading/recording of values on split meters at regular intervals. Other components, such as solar gains and disaggregated energy use in gas heated houses, are measured and then converted by calculation to give final results. This second tier of data uses a well-established calculation methodology to give results. For example, in the case of solar gains to the houses, assumptions with respect to shading co-efficient and the use of curtains have to be made; and in the case of disaggregated energy uses in gas heated houses, estimates of respective efficiencies and split between energy uses have also been made. This will render the result somewhat less accurate than the first tier of directly measured data.

The third tier of data mainly comprises calculated theoretical data from known sources - e.g. U-values of building materials from manufacturers' values of conductivity and incidental gains calculated from disaggregated energy use where this has been measured (electric houses) and estimated in other case (gas houses). This tier of data is not necessarily very inaccurate, but inevitably there is a ranking of reliability. For example, there will be a higher degree of confidence in results for all first floor houses compared with the ground and top floor houses as a result of uncertain floor and loft transmission loss; just as the disaggregation of energy use is more reliable in the case of electric houses.

The fourth tier of data is a combination of questionnaires, personal interviews, detailed diary kept by four of the occupants and the author's observations. The last are concerned primarily with the impact of occupants' intervention in negating optimum energy saving due to both thermal buffering effects and ventilation preheat aspects of small sunspaces. This tier of data gives a 'feel' of occupants' interventions relative to sunspace energy performance, and is an important back-up to the measured temperature profiles as well as post-monitoring calculations of air change rates. It is simply not possible to arrive at fixed values for respective air change rates between heated zones and buffer spaces, between heated zones and outside and between buffer spaces and outside. But it is possible to calculate a range of values with a reasonable degree of confidence; and given that intervention by occupants is by nature uncertain, and sometimes random, the establishment of trends is a valid objective. More extensive monitoring work, such as video-recording the opening of windows and doors and logging occupants' daily or hourly activities; more accurate measured data in the second tier (e.g. solar radiation measured on wall surfaces) and in the third tier (e.g. the use of heat flux sensors to measure transmission loss through building materials) would have given additional focus to the programme. However, it would still not have provided certainty with respect to the ventilation rates/split, and in any case the limited budget precluded such tactics. So in the context of monitoring a relatively large sample on a 'shoe-string' budget, this work does not set out to look at the absolute results in terms of energy performance of sunspaces. Rather it examines the range of effects in terms of higher or lower than anticipated air change as a result of occupant's interventions with

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[3] ENERGY EFFICIENCY OFFICE FUEL EFFICIENCY BOOKLET 7 - DEGREE DAYS Dept. of the Environment 1993 p.p.2- 6.

respect to opening up of the sunspaces on to the heated zones (extended heated volume), and keeping the sunspace windows ajar (ventilating the sunspace) at different months within the monitored heating season.

The monitoring strategy of the Solar Energy Demonstration Project at Easthall falls between Level B and C of monitoring outlined by Ferraro[4]. All thirty-six solar and two control houses were instrumented to Level C of monitoring while a smaller number of houses - eight solar, two control houses as well as sixteen electric-heated houses - were more vigorously monitored to Level B standard (see Figure 3.1), with the main objective to obtain statistical data (on fuel consumption and comfort level achieved) augmented by detailed user response information. The level of monitoring is designed to exploit a relatively large number of houses to test design hypotheses, particularly with respect to the overall performance of small sunspaces and their sensitivity to intervention by the users.

Ferraro's Level of Monitoring
Three levels of monitoring are appropriate for different types of solar heating projects:

Level A - Highly instrumented and controlled experimental projects. This type of project falls within research and development programmes for assessing the performance of the various components of a system, and for validating detailed hourly models. Projects falling in this category tend to be built on a one-off basis and their data requirements are highly specific, largely because of their experimental nature.

Level B - Well instrumented projects. These are mainly group projects developed from experience gained with Level A projects, and include better optimised systems. Their purpose is to verify models and design hypotheses, to obtain load data and to gain practical 'field' experience. In order to achieve these objectives it is necessary to build a larger number of dwellings thus making possible the sharing of some of the monitoring facilities with subsequent reductions in cost.

Level C - Projects with minimum instrumentation built for large-scale demonstration purposes using optimised systems. The main objective of monitoring these projects is to obtain statistical data and user response information.

W/5	W/6	W/11	W/12	**W/17**	**W/18**
W/3	W/4	W/9	W/10	W/15	W/16
W/1	W/2	W/7	W/8	**W/13**	**W/14**

G/5	**G/6**	G/11	G/12	G/17	G/18
G/3	G/4	G/9	G/10	G/15	G/16
G/1	**G/2**	G/7	G/8	G/13	G/14

Figure 3.1 Location of Level B and C of monitoring (Level B in bold and highlighted).
Legend: W for Wardie Road; G for Glenburnie Place.

Instrumentation began in March 1991 just after the first group of tenants moved back in. As stated above, there were four levels of data summarised as follows:

1. directly measured data (datalogger and manual recording from meters);
2. data calculated from direct measurement;
3. data calculated from known reference sources;
4. data from questionnaires, personal interviews, occupants' diary in four solar houses and author's observations.

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[4] FERRARO R. (Editors), GODOY R., TURRENT D. MONITORING SOLAR HEATING SYSTEMS - A PRACTICAL HANDBOOK. Commission of the European Communities Pergamon Press 1983 p.p. 7 - 17.

There was also additional monitored information available from the earlier pilot scheme of 6 houses in Edderton Place which included strategic short-term measurements (e.g. air infiltration) as well as other long-term measurements (e.g. relative humidity) which were not repeated in the larger demonstration project.

3.2.1 DATA FROM PILOT SCHEME - AIR INFILTRATION TEST AND RELATIVE HUMIDITY MEASUREMENTS

The background to the 9 Edderton Place Pilot Scheme has been described in Chapter 2. Since its origins, design strategy and, to a large extent, specifications are similar to the 36-house Demonstration Project, the results of specific short term measurements, such as the air infiltration test, are relevant to the latter project. The detailed method of measurement for one first floor flat using tracer decay technique is given by Vaughan et al.[5]. The air infiltration rate from the decay test was calculated to be 0.9 air change per hour. It is important to note that the test was carried out in late spring (4 May 1991) and the external wind speed was 2 m/s on average with a maximum of 5 m/s south-westerly. The mean internal and ambient temperatures were 21°C and 11.2°C respectively. It is known that all windows were closed and that the mechanical stack ventilation system was set in the closed position, but it is assumed that the permanent ventilation to the living room (to provide combustion air for gas appliance) was not sealed up. Due to the North-South oriented sunspaces as well as sheltering by adjacent buildings, 9 Edderton Place is less exposed to the prevailing westerly wind than the East-West oriented Glenburnie Place and the SE-NW oriented Wardie Road. In particular, the West facing facade of Glenburnie Place, built on elevated ground and with no obstructions, may be expected to incur a somewhat higher than 0.9 air change per hour infiltration rate - especially in late autumn, winter and spring when stronger westerly winds are the norm. Long term measurements reported by Plant[6] for Glasgow Airport give approximately 14% of the 6 - 11 m/s velocity range in the 200 - 280° sector in September, and 19%, 17%, 16% and 17% in October, December, April and May respectively. In addition, higher rate of infiltration may reasonably be expected in a ground and second floor flat than first floor.

So in spite of the combination of external and cavity insulation, new uPVC windows and the sheltering effect of the sunspaces, it appears that the flats are not achieving the kind of air-tightness one might expect from typical new build, energy efficient projects, such as that at Linford[7]. However, applying the Linford empirical prediction formula, with a mean September - May wind velocity of 4.69 m/s in Glasgow, gives 1.23 ac/hr infiltration (i.e. excluding occupant ventilation) for a 150m^3 house as at Easthall and 0.63 ac/hr at the lower velocity of 2.0 m/s measured in May; and the difference between the latter theoretical value and that of 0.9 ac/hr as measured could well be accounted for in terms of the permanent ventilation for the gas appliance.

Relative humidity was also measured in the earlier pilot scheme. The kitchen's average daily relative humidity range was between 30% and 60% and the conservatory's between 30% and 80% over the heating season. There is no doubt that the higher than anticipated peaks in relative humidity in both kitchen and conservatory was as a consequence of the mechanical 'Passivent' system operating only in natural stack mode as a result of the

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[5] VAUGHAN N., JONES P., ALEXANDER D. ET. AL. ENERGY PERFORMANCE ASSESSMENTS - 9 EDDERTON PLACE, EASTHALL Welsh School of Architecture, March 1992 p.p. 1/29, 30 and 3/13, 14.

[6] PLANT J.A. CLIMATOLOGICAL MEMORANDUM NO. 60, Climatological Services (Met, 0.3), July 1967 (revised Sep. 1973) Meteorological Office, Table 4D.

[7] EVERETT R., HORTON A., DOGGART J. LINFORD LOW ENERGY HOUSES, Chapter 9 - Infiltration and Ventilation. Open University, Energy Research Group under contract to Energy Technology Support Unit, Harwell 1985, p.p. 9.10 - 9.44.

interventions of the occupant (the top floor occupant apparently switched off the fan because of the noise, which could be heard in Bedroom 2). So having established that there were no physical problems despite such intermittent peaks when ventilated passively, it was felt unnecessary to measure relative humidity in the large demonstration project with mechanical ventilation continuously operational.

3.2.2 DIRECTLY MEASURED DATA

Data measured on site constitutes a vital source of information in assessing the energy performance of the sunspaces. Physical monitoring and instrumentation were phased in from March 1992 and the last solar house was instrumented in early November 1992. The project was monitored from September 1992 to May 1994 - a total period of 20 months. The analysis in this work will concentrate mainly on the first heating season - between September 1992 and May 1993, supplemented by overall results from the second heating season.

As in all monitoring projects involving occupied houses, it is always difficult to decide the range and scope of measurements. The range of measured data is primarily determined by the three steady state heat balance equations summarised above.

3.2.2.a Net Space Heating Load (Fuel Use Measurements) - q^h (W) from Q^h (kWh)

The total delivered energy supplied through meters by Scottish Power and British Gas respectively was recorded manually on a weekly basis by a local agent. Sub-metering was used in all electric-heated houses to give a breakdown energy load for space heating (both storage and non-storage), water heating and by deduction lighting and appliances; hence enabling a fairly detailed account of disaggregated energy uses. Such a system is of course dependent on the accuracy and regularity of manual recording, and this did provide occasional problems. Also in particular cases the fixed electrical appliances in the living room was moved on to the normal circuit for appliances. Fortunately, the relatively large sample mitigated against such occasional irregularities.

Gas centrally heated houses involve a higher degree of estimation due to lack of sub-metering. The net energy consumption for space heating (split between radiators and gas fire due to different efficiency factors) and water heating with respective efficiencies is estimated after Uglow[8].

In summary, the measured energy load from all electric-heated CEC solar houses have a higher degree of reliability than gas heated houses due to the use sub-metering in the former case.

3.2.2.b Temperatures - Ti, Ti^p, T^p, To and Ts

Thermistors were used to measure temperatures in each of the heated rooms and the two buffer spaces in all thirty-six solar houses and two control or reference houses - the same house-type with no thermal improvements. Temperatures were scanned every five minute and the mean temperature measurement over thirty minutes was logged by a Grant Squirrel 8-bit datalogger (Model no. MQ32-16U). Scanning and logging frequency was dictated mainly by cost and practicality - batteries, downloading etc. - and was considered to provide an

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[8] UGLOW C. THE CALCULATION OF ENERGY USES IN DWELLINGS. Building Services Engineering Research and Technology. Vol. 2 No. 1 p.p. 1-12 1981.

appropriate level of accuracy. In eight solar and two control houses, thermistors fitted into a black globe were used to measure dry resultant temperatures in all rooms in addition to air temperatures - to identify any obvious imbalance between air and radiant temperatures, anticipating that the most significant differences would occur in the unheated spaces and in heated spaces in the two control houses. Within the stair-close, air temperature was measured at each floor level of the communal stairwell and store-rooms; while the ambient temperature was measured as part of this group in a shaded/protected situation directly below the eaves on each side of the building, and air temperature in the attic was measured as part of the hybrid solar air collector system.

3.2.2.c Other Measured Data - Water Consumption And Wind Velocity/Direction

3.2.2.c.1 Six Clorius flow meters with pulse generators (Type IPG 10) were installed to measure water consumption as follows:

1. total water consumption (water to cold feed tank) of all six houses of the same stair-close,
2. water consumption of three solar houses (excluding direct main riser to kitchen) all in the same stair-close at Wardie Road,
3. total water consumption (as in 1) and water consumption of one solar house (as in 2) at Glenburnie Place.

Water consumption was measured mainly for the performance assessment of the roof-mounted solar collector, which will form the subject of a separate study.

3.2.2.c.2 The weather station on the Bourdon Building also measured wind speed and direction. This provides useful guidance of the anticipated infiltration rate of the solar houses (air changes when windows and doors are closed). Wind speed was measured by using a 3-cup rotating anemometer and the rotational speed is measured by means of a photo-electronic pulse generator and ratemeter with a millivolt output of 0-25 m/s in 1.0 m/s divisions. A lightweight Porton windvine incorporating a transducer with reed-switches connected to junctions in a chain of resistors forming a switched potential divider. The output voltage is in millivolt with a range of -6.67BV to +6.67V (±5%) differential in steps of 0.33V corresponding to an angular range of 600°.

3.2.3 DATA CALCULATED FROM DIRECT MEASUREMENT

3.2.3.a Solar Gains (Solar Radiation Measurements) - q^S and q^{SS}

Solar gain through windows and glazed areas is computed firstly by converting measured horizontal global and diffuse radiation to the equivalent value for each particular orientation and tilt as described by Markus and Morris.[9]. Secondly, a shading coefficient obtained by modelling is applied to the direct component, and thirdly the heat gain factor through glazing is modified by a further coefficient to allow for curtaining (varying from light-weight net curtain to heavy lining thermal curtains), the values of this coefficient varying in individual cases, and largely based on the author's observations.

Solar radiation was measured by two 'Kipp and Zonen' CM11 pyranometers. Both were mounted horizontally on the rooftop of the Bourdon Building (a three-storey high modern reinforced concrete building with a flat roof) of the Mackintosh School of Architecture. The first pyranometer measured global radiation while diffuse

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[9] MARKUS T.A. and MORRIS E.N. BUILDINGS, CLIMATE AND ENERGY Pitman Publishing Ltd., 1980, p.p.168 - 195.

radiation was measured by correctly positioning a shadowband ring around the second pyranometer so as to exclude direct beam radiation. The location is about four miles away from the Easthall site partly due to the unavailability of an equivalent secure site at Easterhouse and the frequent adjustments of the shadowband ring, and partly due to inadequate funds to mount separate solarimeters to measure global radiation directly on each surface with a different orientation and tilt. However, work by Clement[10] confirmed a high correlation between global radiation received on three sites in or close to Edinburgh - described as urban, coastal and rural for Napier University, East Craigs and Bush respectively. Diffuse radiation totals showed a larger variation indicating that diffuse radiation is more sensitive to local climatological effect and local topography than global radiation, i.e. spells of maritime weather of warm, moist air rise over the Pentlands Hill generated extensive clouds around the coastal site whereas continental air gives very settled weather with the exceptional agreement between intersite diffuse radiation totals.

The high correlation of global radiation measurements in Clement's work confirms the margin of error would be small as both Bourdon Building and the solar houses at Easthall are situated in urban sites. For diffuse horizontal radiation, the margin of error would be somewhat higher than global radiation.

Although not relevant to micro-climate differences, it is also of interest to compare mean monthly measurements with predictions for Glasgow by Page and Lebens[11]. This confirms measured global and diffuse radiation for September 1992 to May 1993 is -19% and -25% respectively less than expected. The summary of weather conditions kept by the author also confirms relatively cold and overcast winter months during the monitoring period. Hourly readings for specific dates (clear sky and overcast horizontal) were also checked and compared, simply to provide a rough-and-ready confidence check. Comparison of horizontal global and diffuse radiation for the period between September 1992 and May 1993 is made in Table 3.1.

Global Rad.	Sep.'92	Oct.	Nov.	Dec.	Jan.'93	Feb.	Mar.	Apr.	May '93	htg. season ave.
Measured	3.14	1.16	0.50	0.44	0.29	0.61	1.56	2.37	3.48	1.51
UK Climate	2.4	1.35	0.62	0.33	0.41	1.00	1.96	3.53	4.56	1 80
(All in kWh)										-19.26%
Diffuse Rad.	Sep.'92	Oct.	Nov.	Dec.	Jan.'93	Feb.	Mar.	Apr.	May'93	htg. season ave.
Measured	2.02	0.76	0.37	0.33	0.18	0.37	0.93	1.20	1.86	0.89
UK Climate	1.51	0.88	0.44	0.25	0.30	0.66	1.23	2.10	2.66	1.11
										-25.06%

Table 3.1 Comparison of Horizontal Global and Diffuse Radiation as Measured and Climate in the UK Handbook.

The pyranometer was connected to a 8-bit Grant Squirrel Datalogger (Model MQ32-4V) with 4 channels for 0-20 *mV*. The Squirrel datalogger was housed in a weathertight box located on the rooftop close to the pyranometers. The pyranometers were calibrated at the time of the purchase and proved to be very reliable, although during the early trial period, moisture from condensation was present on the jack plug connection to the datalogger and caused spurs and spikes. The problem was overcome after silicon sealant was used to seal all junctions.

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[10] CLEMENT H. R. A STUDY OF THE SOLAR RADIATION MICROCLIMATE OF THE EDINBURGH AREA. Naiper University M. Phil Thesis p.p. 76 - 80 1989.

[11] PAGE J. (EDITED), LEBENS R. ibid. p.p. 171.

3.2.3.b Incidental Heat Gains in Electric-heated Houses- $\dot{q}^{i}$ (W) from Q^{h} (kWh)

Incidental heat gains arise from metabolic output from the occupants and the use of fuel and power for non-space heating activities such as cooking, lighting, water heating and the use of miscellaneous appliances. Information with respect to metabolic gain is derived from the questionnaire - i.e. the number of occupants, and their pattern of occupancy. In the all-electric houses, the incidental gains can be fairly accurately estimated since the energy consumption for water heating is known, as is the residue for cooking, lighting and appliances. Sources such as Uglow[12] and Anderson et al.[13] give the relationship between consumption and incidental gain. So the methodology for calculating $\dot{q}^{i}$ for electric houses comes under the tier of data calculated from direct measurement. But in the case of gas houses, there is reliance on known reference sources as will be described in Section 3.2.4.b.

3.2.3.c Ventilation Loss - $0.33n^{e}.V$, $0.33n^{s}.V^{s}$, $0.33n^{b}.V$

The various values for 'n' - n^{e}, n^{s}, $n^{b/p}$ - are the critical unknowns found after all other variables have been identified to a reasonable degree of accuracy as described above. Although equations (1-3) describe the methodology in broad brush terms, there are implied assumptions with respect to air flow through sunspaces which are not necessarily met. Therefore it is more appropriate to describe the method used to elicit these values under Section 3.3 - detailed methodology below.

3.2.4 DATA CALCULATED FROM KNOWN REFERENCE SOURCES

3.2.4.a Transmission Loss - $\Sigma A.U$, $\Sigma A.U^{s}$, $\Sigma A.U^{b}$, $\Sigma A.U^{p}$

The U-values of the main building components are given earlier in this Chapter. These have been calculated using manufacturer's specifications and are therefore thought to have achieved a reasonable degree of accuracy. All the first floor solar houses, as described previously, have a higher degree of accuracy in terms of transmission loss calculation than the ground and top floor houses. The three main transmission loss calculations (also see Appendix 3.1) for a first floor gable end house are summarised as follows:

- transmission loss of solar house as built (SOL) to bounding surface, i.e. heated zone to sunspace bounding surfaces - 83.78 W/K,
- transmission loss from heated zone of solar house to outside - 57.2 W/K,
- and transmission loss of theoretical model (all thermal improvements but no sunspaces as described in details later in this chapter of research methodology) to the outside - 54.97 W/K.

3.2.4.b Incidental Heat Gains in Gas-heated Houses- $\dot{q}^{i}$ (W) from Q^{h} (kWh)

Unlike electric-heated houses, the methodology for calculating $\dot{q}^{i}$ in gas-heated houses relies on known reference sources. There is a total for electrical lighting and appliances, but cooking and water heating by gas are not disaggregated from space heating. The same sources described in Section 3.2.3.b also give estimates of average consumption with respect to incidental gain, but clearly there is more scope for error compared with the all electric houses.

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[12] UGLOW C. ibid. p.p. 1-12 1981.

[13] ANDERSON B.R., CLARK A.J., BALWIN R., MILLBANK N.O. ibid. p.p. 39 1984.

3.2.5 DATA FROM QUESTIONNAIRES, PERSONAL INTERVIEWS, OCCUPANT'S DIARY, AUTHOR'S OBSERVATIONS, PHOTOGRAPHS AND DAILY NOTES ON WEATHER CONDITIONS - 'QIDO' DATA

This section of data constitutes an essential part of the monitoring programme. It not only gives practical information with respect to family size and structure, but also gives an added insight and understanding into measured data, i.e. house and sunspace temperature profiles and deduced ventilation regimes. The closer the author became to individual households, the greater the understanding of how the system was being used and the more easily unexpected (or non-optimal relative to the yardstick) results could be explained. The ultimate objective of this work is to test the robustness of the small unheated glazed spaces as an energy-saving strategy to inappropriate interventions on the part of occupants; but this set of data also provides valuable links between household characteristics and a more general level of information with respect to energy use - e.g. desired heating regime, hot water consumption etc.

Questionnaire

By setting questions in an orderly manner, a questionnaire is an information collection instrument to elicit the data sought. The questionnaire covers three aspects - demographic, comfort and operation/controls. The wording of the questionnaires is designed to avoid unfocused questions and leading or loaded words or phases. Such techniques are fully discussed in Dodge and Fullerton[14]. Preluded by an introductory letter, the questionnaire is structured into three sections as follows:

THERMAL COMFORT	- thermal comfort survey and the uses of the sunspaces,
PERSONAL DETAILS	- household profiles and occupancy patterns,
HEATING & VENTILATION CONTROLS	- heating and ventilation control patterns.

To place emphasis on the study of thermal comfort improvement after the retrofit, Section 1 sets out to measure occupants' level of satisfaction in these solar houses. The level of comfort is measured by posing the first two questions in Section 1 with closed statements. Occupants were asked to indicate their degree of agreement on a response scale (i.e. very comfortable to very uncomfortable). Open ended questions were used in the five out of the following six questions within the same section and occupants were asked to provide qualitative or explanatory statements. Usually, these were follow-up questions to dichotomous ones to which the occupant had to answer 'yes' or 'no'. For example,

'1.7 Have you noticed any improvements in health amongst members of your household ? yes or no
If yes, please give details, i.e. asthma in young children

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Closed end questions were again used for the collection of quantitative data in Section 2, providing personal details such as the demographic characteristics of the occupants and their occupancy patterns. In Section 3, occupants were invited to make any comments in respect of the solar houses. The last section measured the

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[14] DODGE H.R., FULLERTON S., RINK D. MARKETING RESEARCH Charles E. Merill Publishing Company, Columbus, Ohio p.215 1968.

degree of heating and ventilation controls. Again closed end questions with a response scale of three (i.e. often, sometimes and hardly ever) were used in all questions.

Questionnaire samples were first tested among colleagues at the department and then on two solar house occupants. A copy of the questionnaire was also sent to the chairperson of the Easthall Residents Association for comments. Participants were asked to comment on any ambiguous questions, words/questions with no clear meaning and any questions that they felt were invading their privacy. The importance of a pilot test is described in detail by Converse and Preser[15].

After the pilot test, it was decided that the 'drop-and-collect' was the most appropriate method for the distribution of questionnaires. This method allowed the interviewer to:

- explain the objectives of this survey,
- provide necessary instructions in answering the questions,
- overcome problems of hesitation by personal contacts/requests and emphasise the importance of information,
- let the occupants know that the questionnaire would be collected a fortnight later and a brief interview would be conducted at the same time.

A questionnaire was sent to all thirty-six CEC Easthall households in April 1993 - at least eight months after the residents had moved back into their solar houses. A copy of the questionnaire is included in the Appendix 3.2.

Interview

A brief interview was conducted a fortnight later when collecting the questionnaires. The interviews were mostly conversational aiming to:

- verify author's observations,
- cross-check answers on questionnaires,
- and assist some occupants in completing questionnaires.

Twenty-eight out of thirty-six CEC Easthall households - a response rate of 78% - returned the questionnaire and were subsequently interviewed. This is then supplemented by the author's observations which form the main source of information with respect to the following:

- resident's understandings and use of optimum heating and, most importantly, ventilation controls at different times during the heating season;
- the use of curtains or blinds during the day when solar gains may bring maximum benefits;
- and special 'inside' knowledge of certain idiosyncrastic behaviour of some occupants in negating optimum energy saving - e.g. in one case a night shift nurse often leaves the patio door of the main bedroom ajar while sleeping during the day; and in another, the conservatory is being used as a dog kennel and often has its door left ajar.

Thus these observations often provide some 'tell-tale' signs suggesting why a particular household fails to achieve optimum energy saving by operating the heating and ventilation controls appropriately.

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[15] CONVERSE J.M., PRESER S., SURVEY QUESTIONS Sage, Beverley Hills, USA 1973.

Occupants' Diary

In order to provide a more detailed picture of the daily pattern of heating and ventilation controls and its impact on thermal comfort, four households, one gas heated and one electric heated house from each of Wardie Road and Glenburnie Place locations, agreed to keep a diary for the duration of the project. All four participating residents were asked to enter time and duration of all window openings and the ventilation control pattern once a week on Wednesdays. All record sheets were collected and new one distributed once a month by the author. Other information including heating control, comments on the weather and thermal comfort by the occupants and general activities, e.g. washing loads, was also sought. Sadly, only one resident managed to complete the marathon monitoring task. Nevertheless, the once-a-week diary (see Appendix 3.3) gives a useful insight to the psychological as well as physical needs of all four households with respect to thermal comfort and operation of controls, and such an insight inevitably yields clues with respect to the thermal performance of other houses.

Photographs And Daily Notes on Weather Conditions

Photographs were taken by the authors to record windows opening and the use of curtains/blinds when making site visits in different weather conditions, seasons and time of the day. Daily weather condition was noted in the author's diary and was then correlated with the photographic records. This set of data provides a useful cross-checking function in verifying other aspects of the 'qido' data.

3.3 DETAILED METHODOLOGY

The previous sub-Section 3.2 has outlined how all the components of three steady-state heat balance equations may be found and broadly how three output questions can be answered. This sub-section deals with the methodology in more detail.

3.3.1 HOW USEFUL AND USABLE ARE THE SUNSPACES ?

The high amenity value of sunspaces has long been established through previously described projects, such as Carrigen park at Clonmel and the Netherspring co-operative, self-build houses at Sheffield. The methodology for establishing the usability and usefulness needs no further elaboration, see Section 3.1 above. However, it remains an important aspect of the output in that if usability and usefulness is seen to be of a high order, the implication is that this may significantly offset the capital cost of the provision. Further, the issue of user-satisfaction must be considered in an overall context. In this case the 'satisfaction-context' necessarily includes satisfaction with the house as a whole; and logically since the entire project concerns transformation from a damp, cold house to a warm, dry one, the issue of comfort, usability and running costs applied to the house as a whole are a necessary preface to the usability and usefulness of the sunspaces. Again, this information is readily available from measurements augmented by 'qido' data; and it is relevant to compare results for the solar demonstration houses to those of the 'before' reference houses, denoted REF.

3.3.2 TO WHAT EXTENT ARE OCCUPANTS' INTERVENTIONS AFFECTING ENERGY SAVING ?

This work examines two categories of variable namely, the physical and occupant-related, which affect the energy demanded for space heating. The first category examines tangible and physical differences of the solar houses whereas the second category elaborates the variables principally affected by occupants' interventions/needs. Both categories and its subsets are listed in Table 3.2.

Physical Variables
a. **Heating fuel**: a.1 gas; a.2 electric.
b. **Orientation**: b.1 Wardie Road; b.2 Glenburnie Place.
c. **House location**: c.1 gable ground; c.2 gable first; c.3 gable second; c.4 mid-terrace ground; c.5 mid-terrace first; c.6 mid-terrace second.
Occupant-related Variables
d. **Heating regime**: d.1 all day/whole house; d.2 all day/Zone 1; d.3 2xday/whole house; d.4 2xday/Zone 1.
e. **Household age profile**: e.1 Infant*; e.2 Adult*; e.3 OAP*.
f. **Smoking habits**: f.1 smoker**; f.2 non-smoker**.
g. **Pet**: g.1 with pet; g.2 no pet.

Table 3.2 The Category of Physical And Occupant-related Variables and its Subsets.
(* Classification of age profile is given in Section 3.3.2.5 and ** Smoker refers to households with one or more occupant who smokes and non-smoker refers to a fully non-smoking household)

Benchmark And Subset Comparison

Having established the two categories of variables and their subsets as above, two comparative techniques known as 'benchmark' and 'subsets' will form the basis of comparison as described in following Section and Chapter 5. The benchmark comparative technique compares the mean periodic value for that combination of variables/subsets to the same as a mean for the whole sample of 34 solar houses (two tenants did not co-operate with the monitoring programme). For example, the mean periodic value of one or more subset group(s), e.g. infant (and smoker), compares with the mean value of all 34 solar houses. This is a useful overall performance indicator of the subset(s).

However, 'subset' comparison contrasts the mean periodic value for one combination of variables/subsets with another. For example, the mean periodic values of smokers living in gas-heated houses may be directly compared with non-smokers living in the same heating fuel houses. Equally, smokers living in electric-heated houses may also be compared with non-smokers living in the same heating fuel houses.

Key Indicators - Energy Loads and Costs for Space Heating

Having established the terminology - variables and subsets - and the comparative analysis technique using benchmark and subset comparisons, it is necessary to elaborate on the three sets of key indicators for the comparative analysis as follows:

1. **Fuel:warmth Ratio** (in kWh/m^3K) - can be expressed by the formula **$(Qh\_m / V .\Delta T)$** where V is the heated volume and $\Delta T = Ti - To$. This value provides a useful indicator of energy consumption relative to purchased comfort.

2. **Volumetric Space Heating Load** (in kWh/m³) gives a simple measure of energy load per unit of heated volume.

3. **Cost:warmth Ratio** (in £/K) - a value similar to the fuel:warmth ratio except the space heating demand in kWh is replaced by cost and so reflects the disparities in gas/electric fuel tariffs.

These three output values form the core of the comparative analysis for various variables/subsets. Data including temperatures (heated zones and sunspaces), effective rate of air change and 'qido' data will also be compared between variables/subsets in order to establish causes and effects with respect to the ventilation regimes and consequently space heating loads.

A further level of comparison relates measured space heating load, Q^h (kWh) or q^h (W), to an adjusted predictive values from equation 3 where an assumed 1.5 ac/hr mean whole-house rate of air change is used consistently throughout the heating season, and n^p distributed on a pragmatic 'what if ?' basis between various perimeter conditions as in the original SODEM analysis by Porteous. This adjusted value for q^h can then be used in equation 1 to yield an adjusted 'SODEM prediction' value for n^e. Such comparison is useful in that it highlights the implausibility of a uniform ventilation regime throughout a heating season.

The three physical variables are initially examined, each compared with the mean benchmark value and then the subset values.

3.3.2.1 Single variable - heating fuels

Heating fuel which has two subsets of electric (a.1) and gas (a.2) may be one of the most influential physical variables. By using Excel - a spreadsheet software, the three sets of key space heating indicators as described above for the two subsets (14 electric-heated and 20 gas-heated solar houses) are extracted and ranked in descending order and their mean value calculated. The mean values of the two subsets are then compared with the benchmark value and with each other. The subset with a higher than benchmark value is thus identified for further examination relative to another variable/subset.

3.3.2.2 Two variables correlation - heating fuel and orientation

A second variable, namely, orientation (b.1 Wardie Road; b.2 Glenburnie Place) is then added to the first search criterion. This allows like-for-like comparison between solar houses with the same orientation, but different heating fuels and the same heating fuel, but different orientations. This comparison is particularly valid for this project in respect of the performance of small sunspaces. For instance, the S-E/N-W houses at Wardie Road will have a different pattern of solar gains in the houses and sunspaces compared with the E/W houses at Glenburnie Place. This no doubt will affect the usability and its usefulness of sunspaces which may lead to more opening up. The mean periodic values for these four subsets are again compared with the benchmark, and other subset values and correlated with the 'qido' data. The subset whose value is higher than that of the benchmark and previous subset values is thus identified. It is necessary at this stage to emphasise the importance of the maximum variables/subsets used in the correlation search in order to give a subset result with a degree of confidence in statistical terms. So for this reason instead of adding the subset (the one with a higher than benchmark and subset values) on to the next correlation search criterion, the subset and indeed the variable concerned will be set aside and replaced by a new variable known as location (c.1 - c.6). Therefore, the two variables - heating fuel and location - are the subject of the next correlation search.

3.3.2.3 Two variables correlation - heating fuel and house location

House location (c.1 - c.6) at first sight seems to be one of the most influential factors affecting space heating energy consumption, at least in the theoretical heat loss calculations. In reality, occupant-related variables and other physical variables; namely, heating fuel, orientation, may be equally if not more influential. Given that the solar houses are insulated to such a high level as previously described in the design strategy in Section 2.7, the differentials in transmission loss of various house locations will be relatively low. This leaves ventilation loss which is strongly influenced by occupant-related variables. For this reason, a simple search of the house location variable is necessary. It is important to acknowledge that such a simple, single variable search will only give a 'feel' of the subset results of key indicators - negating the effect of other variables. And half of the subsets (e.g. c.1 - c.3) indeed gives a relatively small sample - a maximum of four. Despite this, the mean periodic values of all six subsets (c.1 - c.6) are compared with the benchmark value and with each other. The house location subsets with higher mean values than the benchmark values are then subject to further analysis relative to another variable - heating fuel.

The search results for the two variables, heating fuel and house location, have to be taken with extreme caution and correlated with 'qido' data. This is due to the relatively small samples in at least three subsets. This time the mean values of subsets are mainly compared with the benchmark values. Comparison of subset results with each other is virtually impossible in some cases due to insufficient samples even with the support of 'qido' data. For instance, there was only one gas-heated, ground floor, gable-end house and two electric-heated houses with the same house location. Similar to previous section, the subset results are then set aside and a second category of variables - heating regime - is used for the next correlation search.

3.3.2.4 Two variables correlation - heating regime and heating fuel

Having analysed the three physical variables, namely heating fuel, orientation and location, the second category (occupant-related) of variables examines the human aspects affecting the key indicators. Having insulated the solar house to such a high level, the necessity to have a whole house heating system is always questionable. However, it would have been unacceptable to both housing authority and tenants not to have a whole house heating system installed in newly rehabilitated houses. In reality, most occupants in the electric-heated houses have hardly used their convectors in both bedrooms whereas some occupants in gas-heated houses find using the gas-fire (Zone 1 heating) in the living room has satisfied all their needs for warmth. The diversified needs for warmth of the occupants suggest the heating regime (d.1 - d.4) as an occupant-related variable is perhaps influential. The four mean values of these subsets are extracted, ranked and compared with the benchmark value and with each other.

The mean subset values are then correlated and compared with another physical variable of heating fuel which is expected to be influential from previous correlation search. This combined correlation search aims to give a 'feel' of an economical energy use for space heating. Again, the two comparative techniques are used for analysis.

3.3.2.5 Two variables correlation - household age profile and heating fuel

The composition of family structure is an important factor affecting space heating requirement, although little systematic research has been carried out in this subject. Hence, household age profile becomes the second occupant-related variable to be scrutinised. The three subsets (e.1 - e.3) - namely; infant, adult and OAP household groups - are examined individually and compared with the benchmark and each other. There were four subsets in the original questionnaire under the age group, namely; infant (below 10 years old), teenage (10 -17 years old), adult (over 18 years old) and OAP (over 60 years old). However, it was necessary to combine the two subsets of infant and teenage (infant for occupants aged below 17 years old) as a result of the relatively small sample of the project. The age subset with a higher benchmark value is taken for the next correlation search with the heating fuel's subset that also has a higher mean value. The main characteristics of the household profile are described in Chapter 5.

3.3.2.6 Three variables correlation - smoking habit, heating fuel and age group

Having established which combination of household age profile and heating fuel subset is consistently resulting in values higher than benchmark, the search then carries on to examine another variable - smoking habits. Smoking may cause occupants to demand a higher degree of ventilation, and perhaps more opening up between heated rooms and glazed spaces. The mean periodic values of the two subsets (f.1, smoker and f.2, non-smoker) are extracted, ranked and compared with the benchmark value and each other. The subset with a higher mean value is then correlated with both subsets of the heating fuel variable - gas (a.1) and electric (a.2). A subset with an apparent high mean value is finally correlated with the highest age profile subset. It is necessary to emphasise that the screening process inevitably leads to smaller and smaller samples; hence, the subset results have to be treated with caution. This renders cross-referencing with the 'qido' data extremely important. After examining all variables directly related to occupants, the last variable in the second category is pet ownership.

3.3.2.7 Two variables correlation - households with pet and heating fuel

This work is essentially studying the user-performance sensitivity of small sunspaces in the Scottish climate. The 'qido' data confirms that households with a pet or pets, mainly dogs, are intermittently using the sunspace as a dog kennel or pet corner, more frequently in the veranda during early autumn and late spring. This may lead to more opening up of the sunspace - resulting in effectively enlarging the heated volume, reducing the thermal buffering effect and marginalising ventilation preheat benefits from the sunspace. It is necessary to point out that the correlation search may give a subset result which is unable to screen out other influential variables/subsets. For example, nine households with pets (dogs or cats) are also all smokers, have a whole house heating regime and have heated their house all day (with the exception of one in the latter case). Almost being a stand alone variable, the household with pet subset is less likely to have any logical correlation with most of the physical and occupant-related variables. This leaves the heating fuel as an occupant-related variable for the correlation search with the subset.

3.3.2.8 Summary of the section

The methodology of the correlation search aims to give a 'feel' of the effects of the two categories of variables in respect of the three sets of key indicators by using the two comparative techniques. It is necessary to iterate that the monitoring objective is to give a sense or understanding of the causes and effects of the variables negating optimum energy savings instead of looking for absolute values. Indeed, the level of monitoring of a relatively large sample on a tight budget makes such a task unrealistic.

3.3.3 WHAT IS THE ENERGY 'WORTH' OF THE TWO SUNSPACES ?

Energy saving as a result of passive solar features in the form of small sunspaces constitutes the core of this work. The problem lies in identifying a 'saving' or at least a strong indicator of energy 'worth'. This can be done in at least two ways outlined briefly in Section 3.1 above. The assumption in the first scenario is that there could well have been a more economical (in terms of building cost) retrofit of a house of identical plan and orientation, which included all measures except the two glazed spaces. The constructional differences in this theoretical model are that windows to the main bedroom and kitchen remains the original size and the external insulation covers all the external walls; unlike the demonstration project where only the cavity insulation is used between sunspaces and heated interior - Figure 3.2. The transmission loss $\Sigma A.U$ (W/K) taken from heated zone to outside for a first floor gable-end solar house (SOL) as built is compared with the theoretical non-solar reference model (REF+) as in Table 3.3. Therefore in this comparison the sunspaces are competing in energy terms (not cost) with smaller windows and more insulation. The other necessary assumption in this scenario is that the real rate of air change found in the case of the solar house (denoted SOL) is also used in the theoretical reference house (denoted REF+). So in this case the energy 'worth' = q^h (REF+) - q^h (SOL). However, the split of n^p to different perimeter conditions in the SOL case depends on successfully having found n^s and n^b from equations 2b and 2c. Since there are two unknowns, this is difficult unless there is an optimum situation where all of the air entering the sunspace from the outside is transported into the heated interior. However, other air flow combinations are quite possible as shown in Figure 3.3.

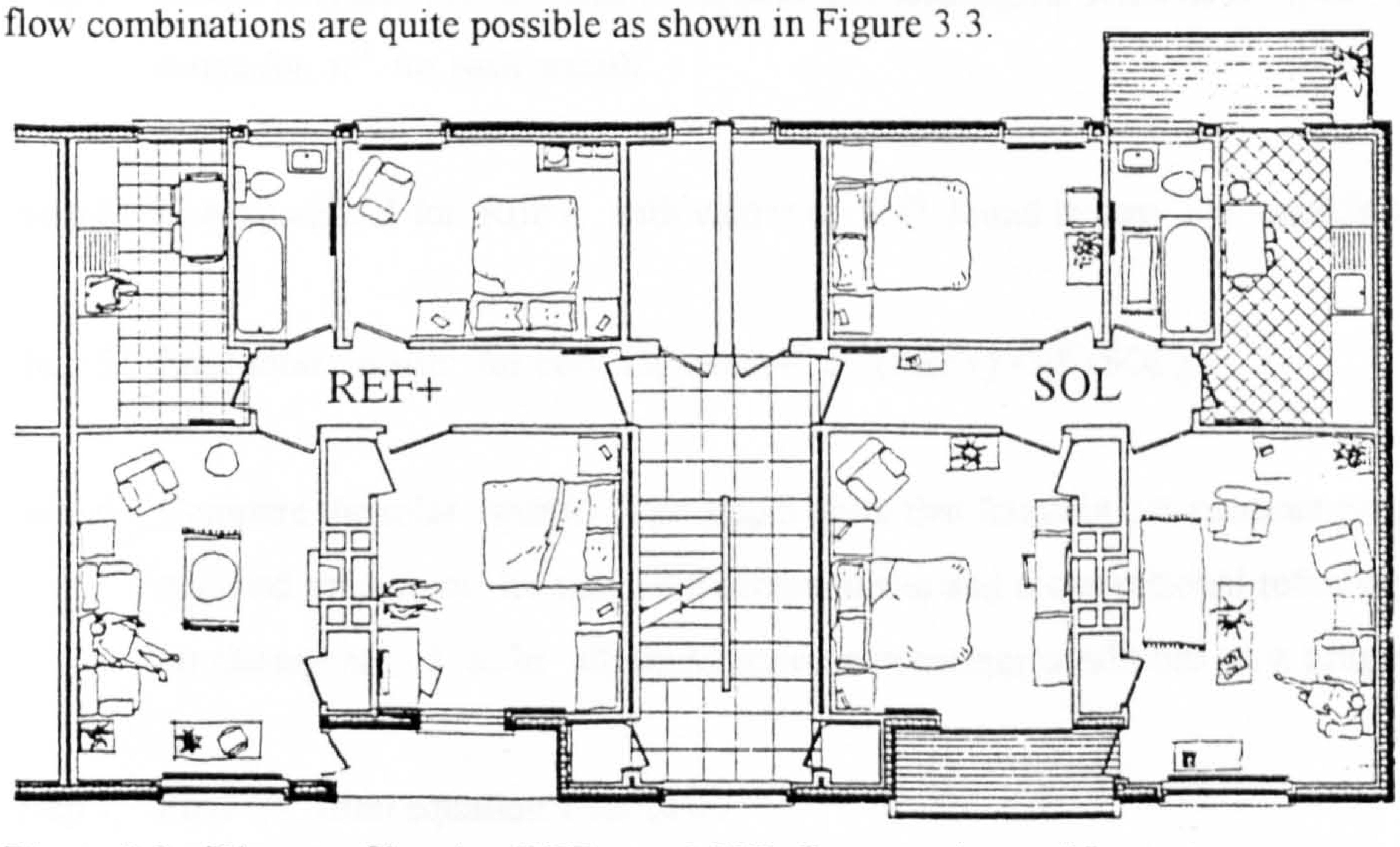

Figure 3.2 Diagram Showing REF+ and SOL Construction and Layout.

Model	Location	Zone 1	Zone 2	Total (W/K)
REF+	Gable end - 1st Floor	18.79	36.18	54.97
SOL	Gable end - 1st Floor	17.95	39.24	57.20

Table 3.3 Comparative Transmission Losses (REF+, SOL).

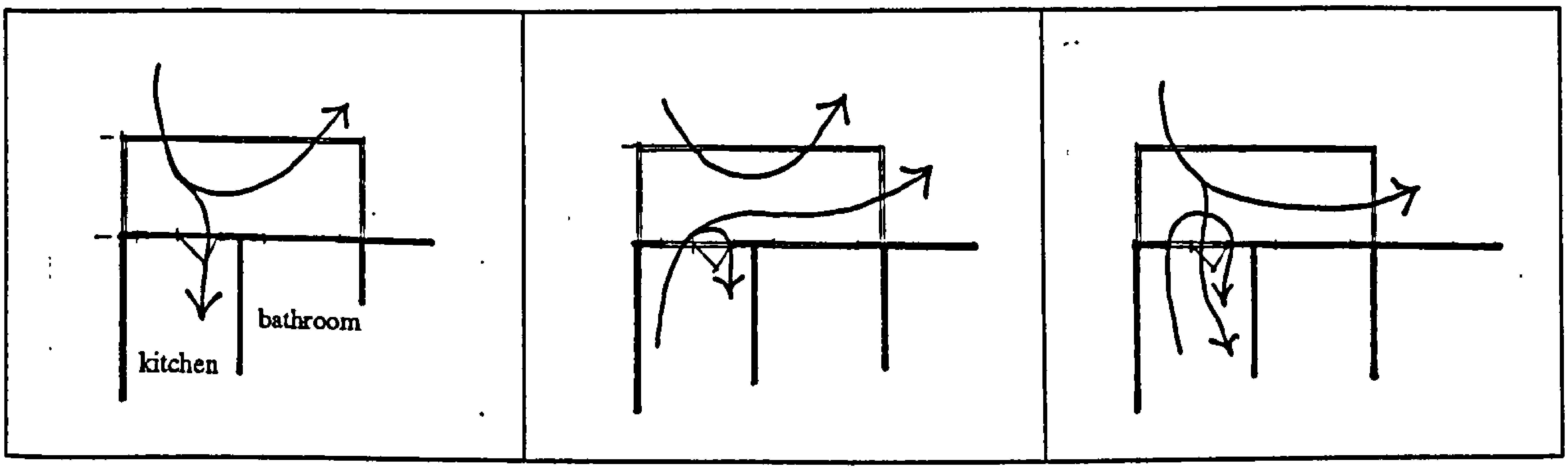

Figure 3.3 Air Flow Combination for the Conservatory.

In this case the only way to arrive at a split for Σn^p is by adopting a 'probable scenario' approach to represent a range of probability in terms of the air change split from heated zones directly to the outside, and via various buffer spaces, including the two glazed spaces. The varying values for n^p (equation 3) can then be fed back into the variants of equation 2 and cross-checked with 'qido' data. In this way a tangible seasonal profile for the likely range of real rates of air change through the various perimeter conditions is established.

So taking this approach step by step, firstly in summary form:

Step 1. Use equation 3 to find Σn^p using alternative n^p-split scenarios for SOL.

Step 2. Use equations 2b and 2c for SOL and substitute alternative n^p values from step 1, to give values for n^b and n^s.

Step 3. Check if values for n^b and n^s appear sensible/logical relative to 'qido' data; and identify most likely range for n^p for each month.

Step 4. Use equation 1 for REF+, with values of Σn^p found in step 1-3 substituted for n^e, to find q^h.

Step 5. Find solar 'worth' for each scenario = q^h (REF+) - q^h (SOL).

Step 6. Compare the solar 'worth' from step 5 with that found in pre-contract predictions by Porteous[16], having adjusted predictions for measured temperatures and constructional refinements, but kept the mean rate of air change at 1.5 ac/hr allocated between perimeter conditions on a pragmatic 'what if ?' basis.

Step 7. Find n^e from equation 1 for SOL.

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[16] PORTEOUS C.D.A. ibid. p.p. 56 - 59 April 1988.

Step 8. Find 2nd evaluation of solar 'worth' by comparing $0.33.n^e.V(Ti - To)$ with $0.33.n^p.V(Ti - To)$.

Then in more detail:

Step 1.1 Find q^h (W) mean monthly daily value for gas and electric houses. In the case of gas houses, q^h is calculated as follows:

Deduct water heating and cooking, then split the remaining units into q^h between radiators and gas fire due to different efficiency ratio. q^h in Watts is obtained by dividing by the number of days and then by 0.024.

In case of electric houses q^h is simply the sum of q^h storage and q^h non-storage - i.e. direct meter readings in kWh for month, divided by the number of days and then by 0.024 to convert to q^h in Watts.

Step 1.2 Find q^s (W) - using the standard solar geometry methodology to estimate solar gains to the heated zone and sunspaces as described in Section 3.2.3.A.

Step 1.3 Find q^i (W) - using the methodology described in Section 3.2.3.B for electric-heated houses and Section 3.2.4.B for gas-heated houses.

Step 1.4 Find $\Sigma A.U^p$ (W/K) - using the methodology in Section 3.2.4.A.

Step 1.5 Find Ti and T^p (°C) - mean monthly daily values from recorded data.

Step 1.6 Find unknown n^p for two perimeter - apportioned ventilation scenarios A and B (see Table 3.4 for a first floor gable end house); A representing a fairly optimistic regime where a significant proportion of the ventilation takes place via the sunspaces; and B representing a fairly pessimistic regime where a small proportion of the ventilation is via the sunspaces. Scenario A will yield a relatively large value for n^p relative to scenario B. In other words, the greater the $(n^p - n^e)$ difference, the more effective the sunspaces.

Location \ Scenario (% of ventilation)	ΣA.U(W/K)	Scenario A (%)	Scenario B (%)
A. (Z1)-Living room to outside	13.43	10%	25%
B. (Z1)-Living room to veranda	6.47	15%	10%
C. (Z2)-Kit/bath to conservatory	19.97	30%	20%
D. (Z2)-Kit gable to outside	2.61	2.5%	2.5%
E. (Z2)-Bed 1 to veranda	17.98	25%	15%
F. (Z2)-Bed 1 to fuel store, stair	7.58	1.25%	1.25%
G. (Z2)-Hall (door) to stair	4.38	5%	5%
H. (Z2)-Bed 2 to store	4.86	1.25%	1.25%
I. (Z2)-Bed 2 to outside	6.51	10%	20%
Total (A - I)	83.79	100%	100%

Table 3.4 Ventilation Loss To Adjoining Zones Pro-rata to Surfaces For Scenario A and B.

Step 2.1 Find values for Ts, q^{ss}, q^{is}, Hb(ΣA.U^b + 0.33.n^bV), Hs(ΣA.U^s + 0.33.$n^s$$V^s$) in equation 2b for conservatory and 2c for glazed veranda.

Step 2.2 Insert alternative n^p values found from step 1.6 in place of n^b and solve n^s for equations 2b and 2c. Follow through from step 3 to step 8 as described above

It is tempting to think of $n^p = n^e$ as the worst-performance condition for the sunspaces. However, the tendency to open up alters other variables in both equation 1 and equation 3, since the thermal resistance of the buffer will disappear. In equation 1, q^h is unaltered, q^i may be somewhat larger since it includes incidental gains in the sunspaces, q^s is significantly bigger due to the large amount of glazing to the sunspaces, and ΣA.U is bigger, and Ti is slightly smaller. The net effect would tend to lower the value for n^e to an unrealistic level. Therefore it may be concluded that the buffering/SVP effect is never entirely lost. Even if it were, the same tendency to the limit where $n^p = n^e$ at a much lower value runs counter to logic - i.e. a very low value for n^p or n^e is contrary to the reality of opening up.

A further check against such limits is the constantly running extract fans from kitchen and bathroom. These guarantee a minimum air change rate of 0.12 ac/hr averaged out for the whole house, even if it were otherwise completely closed up.

3.4 SUMMARY

The design strategy - insulation, ventilation and heating - embodies the basic principles of providing a low technological, but practical solution in the context of a thermal improvement package for public sector housing in Scotland. The level B and C of monitoring the CEC Easthall solar energy project inevitably reflects the compromise between working on a small budget on one hand and monitoring a relatively large number of solar houses and control houses on the other. Despite these limitations, trends in terms of physical and occupant-related factors negating optimum energy savings are anticipated. These trends will be thoroughly examined in Chapter 5 - user's interactions and 6 - case study. The core of this work will focus on the analysis in the first heating season results - September 1992 and May 1993 - supplemented by overall results of the following year. This work sets out to examine the range of energy influence as a result of occupants' interventions, particularly in respect of ventilation controls. Although it is not intention of this work to identify an absolute energy saving as a result of solar retrofits, it is felt necessary to provide an overview of energy performance in Chapter 4 as a prelude to answering the three main questions posed in Section 3.1.

CHAPTER 4 OVERVIEW OF ENERGY PERFORMANCE OF THE PROJECT

INTRODUCTION

The preceding chapter sets out the methodology for assessing performance and in particular the impact of the occupants' interventions, mainly with respect to ventilation and/or buffer spaces. As a prelude to answering the three questions posed in Section 3.5.6, an overview of the energy performance is provided. The measured energy consumption and costs, temperature profiles relative to other variables and deduced effective and real rates of air change during the heating season - September 1992 and May 1993 - are thus examined in this chapter.

Physical monitoring and instrumentation were phased in from March 1992 and the last solar house was instrumented in early November 1992. Detailed analysis was focused on the heating season between September 1992 and May 1993 - supplemented by overall results of the following heating season. All energy consumption was obtained by weekly meter readings. Thirty-four out of thirty-six solar houses (seventeen solar houses at each of Wardie Road and Glenburnie Place), as in Figure 4.1, were monitored and data analysed in accordance with the methodology set out in Chapter 3. Temperature was monitored in the remaining two houses, but the energy consumption record was incomplete due to occupants' failure to co-operate with monitoring.

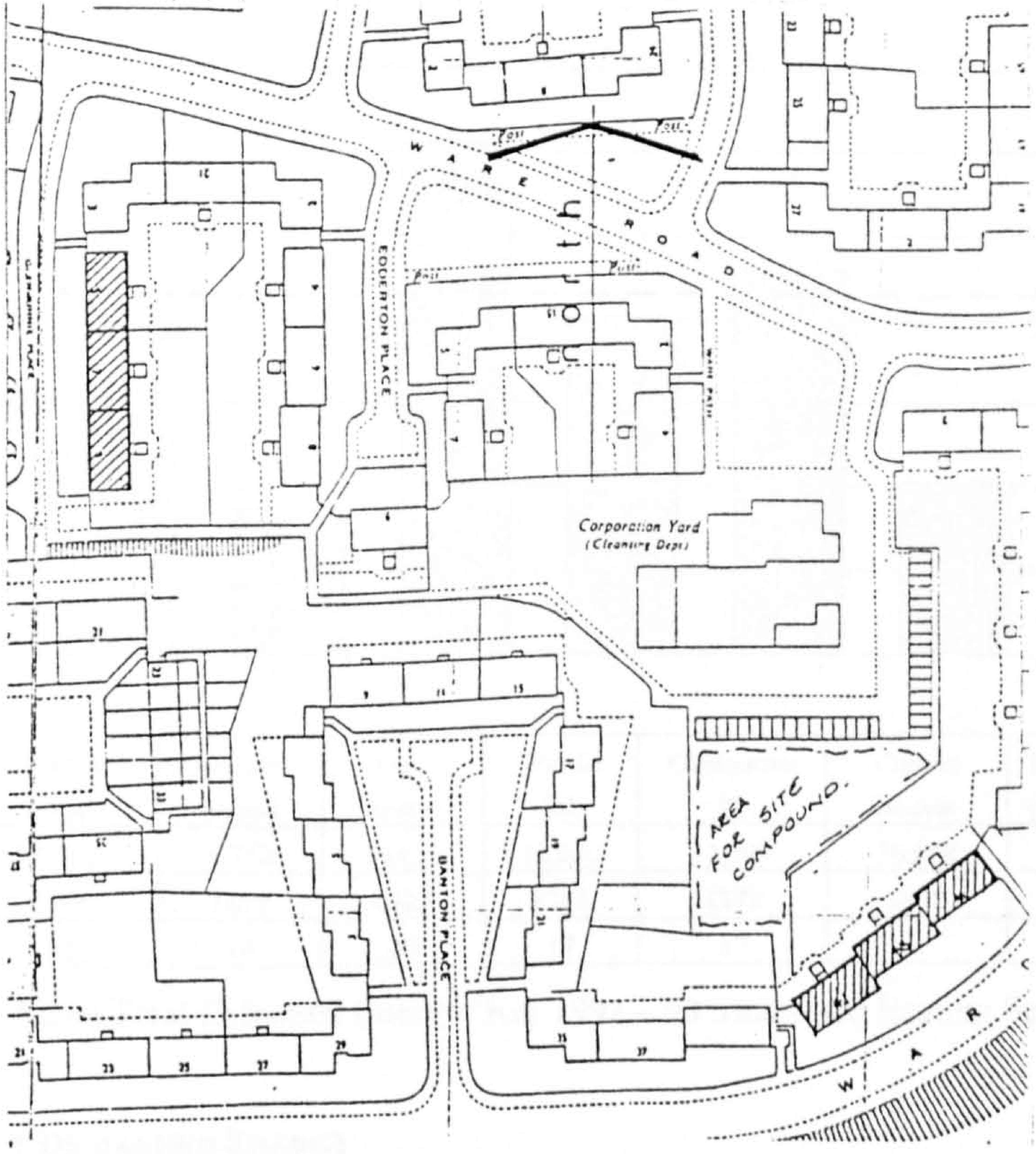


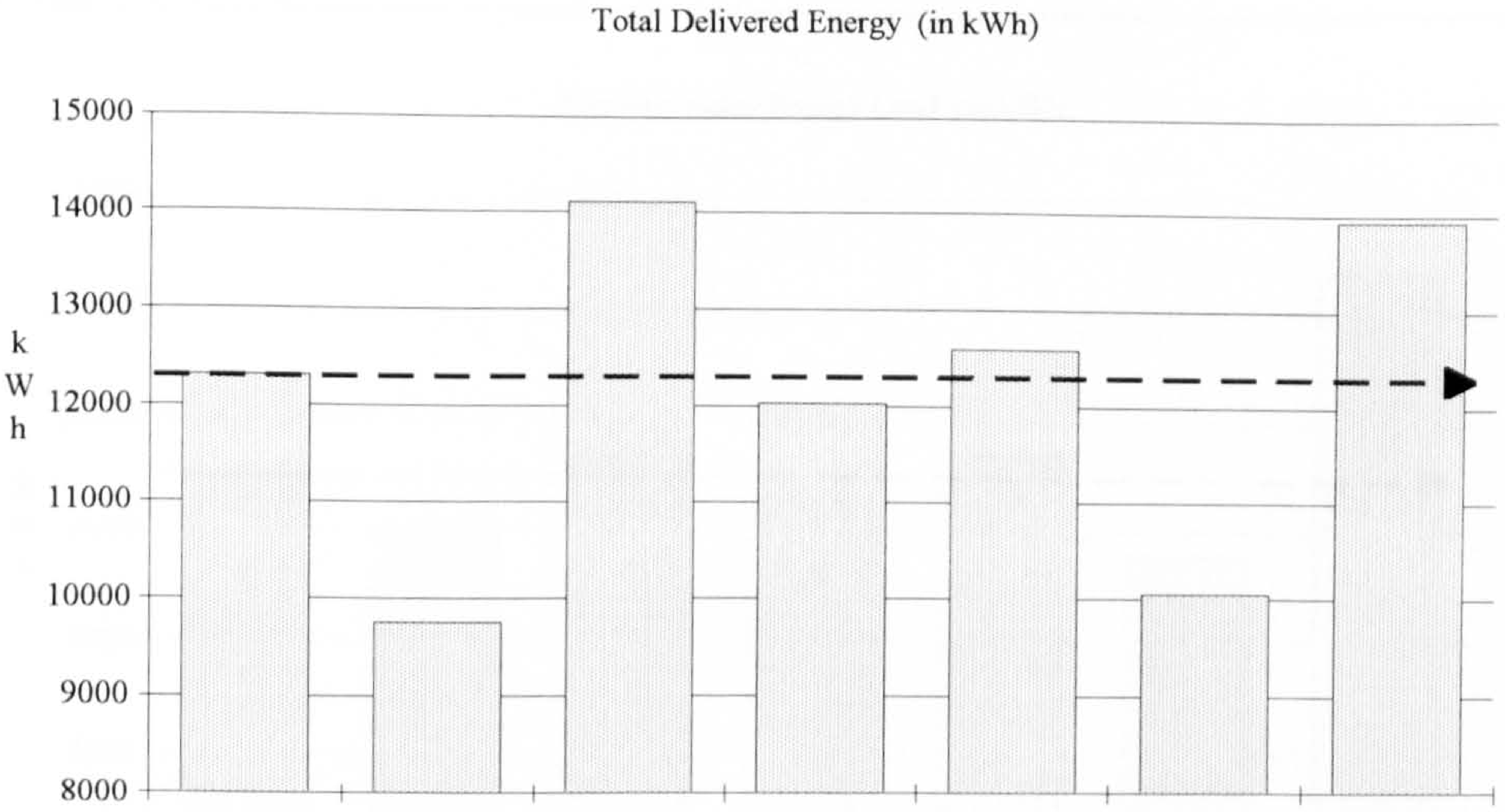
Figure 4.1 Location Plan of Thirty-six Solar Houses of the CEC Easthall project.

4.1 FUEL CONSUMPTION & COSTS DURING THE HEATING SEASON, SEPT. '92 - MAY '93

4.1.1 DELIVERED ENERGY

During the first monitored heating season (September 1992 - May 1993), the mean total delivered energy of thirty-four solar houses as illustrated in Figure 4.2 is +22.4% higher than the electrically and gas-heated control or reference houses (existing houses with no thermal improvements), thereafter denoted as REF-. What is significant for the users is firstly what this energy costs to deliver and secondly how much comfort it purchases. So from the outset, it must be accepted that although users' thermal needs and aspirations may well be met, there may be more energy delivered, not less. Nevertheless the re-distribution of this energy is influential - say from electricity to gas, or from peak electricity to off-peak - and it is relevant to compare delivered energy here with an earlier, almost equivalent project. In a comparable EPA[1] study of an earlier prototype block (similar passive solar features, thermal characteristics and floor area, but with a different orientation, gable-end location and no solar collector) at Edderton Place, the mean delivered energy to a gas-heated house for the previous nine-month heating season was +13.2% higher than the mean for the CEC project; but very close to the mean for gas-heated houses, where the delivered energy is naturally higher than for electric.

Comparing the two fuel types employed for space heating, gas-heated solar houses registered +44.7% higher delivered energy than electric-heated houses whilst solar houses at Glenburnie Place, disregarding which fuel was used, consumed just 5% more than Wardie Road.



All solar houses	Electric-heated	Gas-heated	Wardie Rd.	Glenburnie Pl.	Control houses	Edderton Pl. pilot scheme	
12,316	9,752	14,111	12,030	12,597	10,058	13,941	delivered kWh
£364	£419	£325	£365	£378	£490	n/a	net energy cost
34	14	20	17	17	2	6	sample number

Figure 4.2 Mean Total Delivered Energy Over 1992 - '93 Monitored Heating Season.

4.1.2 NET DEMANDED ENERGY

Chapter 3 sets out the limitations with respect to the adopted monitoring strategy. One of these is that since gas fuel efficiencies can only be taken as notional, the analysis with respect to gas houses is inevitably more 'soft-edged' compared with that for electric houses where measurement of space heating consumption is isolated from that of water heating, and efficiency of space heating may be taken as 100%. Nevertheless, the order of

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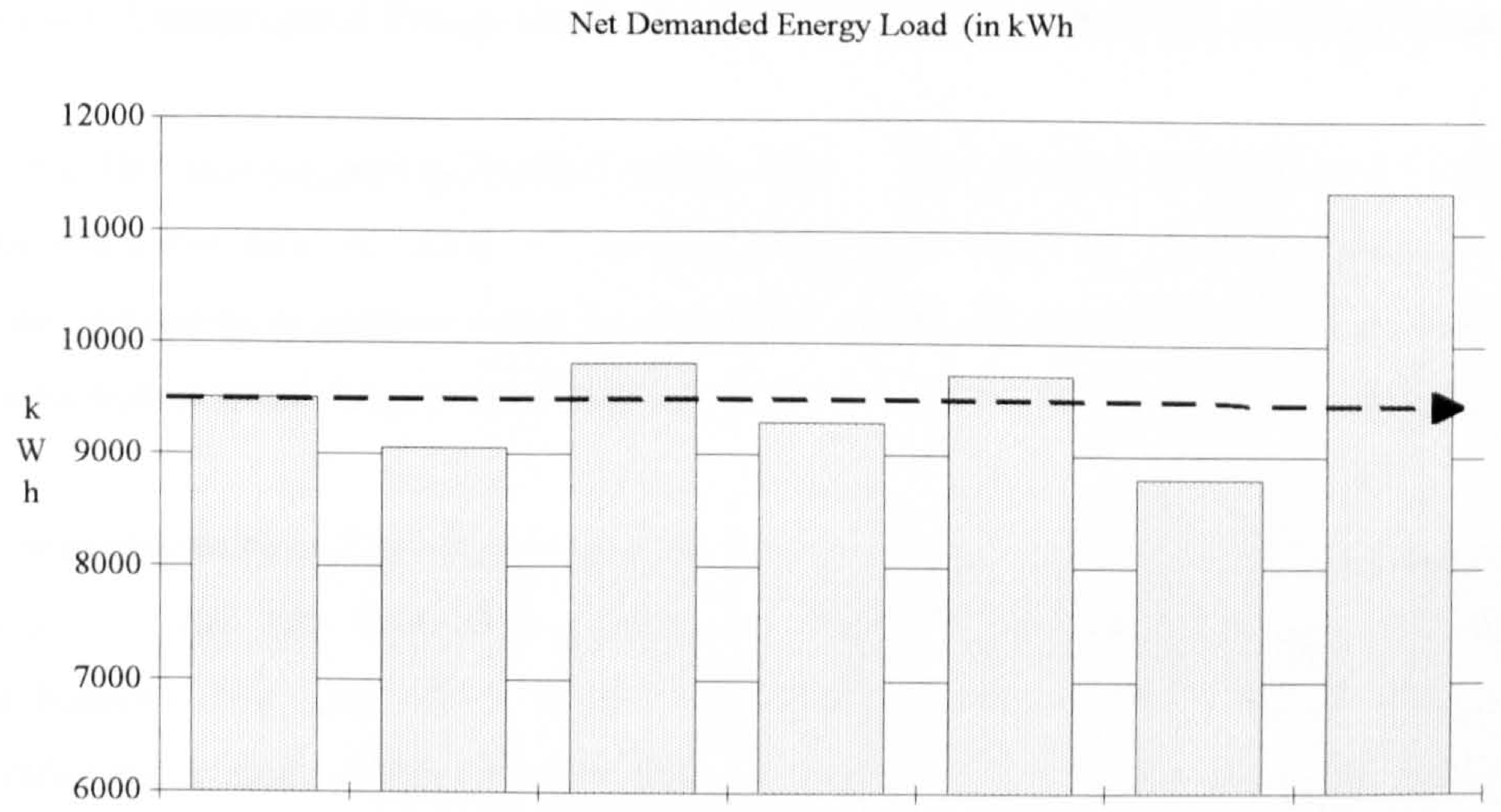
[1] VAUGHAN N., JONES P., ALEXANDER D., ET.AL. ENERGY PERFORMANCE ASSESSMENTS - 9 EDDERTON PLACE, EASTHALL, SOLAR BUILDING STUDY- FINAL REPORT ETSU S 1163/24 Welsh School of Architecture, March 1992. P.P. 1/10 - 33.

variation in actual efficiencies should not be high enough to call into question, the generally known trend that for a particular heat loss and demand regime, a non-storage system will result in a lower temperature than an electric storage system. It is further likely that since the gas boiler does not have a balanced flue, the requirement for air to support combustion may lead to higher rates of air change compared with an electric house. Hence results which indicate higher net demanded energy load for gas heated houses are to be expected and add confidence to assumptions made with respect to notional efficiencies. Figure 4.3 shows that the mean net demanded energy of the CEC solar retrofitted houses during September '92 - May '93 was 9% higher than control or reference houses (REF-). So even after allowing for flue loss in the latter case, the affordability factor results in energy demand in the solar house being somewhat higher than that of the control houses

Also, despite the somewhat higher demanded energy of gas-heated houses, the findings indicate that gas-heated houses are cheaper to run than electric-heated as the fuel cost per kWh is substantially lower for gas, see Section 4.1.4 below. Further disregarding which fuel is used for the heating system, demanded energy of solar houses at Glenburnie Place is 4.7% higher than Wardie Road, suggesting perhaps a dominance of gas houses, or a more exposed location, or less appropriate control by tenants, or a combination of all those.



All Solar Houses	Electric-heated	Gas-heated	Wardie Rd.	Glenburnie Pl.	Control houses	Edderton Place	(all in kWh)
9,568	9,057	9,812	9,284	9,718	8,797	11,365	Net Total Energy Load
34	14	20	17	17	2	6	Sample Number

Figure 4.3 Net Demanded Energy Load over First Monitored Heating Season (all in kWh)

4.1.3 DISAGGREGATED DEMANDED ENERGY

The mean net demanded energy load of thirty-four CEC Easthall solar houses, disaggregated in accordance with uses, is summarised in Figure 4.4 and compared with the EPA[2] prototype block at Edderton Place. The mean net demanded energy loads for space heating and water heating of the former are respectively -12.4% and -14.5% lower than the latter, as a result of the poorly insulated Glenhill Boilermate being influential in its case. The

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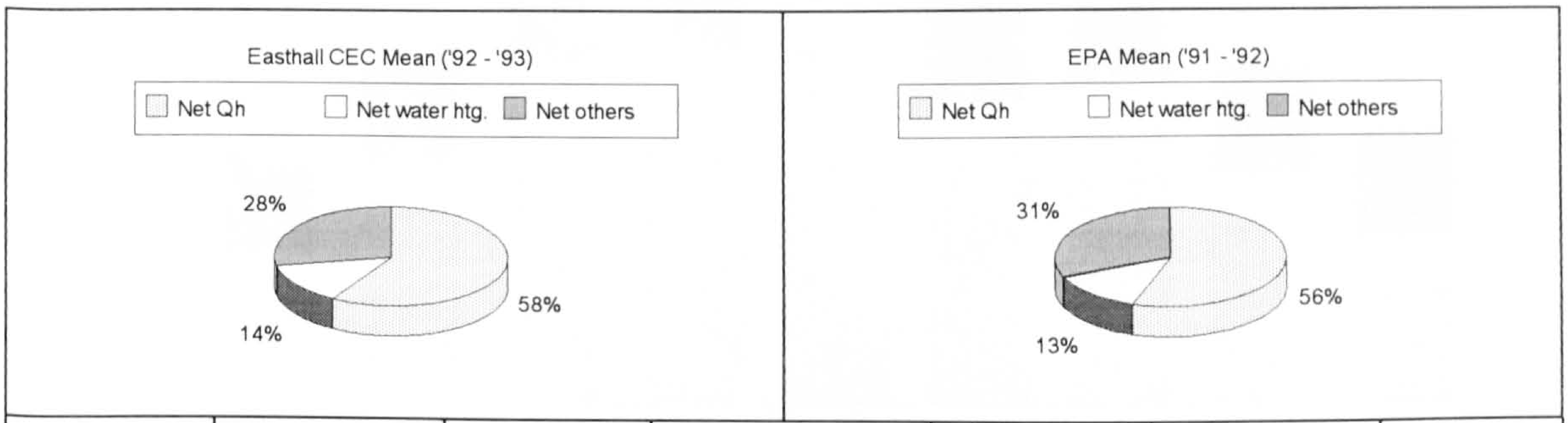
[2] VAUGHAN N., ET.AL. ibid P.P. 3/3 - 4

remaining disaggregated net demanded energy load for lighting, appliances and cooking confirms the CEC houses as -24.8% lower than that of the EPA. Note that the total for the Edderton Place pilot study is significantly higher than that for the equivalent mean for the CEC gas-heated houses, as in Figure 4.3. This then suggests greater efficiency for the former since the delivered totals were approximately the same. However, the value is obtained by deducting flue losses only from the delivered total, with all standing losses from the Gledhill Boilermate assumed to contribute usefully to space heating. In fact overheating due to this unit was reported in the main bedroom.

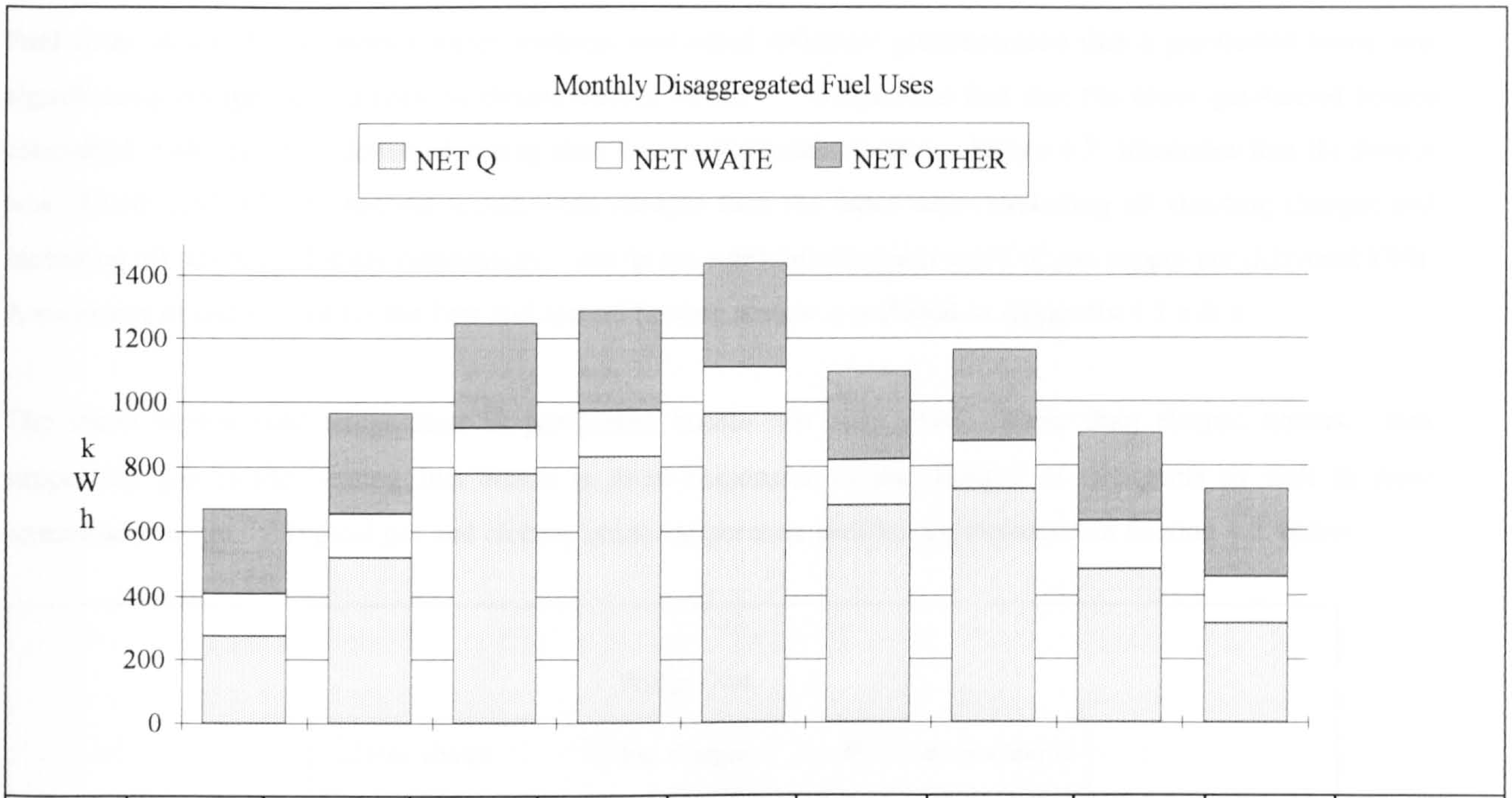


Net Qh	Net Water htg.	Net Others	Easthall / Edderton	Net Qh	Net Water htg.	Net Others
5,630	1,284	2,654	(All in kWh)	6,330	1,502	3,533
58.8%	13.4%	27.7%	% in total	55.7%	13.2%	31.1%

Figure 4.4 Disaggregated Energy Loads of the CEC Solar Houses and EPA Prototype Houses.

The monthly disaggregated demanded energy load, as illustrated in Figure 4.5, shows that space heating constituted a minimum of 42% of the total energy load (Sep-92) and a maximum of 67% (Jan.'93), the autumn and spring proportion being unexpectedly high given the energy efficient aims of the project. This indicates high internal temperatures and/or high rates of ventilation at the fringes of the heating season.

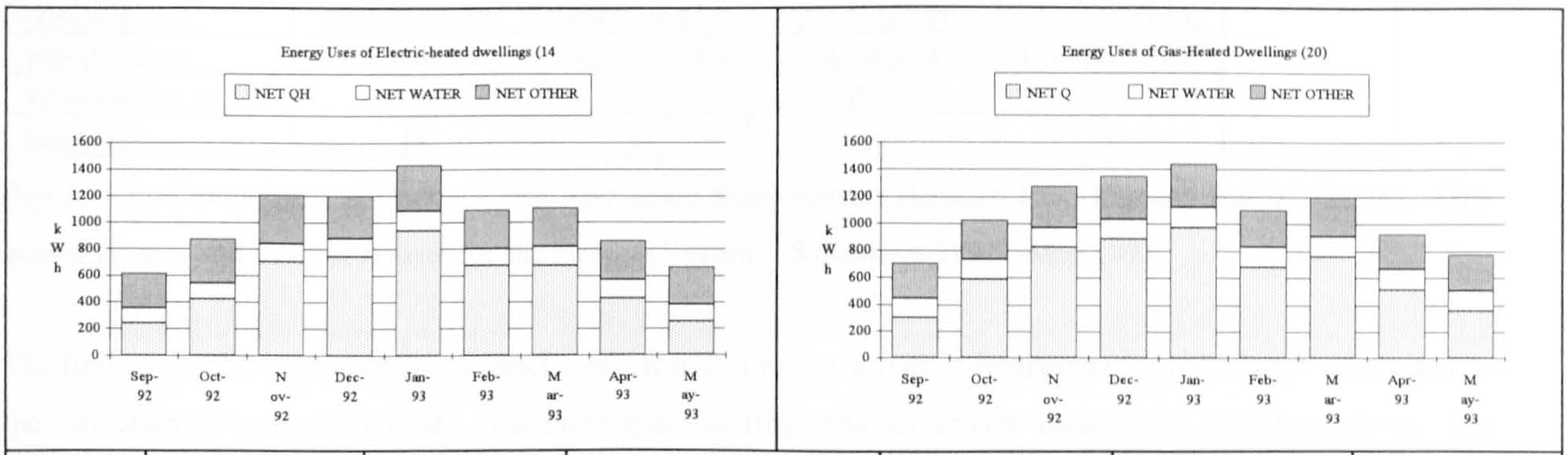
The mean demanded energy load for water heating was fairly constant throughout the period with a monthly range between 133 and 148 kWh whereas other uses, including lighting, appliances and cooking registered a wider range between 261 and 329 kWh. The net demanded energy load in the latter category peaked during December and January reflecting longer lighting-up time, longer stay-in hours and other more frequent activities during winter months, such as use of tumble-dryers.



Total net	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93	May-93	(All in kWh)
5,630	283 /42%	527 /54%	785 /63%	838 /65%	969 /67%	686 /62%	734 /63%	488 /54%	320 /43%	Net Qh (100%)
1,284	133	135	142	143	148	142	148	147	146	Net water htg.
2,654	261	311	329	314	329	277	290	273	270	Net others
(9,568)	(677)	(973)	(1,256)	(1,295)	(1,446)	(1,105)	(1,172)	(908)	(736)	(Total)

Figure 4.5 Monthly Disaggregated Energy Uses of the CEC Easthall Project - Thirty-four Solar Houses.

The net demanded energy load for space and water heating of gas-heated house (after multiplying delivered gas values by efficiency co-efficient) was 15.7% and 11.8% higher than electric-heated houses respectively. The possible reasons have been indicated above and, as stated, are not unexpected. The net demanded energy load for other uses, i.e. lighting, appliances and cooking, was fairly closely matched in both types of houses with less than 8% difference. Figure 4.6 illustrates the net monthly energy uses broken down for electricity and gas.



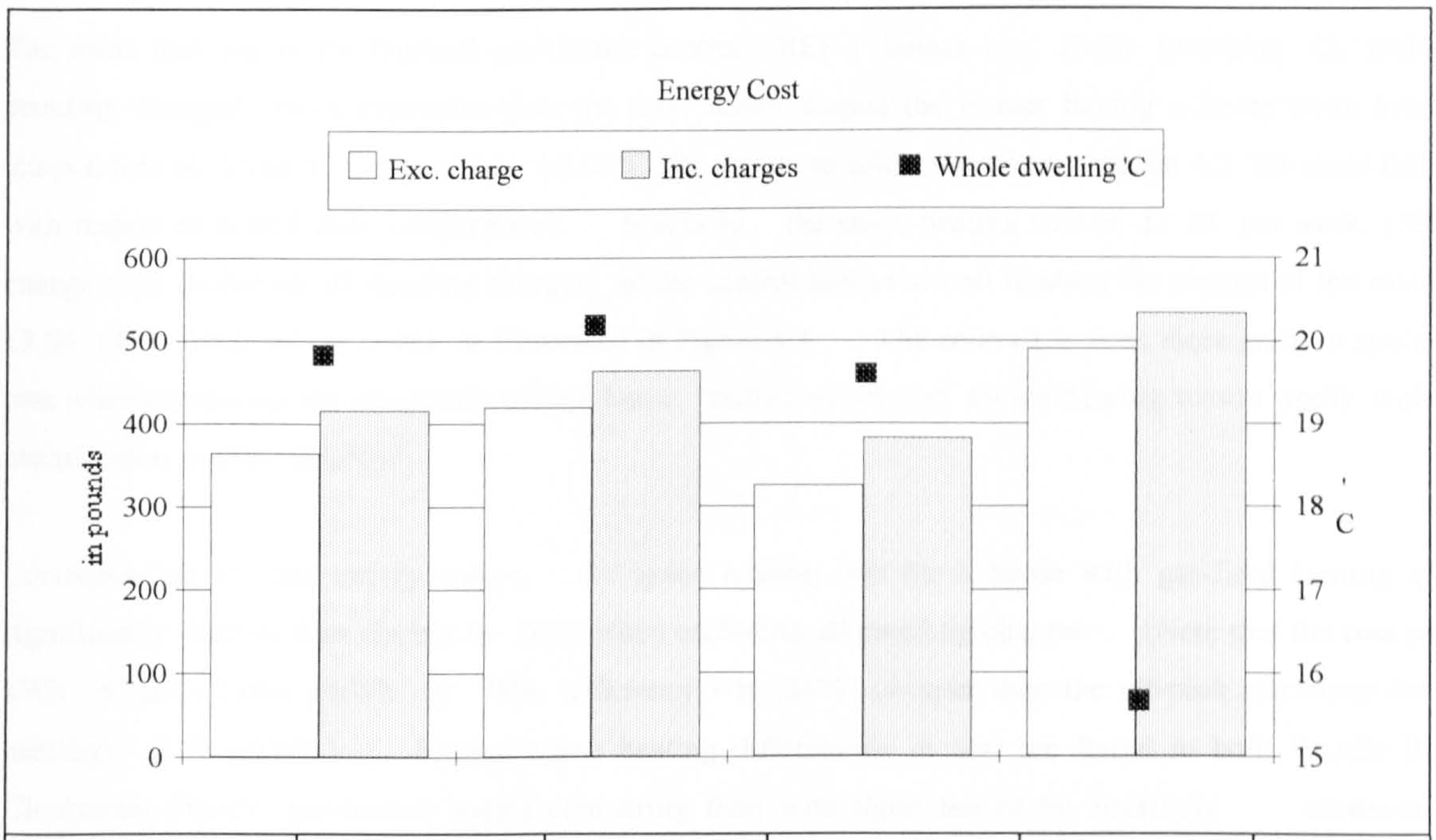
Net Qh	Net Water Htg.	Net Others	Electric / Gas-heated	Net Qh	Net Water Htg.	Net Others
5,092	1,200	2,765	Htg. Season total (kWh)	5,893	1,342	2,577

Figure 4.6 Disaggregated Energy Uses of the CEC Project - 14 Electric-heated and 20 Gas-heated Houses.

4.1.4 ENERGY COST

Fuel costs obtained from weekly meter readings confirmed residents' preconception that a gas-heated house was significantly cheaper to run than an electric-heated house. Despite the fact that the mean gas-heated houses consumed +44.7% more delivered energy than the electric-heated houses, Figure 4.7 illustrates that the former was £2.40 and £2 per heating season week cheaper than the latter when excluding all standing charges and including all standing charges respectively, due to the substantially lower tariff of gas supply per delivered kWh. A summary of energy cost for the first and second heating season is included in Appendix 4.1.a & b.

The mean heated zone temperature in gas-heated houses was only 0.6K lower than electric houses; thus supporting gas as the heating fuel which is more responsive to the demand of occupants as well as more economical to run. Typical gas and electric house temperature profiles are examined in Section 4.2 below.



(weekly cost in bracket)	All solar houses	Electric-heated	Gas-heated	Control house
Without charges	£363.83 (£9.32)	£418.87 (£10.74)	£325.30 (£ 8.34)	£490.44 (£12.58)
With all charges	£415.29 (£10.65)	£462.75 (£11.87)	£382.06 (£9.8)	£533.42 (£13.68)
Whole house in °C	19.86	20.21	19.62	15.68
Sample size	34	14	20	2

Figure 4.7 Comparison of Energy Costs And Mean Temperatures Between CEC Easthall Electric-heated, Gas-heated Houses and Control Houses for the Heating Season- September 1992- May 1993.

The findings of this demonstration project contrast with a recent survey at Bournville Solar Village[3] conducted by the University of Central England. The mean space heating costs of fourteen 'direct gain' solar bungalows, two of which were intensively monitored, was £8.07 per week for gas compared with £5.15 for electric both excluding standing charges; whereas the Easthall project costed £3.37 for gas and £4.56 for electric (September 1992 - May 1993 prices). Although both projects covered almost identical monitoring periods, it is irrelevant to compare the absolute space heating cost between the two projects. However, it is very puzzling to

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[3] JANKOVIC L. WHICH IS BETTER: GAS OR ELECTRICITY ? - HARVEY MEWS MONITORING REPORT University of Central England. p.p. 7- 13 5 August 1993.

find gas-heated houses in the Bournville project costing +57% more than electric, but almost -26% less in the case of the Easthall project. This perhaps suggests that the occupant-related factors are critical in determining energy consumption and the relatively small sample may have led to misleading results with respect to gas-electric competitiveness. Chapter 5 will more fully disseminate factors affecting energy consumption relative to the Easthall project.

Since the average installation cost[4] is higher for gas than electric heating systems, the Bournville report confirmed that electricity as a heating fuel benefits from lower running costs and lower installation costs. However, in this case primary fuel mix currently use in the electricity generation industry was criticised[5] for consuming substantially more primary fuel and producing substantially more pollution than gas fired heating systems.

The mean fuel cost of the Easthall gas/electric control (REF-) houses was £3.26 (just over £3 including all standing charges) more expensive than the solar house despite the former having a lower mean heated zone temperature of 15.68°C compared to 19.86°C for the mean solar house - see Section 4.2 for more information with respect to heated zone temperatures. Similarly, the space heating cost of £7.29 per week (58% total energy costs excluding all standing charges) of the control houses almost doubles the amount of the solar houses' £3.86 (41% total energy costs) as illustrated in Figure 4.8. The contrast is even more stark in space heating cost when comparing the all-electric control house (estimated net cost £9 per heating season week) with the all-electric solar houses (£4.56).

Corresponding to total energy values, the space heating cost for a house with gas-fired heating system is significantly cheaper than electric by 26% when excluding all standing charges. (Note that the cost per useful kWh of gas - 2.066 p/kWh @ 76% efficiency - is 26% cheaper than the off-peak electricity for storage heating's 2.79 p/kWh.) Similar space heating differentials in cost are found in both Wardie Road and Glenburnie Place's gas-heated houses comparing than with those heated by electricity. However, it is interesting to find the average heating cost of Wardie Road is fifty pence cheaper than Glenburnie Place in the case of gas-heated houses; whereas electric-heated houses at Wardie Road are thirty-three pence more expensive than Glenburnie Place. The reverse trend in both locations (Glenburnie Place's gas-heated houses and Wardie Road's electric-heated houses are dearer) largely reflects what tariffs the occupants, especially in electric-heated houses, are using for space heating and the individual needs for heating and ventilation.

The mean space heating cost of £3.85 for the following heating season (September 1993 - May 1994) was almost the same as the first heating season's £3.86, despite an increase in electricity and a reduction in gas tariffs. There was also a slight reduction of heating costs (from £4.56 per week in the first year to £4.08 in the second) in electric-heated houses; in contrast with an increase from £3.37 to £3.67 in the case of gas-heated houses.

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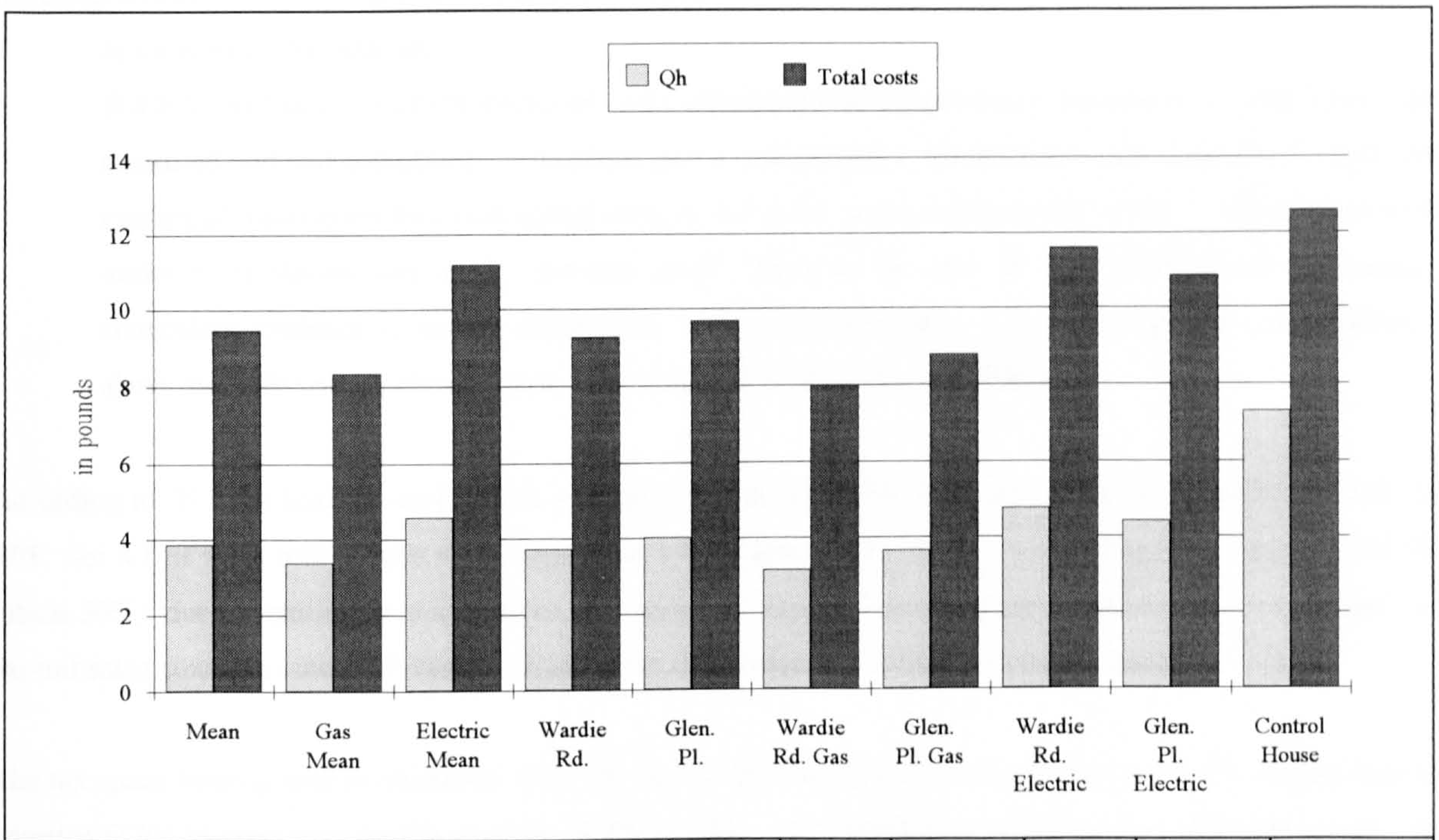
[4] BRIDGEWATER AND COULTON HEATING AND INSULATION COSTINGS - MEADOW RISE DEVELOPMENT p.p. 12 - 14 1990.
[5] JANKOVIC L. ibid p.p. 8 - 9 5 August 1993.

Before embarking on occupant-related factors, which are fully explored in Chapter 5, the space heating load of the solar houses are scrutinised in more depth in the following section.



Qh £/wk	3.86	3.37	4.56	3.72	4.01	3.15	3.64	4.75	4.42	7.29
Total	9.32	8.34	10.74	9.27	9.68	8.00	8.78	11.6	10.84	12.58
Samples	(34)	(20)	(14)	(17)	(17)	(11)	(9)	(6)	(8)	(2)

Figure 4.8 Space Heating Cost Per Week For the CEC Easthall Project (September 1992 - May 1993).

Energy cost calculations were based on unit price of energy provided by British Gas[6] and Scottish Power[7] for the period of September 1992- May 1993 as in Table 4.1 (a change of tariff for both heating fuels took place in April 1993).

		Sep. '92- Mar. '93	Apr. '93- May '93
British Gas	Standing Charge	10.1 p/day	10.1 p/day
	Fuel Tariff	1.57 p/kWh	1.48 p/kWh
Scottish Power	Standing Charge	10.58 p/day	11.08 p/day
	Domestic Tariff	6.94 p/kWh	7.13 p/kWh
Scottish Power	Standing Charge	15.9 p/day	16.68 p/day
White Meter	Low	2.85 p/kWh	2.93 p/kWh
Tariff No.4*	Normal	7.49 p/kWh	7.7 p/kWh
	Control	2.79 p/kWh	2.79 p/kWh

Table 4.1 Energy Tariff of Gas and Electricity During The Monitored Period.

* White Meter Tariff No.4 is supplied for premises used exclusively as a single private dwelling where use is made of storage heating appliances. The 'Low' circuit will supply electricity any period of 8½ hours between 10 p.m. and 8:30am Greenwich Mean Time, the exact times to be at Scottish Power discretion. The 'controlled circuit' will be solely for storage heating purposes. Supply through the circuit will be available for a period or periods totalling 8½ hours in each 24 hour period commencing at noon.

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[6] BRITISH GAS BRITISH GAS - GUIDE TO DOMESTIC TARIFFS - 1992. p.p. 2.
BRITISH GAS BRITISH GAS - GUIDE TO DOMESTIC TARIFFS - 1993. p.p. 2.
[7] SCOTTISH POWER YOUR GUIDE TO ELECTRICITY PRICES - 1992. p.p. 1.

4.1.5 DEMANDED ENERGY FOR SPACE HEATING COMPARED WITH PREDICTIVE ANALYSIS

This section examines the net space heating load (previously termed 'net demanded space heating load', and thereafter termed Net Qh) with abbreviations as follows:

a. as measured (**Net Qh_m**);

b. SODEM predictive results by Porteous[8] with adjustments to temperatures (measured), solar gains (part measured and part calculated), incidental gains (calculated), transmission loss (calculated) and 'pro-rata areas' ventilation loss (calculated using a 1.5 ac/hr mean whole house value). The allocation of a uniform ventilation loss on a 'pro-rata areas' basis in the case of Qh_SODEM-adj is simply a convenient yardstick to enable comparison with monitored data - e.g. space heating consumption as above and effective air change rates, see Section 4.3 (**Net Qh_SODEM-adj**).

According to 'b', the heat loss co-efficient was calculated as 158 W/K for a typical first floor gable-end and 152 W/K for a first floor mid-terrace solar house with a floor area of 66.19m^2; with a large proportion of the loss (about 50%) due to ventilation at a mean of 1.5 ac/hr. The heated volume of a solar house is 149.14m^3 and the unheated sunspaces total 17.94m^3 (7.28m^3 for veranda and 10.66m^3 for conservatory).

The net space heating load as measured (Net Qh_m) for the monitored heating season is 23.5% higher than the adjusted SODEM predictive results (net Qh_SODEM-adj). The findings may indicate two different trends, one related to users' interaction/orientation, and the other to users' interaction/heating fuel. The main interaction is of course the control of ventilation. Whereas the Qh_SODEM-adj assumes a simple value throughout the heating season, results show that the rate of air change tended to be significantly higher than this value in autumn and spring, although generally somewhat lower in the central winter period. These are fleshed out in more details in Chapter 5 and 6. Also the difference in mean net space heating load of merely 4.1% when compared with the same number of solar houses at Wardie Road (facing SE/NW) and Glenburnie Place (E/W) masks the fact that the highest Glenburnie Place house is significantly higher (55%) than the adjusted SODEM-adj. value, while the highest Wardie Road house is lower by 6%. However, Glenburnie Place's lowest is also 30% lower than the adjusted value, suggesting caution in coming to premature conclusions as to cause. Figure 4.9 illustrates net Qh_m and net Qh_SODEM-adj for the first monitored heating season.

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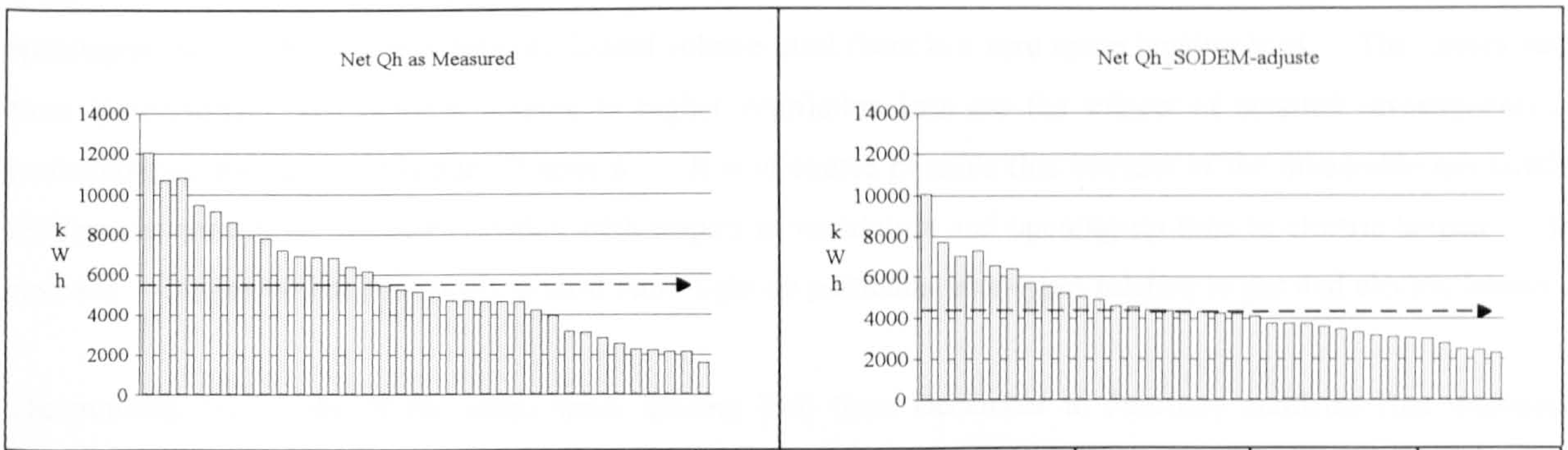
[8] PORTEOUS C. RETROFIT OF THERMALLY SUB-STANDARD HOUSING IN GLASGOW AS A CEC PASSIVE SOLAR DEMONSTRATION PROJECT, Mackintosh School of Architecture, Unpublished, April 1988. p.p. 56 - 64.



Highest (±%)	Mean (±%)	Lowest (±%)	Net Qh_m / Qh_SODEM-adj	Highest	Mean	Lowest
12,023 (19%)	5,630 (24%)	1,623 (-30%)	All solar houses (34)	10,067	4,558	2,314
9,176 (-9%)	5,041 (0%)	1,623 (-42%)	Electric-heated (14)	10,067	5,047	2,790
12,023 (55%)	6,043 (43%)	2,142 (-7%)	Gas-heated (20)	7,740	4,215	2,314
9,480(-6%)	5,517 (19%)	2,174 (-13%)	Wardie Road (17)	10,067	4,636	2,485
12,023 (55%)	5,743 (28%)	1,623 (-30%)	Glenburine Pl. (17)	7,740	4,479	2,314
9,176 (-9%)	5,316 (-8%)	2,813 (-7%)	Wardie Road / Electric (6)	10,067	5,792	3,038
9,480 (71%)	5,627 (40%)	2,174 (-13%)	Wardie Road / Gas (11)	5,537	4,005	2,485
6,918 (-2%)	4,834 (8%)	1,623 (-42%)	Glenburine Pl. / Electric (8)	7,037	4,488	2,790
12,023 (55%)	6,551 (46%)	2,142 (-7)	Glenburine Pl. / Gas (9)	7,740	4,472	2,314

Figure 4.9 Net Demanded Energy for Space Heating as Measured, SODEM-Adjusted Predictive Results At 1.5 ac/hr And Percentage Above Prediction - (mean figure marked with an arrow & house sample in parenthesis).

Gas/electric comparisons are perhaps more consistently revealing. The mean net Qh_m of gas-heated solar houses is significantly higher than Qh_SODEM-adj, with +40.5% and +46.5% above predictions for Wardie Road and Glenburnie Place respectively. The Qh_m consumption of the latter is 924 kWh more than the former; although as stated in Chapter 3 in the case of gas, various assumptions have been made with respect to the space heating, water heating and cooking split, each with respective efficiencies generally. The SODEM adjusted values, based on achieved temperatures, indicate that gas-heated houses should generally have lower values compared with electric. However, the opposite almost always holds true. This indicates a significantly higher than predicted level of autumn/spring ventilation in case of gas-heated houses especially at Glenburnie Place.

Unlike gas houses, those heated by electricity were rather closely matched to Qh_SODEM-adj, with a negligible difference of less than 1% (or 6 kWh) in the mean net space heating load over the heating season; although the difference between the highest and lowest in the electric-heated house was 5.6 times, compared with 3.6 for SODEM-adj., reflecting both diversified energy needs and control of system. It is worth noting that the difference of less than 1% in electric-heated houses between the mean Qh_m and Qh_SODEM-adj space heating load was made up of -8.2% in the case of Wardie Road and +7.7% at Glenburnie Place. Despite having a higher measured energy load than predicted by +8%, electric-heated solar houses at Glenburnie Place (4,834 kWh) consumed -9.1% (482 kWh as measured) less space heating energy than Wardie Road's electric houses (5,316 kWh).

Gas-heated houses registered a similar difference between the highest and lowest net Qh_m (5.6 times compared with 3.3 predicted). It should be emphasised that the adjusted-SODEM values are based on a fairly arbitrary 'what-if ?' assumption with respect to ventilation split directly with outside and via buffers and do not allow for opening-up to include buffers within the heated volume until there is a zero space heating load. The causes and, more importantly, the motives leading to higher ventilation loss are the subject of detailed investigation in particular case studies described in Chapter 6. It is of course possible that because of the favourable gas tariffs, residents in gas houses are more cavalier with respect to ventilation and opening-up than in electric houses. In any case, Chapter 6 will endeavour to shed more light on particular user-types relative to gas and electric houses.

The monthly breakdown of the mean space heating load from December to February confirms that measured consumption is closely aligned with predictions at less than +3%; whereas in autumn and spring, the net Qh_m is considerably higher than Qh_SODEM-adj, especially in September and May. This supports the hypothesis of tardy closing down and premature opening-up of sunspaces and/or leaving outer sunspace windows ajar, resulting in higher ventilation loss in early autumn and late spring when the potential for solar gains is the greatest.

Such interventions appear to result in the loss of much of the potential energy savings from ventilation preheat, which forms the underlying principle of the passive solar design for this project. However, the predictive assumption of a uniform rate of ventilation throughout the heating season is probably unrealistic. Dick and Thomas[9] reported a 75% increase in the number of open window hoppers for a 5K increase in outside temperature from 5 to 10°C. Dickson[10] reported air change rates varying from 0.4 to 20.0 ac/hr depending on number/degree of open windows, wind velocity etc; while Etheridge[11] found that even with all internal doors closed and calm weather (i.e. ventilation dominated by buoyancy) an increase in open window area from 0.1 to 0.3 m^2 resulted in a doubling of air change rate from about 0.5 to 1.0 ac/hr. Therefore, with autumn and spring temperatures averaging from 8 - 8.5°C in this case, it is to be expected that both window opening and air change rates will be significantly higher in these seasons compared with the central winter period. Thus it would appear that the results at Easthall correspond to a user-driven norm of seasonally variable ventilation rates that should be built into predictive models. Accepting this premise, the sunspaces are still in a position to save energy by ventilation preheat at a relatively high rate, as well as at a lower rate in winter.

Indeed, the sunspace performed as expected in heat recovery mode during the central winter months with net Qh_m lower than net Qh_SODEM-adj by -7% in December. Table 4.2 illustrates the monthly space heating load. Both gas-heated and electric-heated solar houses also conform to a similar trend with a higher than predicted space heating load in autumn and spring and closer alignment in winter months.

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[9] DICK J.B., THOMAS D.A. VENTILATION RESEARCH IN OCCUPIED HOUSES. IHVE, 19, British Building Research Establishment, HMSO 1951, p.p. 306 - 326.

[10] DICKSON D.J. VENTILATION WITH OPEN WINDOWS, Electricity Council Research Centre, Report M1329, April 1980.

[11] ETHERIDGE D.W. NATURAL VENTILATION IN THE UK AND SOME CONSIDERATIONS FOR ENERGY EFFICIENT DESIGN, Proceedings; 3rd Air Infiltration Centre Conference, London Sept. 1982; published by British Gas, New Housing, undated, No. 8 in the series 'Studies in Energy Efficiency in Buildings' p.p. 38 - 43.

	Net Qh_m	Qh_SODEM-adj	± % over net Qh_m	± % Seasonal
Sep-92	283	82	+245%	
Oct-92	527	396	+33%	+40% (Autumn)
Nov-92	785	661	+19%	
Dec-92	837	905	-7%	
Jan-93	968	893	+8%	+2.7% (Winter)
Feb-93	685	627	+9%	
Mar-93	733	580	+26%	
Apr-93	488	309	+58%	+55.2% (Spring)
May-93	320	104	+208%	
Total	**5,630**	**4,558**	**+24%**	

Table 4.2 Monthly Mean Space Heating Loads - Qh_m cf. Qh_SODEM-adj at 1.5 ac/hr.

The net space heating load of the CEC Easthall Project is also expressed in energy load per cubic metre (kWh/m³) as in Table 4.3 with respect to the heated volume. This expression together with others which express energy 'worth' will be used throughout Chapter 5 and 6. Correlation between the net space heating load in kWh/m³ with houses and occupants as illustrated in Table 4.4 (overleaf) provides a preliminary insight with respect to the causes and effects leading to higher or lower values compared with SODEM-adj. As described earlier in Section 4.1.3, the net Qh_m of the EPA prototype block and the CEC control house are respectively +12.4% and +17.1% higher than the CEC solar houses. The net Qh_m is 23.5% higher than Qh_SODEM-adj.

	CEC Project			CEC Control	EPA Project
(kWh/m³)	Highest	Mean	Lowest	Mean	Mean
Net Qh_m	80.62	37.75	10.88	32.6	42.44
Net Qh_SODEM-adj	67.5	30.56	15.52	--	--

Table 4.3 Comparison of the Mean net Qh_m, Qh_SODEM-adj of the CEC Easthall, CEC Control House and EPA Edderton Place Prototype.

4.2 TEMPERATURE PROFILES RELATIVE TO OTHER VARIABLES

4.2.1 HEATED ZONES TEMPERATURE PROFILES OVER HEATING SEASON

The mean daily temperature (24-hour) for the whole house was 19.86°C throughout the monitored heating season with 22.21°C and 18.92°C for Zone 1 (living room) and Zone 2 (rest of house - heated part only) respectively. Heated zone temperatures were generally in the comfort range of 18- 24°C as defined by Macfarlane[12] and Huber, Baillie and Griffiths[13].

In Zone 1, the highest mean temperature of 25.92°C during the heating season was recorded in an electric-heated house located at ground floor mid-terrace at Wardie Road, and the lowest at 18.32°C was a gas-heated house occupied by a single adult working on rota shifts at the top floor mid-terrace at Glenburnie Place. The variation in temperatures for Zone 2 reflected a diversity of influences relative to the occupants, i.e. occupancy profile, intermittent or continuous heating and other aspects of heating and ventilation control which will be closely examined in Chapter 5. The mean Zone 2 temperature was generally 2- 4K lower than Zone 1.

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[12] MACFARLANE W. V. THERMAL COMFORT STUDIES SINCE 1958 Architectural Science Review Volume 21, No. 4 pages 86- 92, December 1978.

[13] HUBER J.W., BAILLIE A.P., GRIFFITHS I.D. THERMAL COMFORT AS A PREDICTIVE TOOL IN HOME ENVIRONMENTS. CIB-W77 meeting at Holzkirchen, p. p. 1 - 11 May 1987.

W/5	W/6	W/11	W/12	W/17	W/18
W/3	W/4	W/9	W/10	W/15	W/16
W/1	W/2	W/7	W/8	W/13	W/14

G/5	G/6	G/11	G/12	G/17	G/18
G/3	G/4	G/9	G/10	G/15	G/16
G/1	G/2	G/7	G/8	G/13	G/14

Elevational Key To Solar Houses (W - Wardie Road; G - Glenburnie Place).

Qh/m3 (1)	House No.	Fuel	Location (2)	Sum A.U. (3)	%_OVER (4)	No. of T. & Pet (5)
80.62	G/13	gas	G/M	74.51	83%	1A/2I
72.64	G/5	gas	T/Ga	66.01	114%	3A
71.93	G/7	gas	G/M	74.51	39%	2OAP
63.56	W/14	gas	G/Ga	79.82	71%	2A/1I
61.53	W/13	electric	G/M	74.51	-9%	2A/2I/1DOG
57.74	W/8	gas	G/M	74.51	75%	2OAP
53.53	W/10	gas	F/M	51.88	221%	2A/1I
52.21	W/12	gas	T/M	61	83%	1OAP/1CAT
48.29	W/5	gas	T/Ga	66.01	65%	2A/1I
46.39	G/14	electric	G/Ga	79.82	-2%	2OAP/1DOG
46.16	G/8	gas	G/M	74.51	83%	3A/1 DOG
45.78	G/18	electric	T/Ga	66.01	56%	2OAP/1 DOG
43.05	G/3	electric	F/Ga	57.2	12%	2OAP
41.21	W/2	electric	G/M	74.51	-16%	3A
36.67	G/12	gas	T/M	61	46%	4A
35.14	G/6	electric	T/M	61	15%	2OAP/1DOG
34.4	W/7	electric	G/M	74.51	-20%	2OAP/1 DOG
32.96	W/6	gas	T/M	61	7%	2OAP/2 DOGS
31.44	G/15	electric	T/M	61	10%	4A
31.41	W/18	gas	T/Ga	66.01	6%	1A/1I
31.31	W/9	electric	F/M	51.88	30%	2OAP
31.25	G/1	electric	G/Ga	79.82	13%	2A/2I/1DOG
31.11	G/9	gas	F/M	51.88	39%	1OAP/1A
28.44	W/3	gas	F/Ga	57.2	13%	2A/1I
26.57	W/16	electric	F/Ga	57.2	30%	2OAP/1A
21.08	G/2	gas	G/M	74.51	-40%	1OAP
20.77	G/4	gas	F/M	51.88	34%	2A/2I
18.86	W/4	electric	F/M	51.88	-35%	1OAP
17.19	W/17	gas	T/M	61	-27%	1OAP
15.39	G/16	electric	F/Ga	57.2	-18%	2OAP
15.09	W/11	gas	T/M	61	-27%	1A
14.58	W/15	gas	F/M	51.88	-31%	1OAP
14.36	G/11	gas	T/M	61	-15%	1A
10.88	G/10	electric	F/M	51.88	-46%	1A

Table 4.4 Correlation Between Space heating Load And Household Profile.

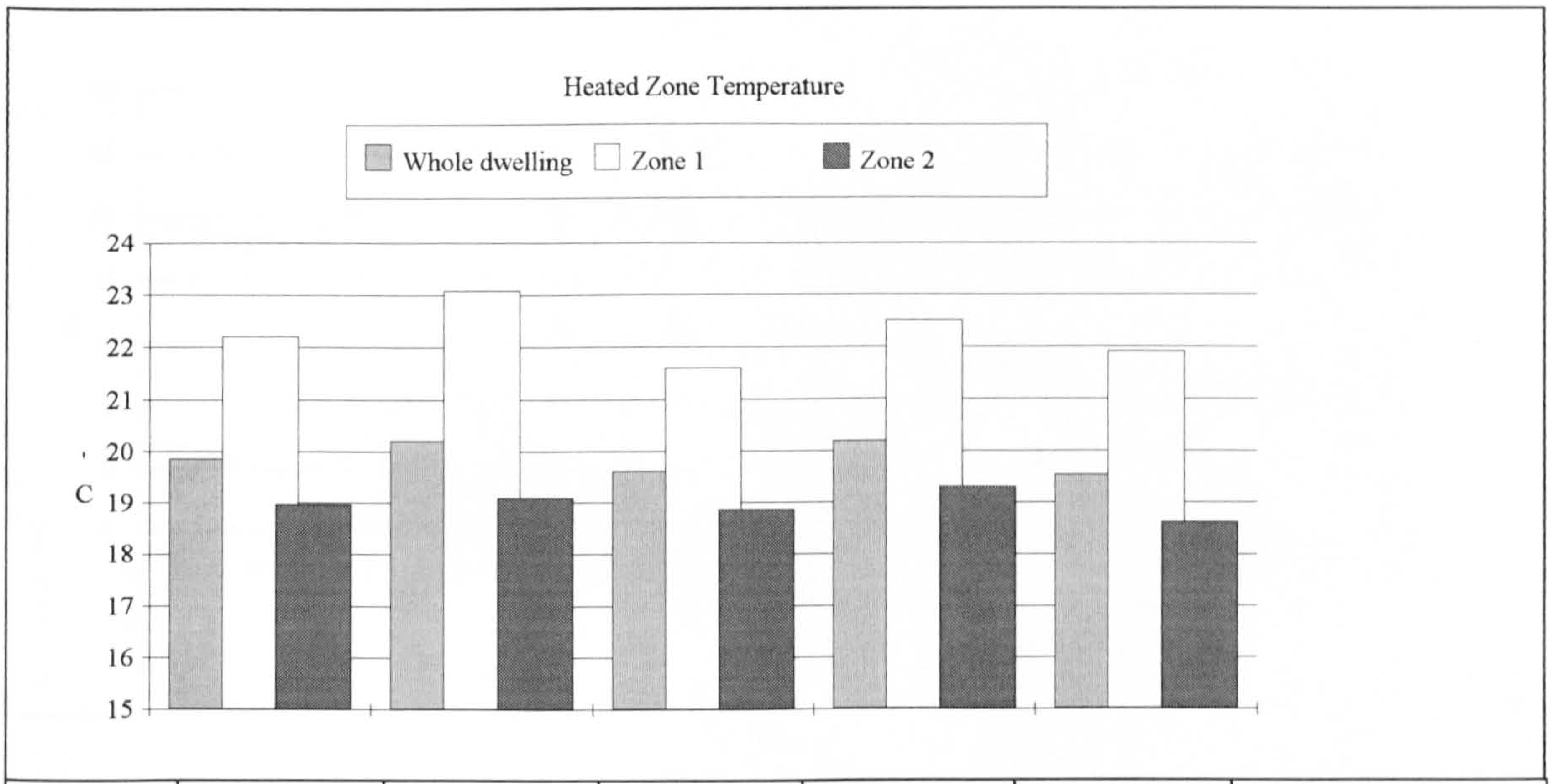
Legends: (1) - net Qh_m in kWh/m3; (2) - G/Ground Floor, F/First, T/Second; Ga/Gable-end, M/Mid-terrace;

(3) - Sum of Transmission Loss; (4) - Qh_m Comparison with Qh_SODEM-adj.;

(5) - Household Profiles

Table 4 4

The mean heated zone temperature (as measured) with respect to gas or electric-heated and orientation is illustrated in Figure 4.10. Anecdotal evidence supported gas as a more controllable heating fuel than electricity and this is well illustrated in Figure 4.11 (overleaf), although this begs the question of whether a temperature of over 25°C was needed at any point and raises the issue of time-lag between user decisions. The temperature profiles over two 24-hour periods of two houses with a continuous heating demand also confirmed that the electric-heated house maintained a significantly higher 24-hour temperature especially at night time (23.00- 07.00hr) in Zone 1 (living room) while the occupants were sleeping. Both temperature profiles in Zone 2 are similar and both heating systems provided adequate warmth to the occupants.



	Solar house	Electric-heated	Gas-heated	Wardie Road	Glenburnie Pl.	
	19.86	20.21	19.62	20.19	19.54	Whole house
	22.21	23.07	21.61	22.51	21.91	Zone 1
	18.97	19.11	18.86	19.31	18.63	Zone 2
	(34)	(14)	(20)	(17)	(17)	

Figure 4.10 Mean Heated Zone Temperatures Of The CEC Easthall Project.

4.2.2 Monthly Mean Temperature Profiles From September To May

The difference in mean monthly whole house temperature throughout the heating season was less than 1.5K (for Z1, 1.04K and for Z2, 1.53K) as illustrated in Figure 4.12. The margin was predictably wider for the unheated sunspaces with veranda, 5.77K and conservatory, 6.66K. A summary of monthly and seasonal air temperatures is included in Appendix 4.2.

It is worth noting that the mean whole house temperature of Wardie Road's electric-heated houses was higher than Glenburnie Place's by 1.58K - Zone 1 by 0.93K, Zone 2 by 1.83K. On the other hand, Section 4.1.5 confirmed that the net Qh_m of Wardie Road's electric-heated house was -8.2% lower than the net Qh_SODEM-adj while Glenburnie Place's was +8% higher. The SODEM-adj values are of course adjusted for measured temperatures and the benefits of Wardie Road's six electric-heated houses. The benefits are that none are located on the top floor (although there are two gable-end houses), and all have rather favourable solar gains to the veranda. The lower than predicted space heating load is most likely derived primarily from savings

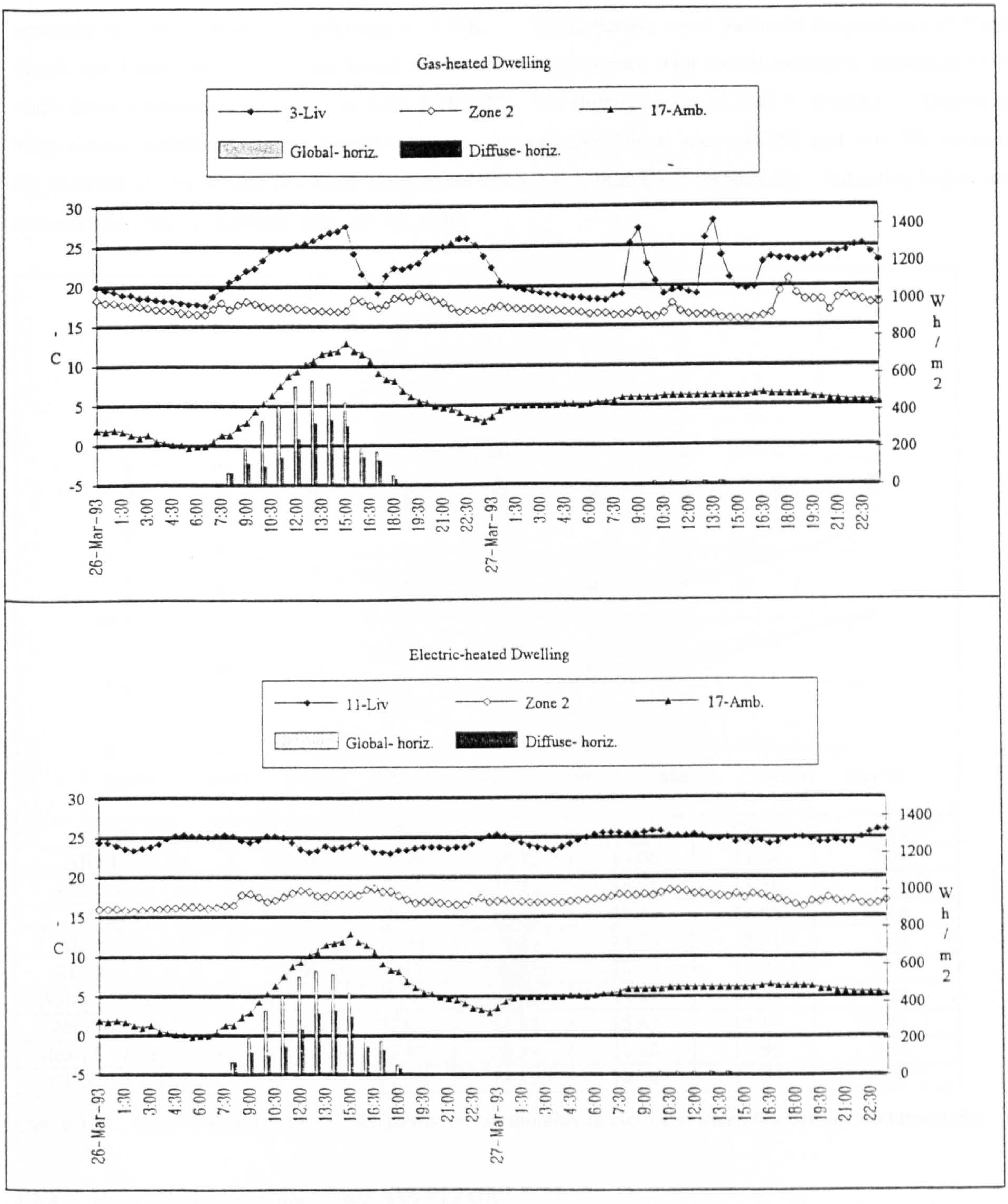
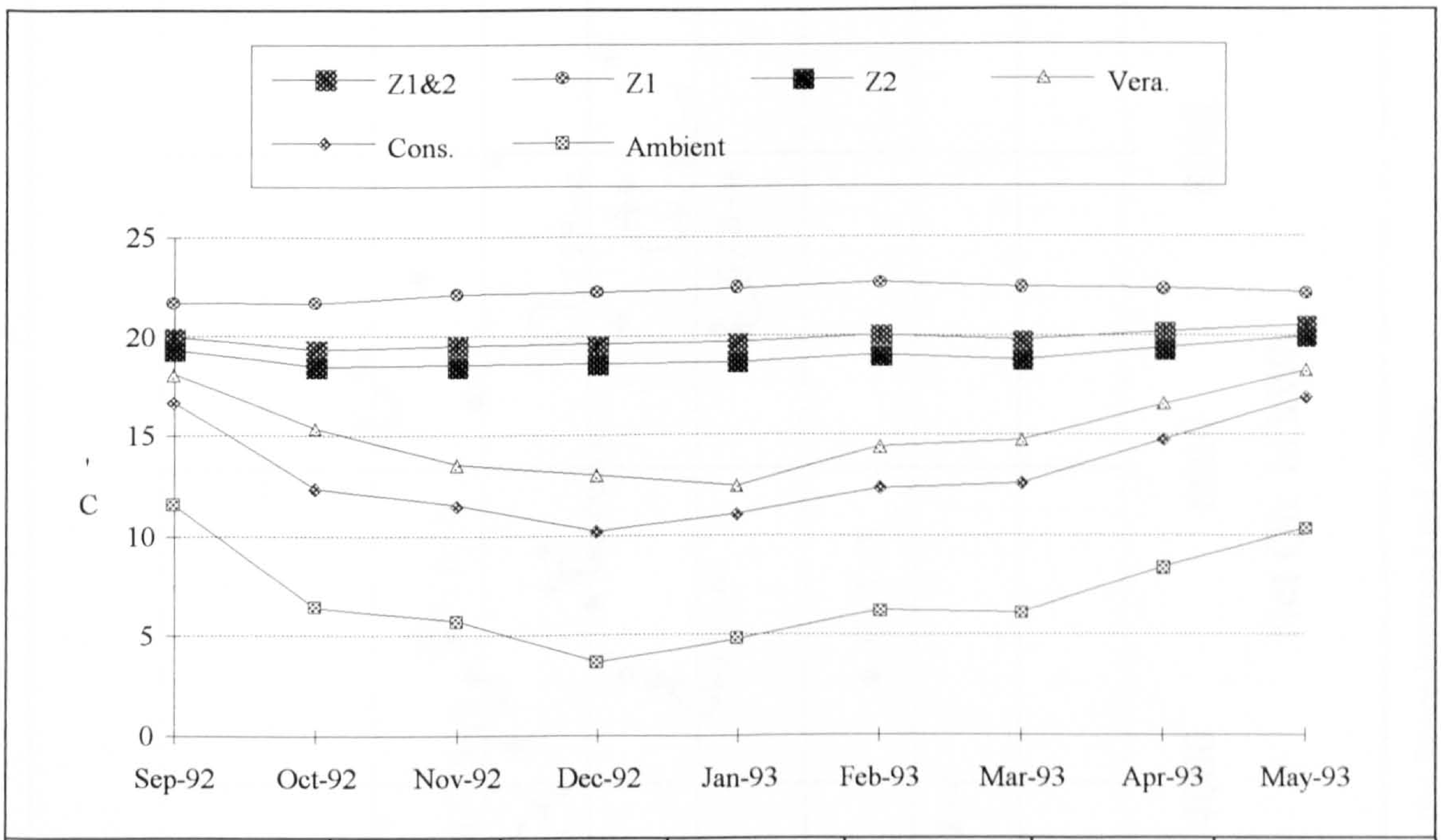


Figure 4.11 Typical Temperature Profile of an Electric-heated and Gas-heated Dwelling at Glenburnie Place.

on ventilation. This work will examine electric-heated houses in more details, with three out of the four case studies selected from this sector.

Gas as a heating fuel, as indicated in Section 4.1.5, is more controllable than electric. Accordingly, it follows that the measured temperature of gas-heated houses is slightly lower than electric-heated houses, especially in Zone 1 where the difference is 1.46K. The respective mean measured temperatures of Wardie Road's and Glenburnie Place's gas-heated houses are closely aligned with almost negligible difference in the whole house temperature (0.15K), in Zone 2 (0.05K), but slightly higher in Zone 1 (0.68K). Despite gas being a more controllable heating fuel than electric, the mean net Qh_m was +40.5% and +46.5% above net Qh_SODEM-adj for Wardie Road and Glenburnie Place's gas-heated house respectively, indicating higher rates of ventilation than the yardstick value of 1.5 ac/hr.



(all in °C)	Z1 + Z2	Z1	Z2	Vera.	Cons.	Ambient
All Mean (34)	19.86	22.21	18.92	15.06	13.08	7.14
All Electric (14)	20.21	23.07	19.11	14.91	13.36	7.14
All Gas (20)	19.62	21.61	18.86	15.16	12.88	7.14
All Wardie (17)	20.19	22.51	19.31	15.58	12.41	7.14
All Glen Pl. (17)	19.54	21.91	18.63	14.53	13.75	7.14
Wardie / Electric (6)	21.11	23.60	20.16	15.57	12.81	7.14
Wardie / Gas (11)	19.69	21.92	18.84	15.62	12.17	7.14
Glen Pl. / Electric (8)	19.53	22.67	18.33	14.60	13.99	7.14
Glen Pl. / Gas (9)	19.54	21.24	18.89	14.74	13.90	7.14

Figure 4.12 Mean Measured Air Temperatures (mean monthly in chart and mean heating season tabulated).

4.2.3 HEATED ZONE TEMPERATURES AND NET QH

Given the same plan, orientation and construction with equal fabric and ventilation loss, and identical heating systems/regimes with respect to storage/responsiveness and demand profile, temperature expressed as a function of space heating load would yield a linear relationship. This correlation is illustrated in Figure 4.13 (overleaf) which should be read in conjunction with Table 4.4 - an additional copy is attached and related information

Figure 4.13

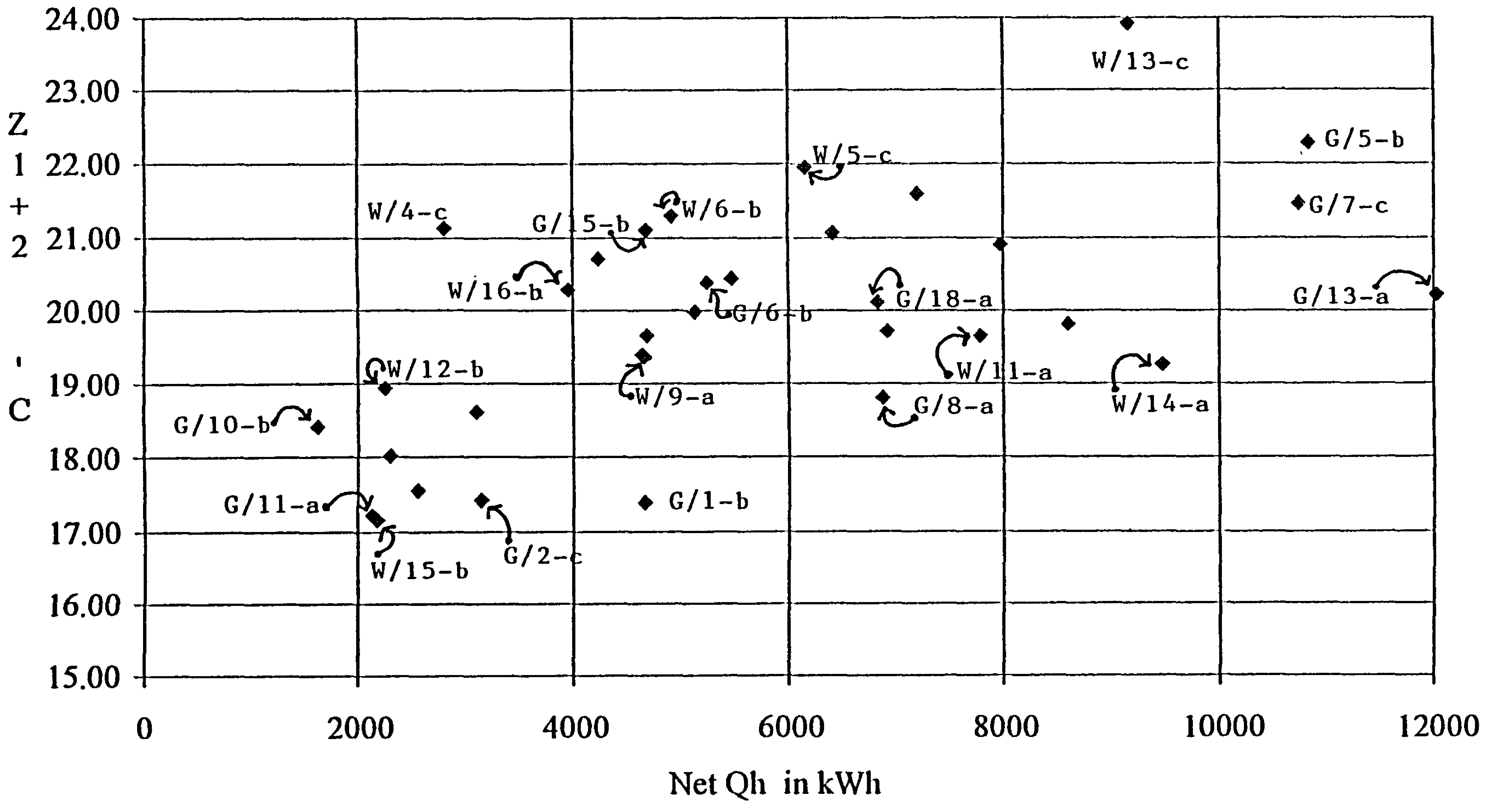


Figure 4.13 Correlation Between Heated Zone Temperatures and Net Space Heating Load (Qh).

Legend: The first set of number (W/9) denotes the location of the solar house, the second number denotes air quality - a for fresh, b for tolerable and c for stuffy.

W/5	W/6	W/11	W/12	W/17	W/18
W/3	W/4	W/9	W/10	W/15	W/16
W/1	W/2	W/7	W/8	W/13	W/14

G/5	G/6	G/11	G/12	G/17	G/18
G/3	G/4	G/9	G/10	G/15	G/16
G/1	G/2	G/7	G/8	G/13	G/14

Elevational Key To Solar Houses (W - Wardie Road; G - Glenburnie Place).

Qh/m3 (1)	House No.	Fuel	Location (2)	Sum A.U. (3)	%_OVER (4)	No. of T. & Pet (5)
80.62	G/13	gas	G/M	74.51	83%	1A/2I
72.64	G/5	gas	T/Ga	66.01	114%	3A
71.93	G/7	gas	G/M	74.51	39%	2OAP
63.56	W/14	gas	G/Ga	79.82	71%	2A/1I
61.53	W/13	electric	G/M	74.51	-9%	2A/2I/1DOG
57.74	W/8	gas	G/M	74.51	75%	2OAP
53.53	W/10	gas	F/M	51.88	221%	2A/1I
52.21	W/12	gas	T/M	61	83%	1OAP/1CAT
48.29	W/5	gas	T/Ga	66.01	65%	2A/1I
46.39	G/14	electric	G/Ga	79.82	-2%	2OAP/1DOG
46.16	G/8	gas	G/M	74.51	83%	3A/1 DOG
45.78	G/18	electric	T/Ga	66.01	56%	2OAP/1 DOG
43.05	G/3	electric	F/Ga	57.2	12%	2OAP
41.21	W/2	electric	G/M	74.51	-16%	3A
36.67	G/12	gas	T/M	61	46%	4A
35.14	G/6	electric	T/M	61	15%	2OAP/1DOG
34.4	W/7	electric	G/M	74.51	-20%	2OAP/1 DOG
32.96	W/6	gas	T/M	61	7%	2OAP/2 DOGS
31.44	G/15	electric	T/M	61	10%	4A
31.41	W/18	gas	T/Ga	66.01	6%	1A/1I
31.31	W/9	electric	F/M	51.88	30%	2OAP
31.25	G/1	electric	G/Ga	79.82	13%	2A/2I/1DOG
31.11	G/9	gas	F/M	51.88	39%	1OAP/1A
28.44	W/3	gas	F/Ga	57.2	13%	2A/1I
26.57	W/16	electric	F/Ga	57.2	30%	2OAP/1A
21.08	G/2	gas	G/M	74.51	-40%	1OAP
20.77	G/4	gas	F/M	51.88	34%	2A/2I
18.86	W/4	electric	F/M	51.88	-35%	1OAP
17.19	W/17	gas	T/M	61	-27%	1OAP
15.39	G/16	electric	F/Ga	57.2	-18%	2OAP
15.09	W/11	gas	T/M	61	-27%	1A
14.58	W/15	gas	F/M	51.88	-31%	1OAP
14.36	G/11	gas	T/M	61	-15%	1A
10.88	G/10	electric	F/M	51.88	-46%	1A

Table 4.4 Correlation Between Space heating Load And Household Profile.

Legends: (1) - net Qh_m in kWh/m3; (2) - G/Ground Floor, F/First, T/Second; Ga/Gable-end, M/Mid-terrace;

(3) - Sum of Transmission Loss; (4) - Qh_m Comparison with Qh_SODEM-adj.;

(5) - Household Profiles

Table 4 4 (extra copy)

highlighted for ease of reading. It seems probable that it is mainly intervention in terms of ventilation and 'opening-up' which renders such a wide scatter, see Figure 4.13, with the placing of the gradient arrow somewhat arbitrary. The discrepancy between gas-heated and electric-heated houses is shown in Figures 4.14 (overleaf). It also confirms that quite high temperatures can be achieved at quite low fuel inputs, although this does incur the likelihood of a more stuffy internal environment. For example in Figure 4.13 under the category of high Qh_m user, both households - W/13 (electric-heated) and W/14 (gas-heated) consumed around 9,300 kWh in space heating energy, but the former achieved a house temperature of almost 24°C whereas the latter is just under 19.5°C. Medium users, G/15, W/9 and G/1 - all electric-heated with a net space heating load of just over 4,660 kWh - achieved a house temperature of 21.09°C, 19.36°C and 17.41°C respectively. Finally, low users, W/11, G/11 and W/15 - all gas-heated with net space heating load of just under 2,200 kWh - achieved 18.94°C, 17.24°C and 17.17°C respectively. That orientation and location had a minor influence on space heating load relative to temperature was confirmed by the almost random nature of the scatter with respect to these two factors. Type of heating fuel and/or regime tends to be more significant. For example, in the 'low-energy users' set W/4 enjoys almost 4K more warmth compared with either W/15 and G/11 and only has to pay for 639 kWh and 671 kWh extra respectively. W/4 has an electric storage heating system which results in a relatively steady house temperature than both W/15 and G/11 which have been intermittently using their gas central heating system.

However, the opening of windows and other devices to control ventilation, both directly to the outside and between buffers and heated zones is undoubtedly the strongest influence. The reason why the two households in the high and medium Qh_m user category, as in the above examples W/14 and G/1, have relatively low house temperature and relatively high heating load appears to be because the occupants opened up the buffer spaces and kept the outer sunspace windows ajar for daily periods during the whole of the heating season and especially in autumn and spring. Opening up the heated zone would raise the sunspace temperature closer to the adjacent heated zone; similarly, keeping the outer sunspace windows ajar would lower its temperatures. In order to broadly verify the degree of opening up of the heated zone, it is necessary to examine the sunspace temperatures.

4.2.4 SUNSPACE TEMPERATURES

This section examines the mean sunspace temperatures throughout the heating season as a prelude in answering the question posed in Section 3.1 (Q. 1 - how useful and usable are the sunspaces ?). The mean measured air temperatures in the glazed-in veranda and conservatory are 15.06°C and 13.08°C respectively; corresponding to an outside mean air temperature of 7.03°C and inside heated Zone 1 temperature of 22.21°C and heated Zone 2 temperature of 18.92°C. The thermal performance of the glazed-in veranda in terms of temperature 'lift' was generally better than the 'extended' conservatory. This is due to a combination of factors: more favourable orientation in half of the houses; recessed configuration being more favourable in winter and so lower heat loss; and the veranda tending to involve less 'opening-up' than the conservatory (see Chapter 5). Table 4.5 (overleaf) illustrates the maximum, mean and minimum sunspace temperatures throughout the heating season 1992- 1993.

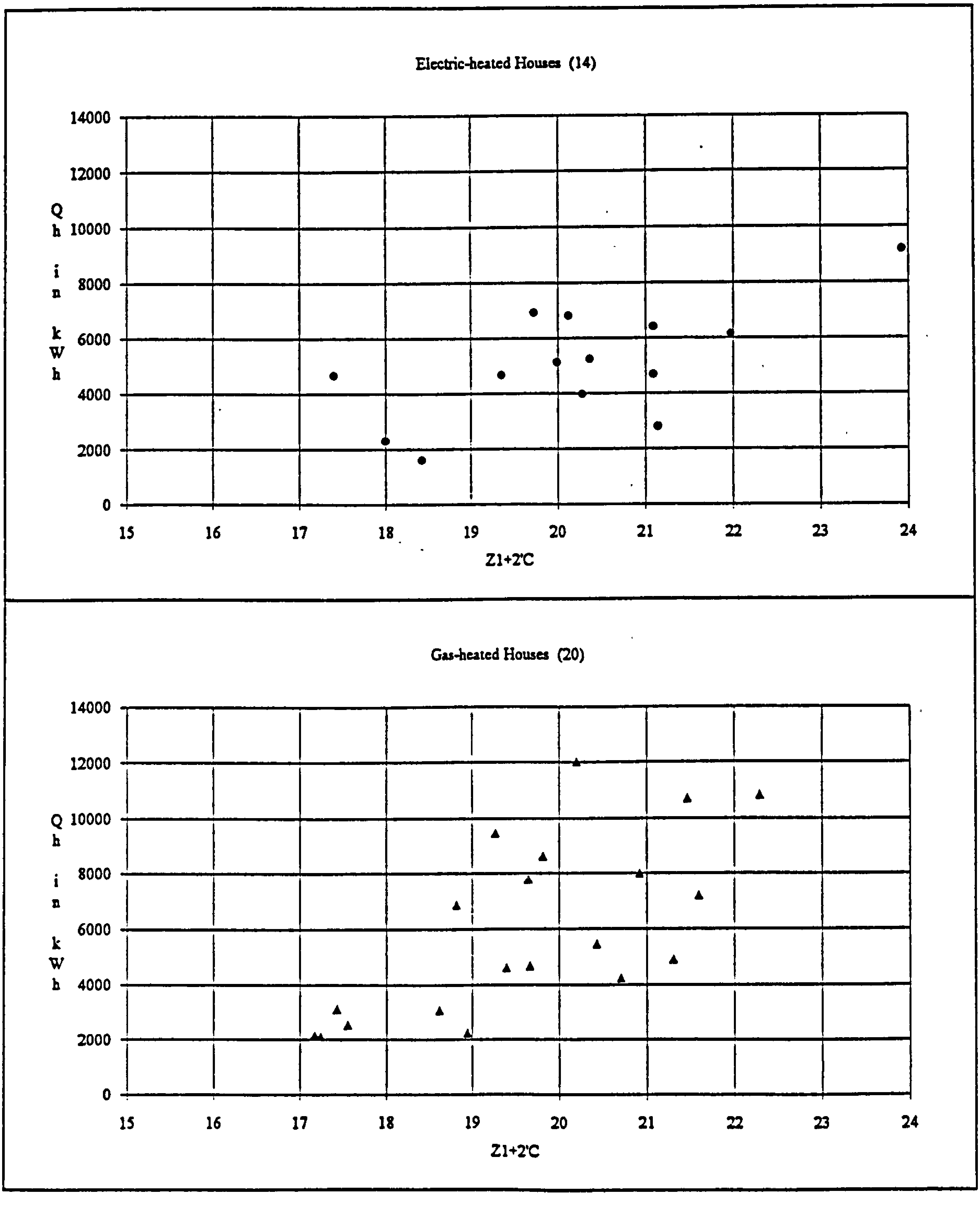


Figure 4.14 Mean Heated Zone Temperatures And Net Space Heating Load (Qh) - September 1992 to May 1993.

[Max./Mean/Min.]	All houses	Wardie Rd.	Glenburnie Pl.	Electric-heated	Gas-heated
Veranda (in °C)	[19.79/ 15.06/ 11.9]	[19.79/ 15.58/ 11.9]	[17.04/ 14.53/ 12.37]	[19.2/ 14.91/ 13]	[19.79/ 15.16/11.9]
Conservatory	[17.18/ 13.08/ 8.81]	[16.04/ 12.41/ 8.81]	[17.18/ 13.75/ 9.97]	[15.94/ 13.36/ 10.06]	[16.04/ 12.88/ 8.81]
Sample no.	(34)	(17)	(17)	(14)	(20)

Table 4.5 Maximum, Mean and Minimum Sunspace Temperatures.

The wide range of sunspace temperatures reflects the factors listed above, for example, the greater east conservatory / west veranda parity in Glenburnie Place compared with the north-west south-east equivalent in Wardie Road. This suggests that orientation, and therefore solar gain, is reasonably significant in affecting sunspace temperatures. Maximum, mean and minimum temperatures of Glenburnie Place's conservatory were all higher than Wardie Road's due to its favourable west facing orientation. The same is also true in the case of Wardie Road's south-east facing veranda, with temperatures all higher than Glenburnie Place's (west facing veranda), with the exception of the minimum temperature of a gas-heated house at Wardie Road (most possibly due to the extreme effect of occupants). There is less apparent difference between the electric and gas-heated houses. The respective temperatures for electric and gas-heated houses at Wardie Road and Glenburnie Place are broken down in Table 4.6. In the case of both fuels, the mean sunspace temperature is almost the same. Nevertheless, for both verandas and conservatories in the case of gas-heated house, the maximum - minimum temperature range is wider. For instance, the difference between maximum - minimum temperature range of the veranda at Wardie Road's electric-heated house is 5.65K whereas gas-heated house at the same location is 7.89K. The difference is even greater in the case of gas-heated houses at Wardie Road where the maximum conservatory temperature is almost double the minimum, reflecting the diversified use of the sunspace as utility room. It is worth emphasising that the maximum, mean and minimum sunspace temperatures are not necessary a good indicator of the usefulness and usability of the glazed spaces. These values only give the range of mean temperatures achieved in the sunspaces. Section 4.5 addresses the question of how useful and usable are the sunspaces.

(in °C)	Wardie Rd.		Glenburnie Place	
[Max./Mean/Min.]	Electric	Gas	Electric	Gas
Veranda	[19.2/ **15.56**/ 13.55]	[19.79/ **15.59**/ 11.9]	[15.39/ **14.42**/ 13]	[17.04/ **14.63**/ 12.37]
Conservatory	[14.39/ **12.8** / 10.06]	[16.04/ **12.19**/ 8.81]	[15.94/ **13.77**/ 12.41]	[17.18/ **13.73**/ 9.77]
Sample no.	(6)	(11)	(8)	(9)

Table 4.6 Breakdown of Electric and Gas-heated House at Wardie Road and Glenburnie Place.

Sunspace temperatures cf. heated zone temperatures

The wide range of the sunspaces' temperatures as shown above indicates that some degree of opening-up did occur in most cases (more frequent in autumn and spring than winter months) resulting in heat loss from the heated zone to sunspaces. In particular, the conservatory, where the combination of opening-up for ventilation whilst cooking and functioning as a utility room, the more exposed configuration and less favourable orientation for solar gains and isolation from zone 1, all cause its mean temperature to be more than 2K lower than that of the veranda. The degree of opening up inevitably has a significant influence on the space heating load. Moving on to investigate the correlation between sunspace and heated zone temperatures, as in Figure 4.15 (overleaf), the first diagram confirms that the mean heated zone and glazed-in veranda temperatures ranged between 17 -

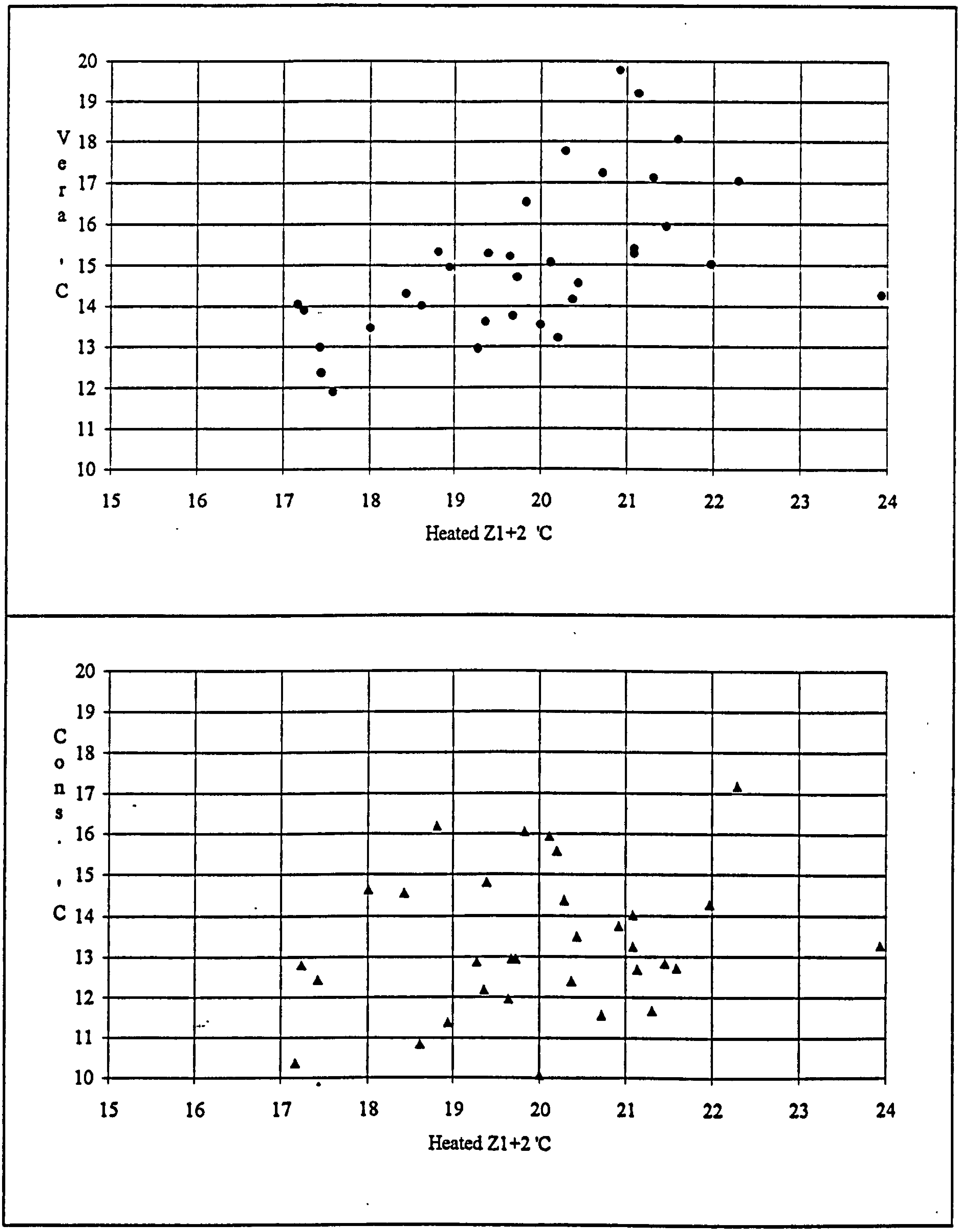


Figure 4.15 Mean Heated Zone Temperatures And Sunspace Temperatures - September 1992 to May 1993.

24°C and 12 - 20°C respectively. The scatter for a particular mean heated zone temperature must partly reflect the south-east to west orientation difference (for Wardie Road and Glenburnie Place respectively), but mainly the degree of ventilation from the heated zone to outside, to the veranda from outside and between the veranda and heated zones. For example, at 21°C heated zone, veranda temperatures vary between just below 20°C to just above 15°C. The former value indicates either that the veranda has been opened-up as part of the heated volume of the house or that the sunspace has been so well heated by the sun that its temperature has frequently equalled or overtaken that of its 'host' heated zone(s). For all the scatter, there is an identifiable slope confirming that all verandas gain some heat from the house.

The scatter is even wider in the case of the conservatory. Mean conservatory temperatures lie in the range 10 - 17°C, significantly lower than the veranda. The widely dispersed pattern suggests that the conservatory as a utility space was diversely used by the occupants in terms of both opening up to the outside and the kitchen. Figure 4.16 and Figure 4.17 (both overleaf) correlate heated zone temperatures and sunspace temperatures in term of heating fuel. Figure 4.16 confirms a slightly greater scatter of veranda temperatures in gas-heated than electric-heated houses although the greater sample in the former case may be partly responsible for this. In the case of the conservatory (Figure 4.17), the scatter is so great that tangible slopes are difficult to identify both for electric-heated and gas-heated houses. Figure 4.18 (overleaf) summarises the mean monthly heated zone and sunspace temperatures, broken down for location and fuel. Compared with Figure 4.12 in Section 4.2.2 above, it may be noted that there is a greater difference between location than fuel type. Hence, although it has been established in this section that there is a correlation between respective 'host' heated zone and buffer space temperatures, also there is a significant correlation between orientation and buffer temperatures. However, fuel type does not appear to be influential. A summary of temperature differences between heated zones and sunspaces/sunspaces and ambient for the first and second heating season is included in Appendix 4.3.a-d. In order to amplify the reasons underlying specific variations, a selection of households with which the author became well acquainted will be closely examined in Chapter 6's case studies.

4.3 'EFFECTIVE' AIR CHANGE

As stated in Section 4.1.5 above, net Qh_SODEM-adj assumes a real rate of air change of 1.5 per hour (for all-day occupancy) which is allocated on a pragmatic 'what-if ?' basis between buffer spaces and directly to the outside. By deduction from measured results (according to the methodology described in Chapter 3 - equation 1), the mean effective air change (n^e) for all solar houses over the heating season is 1.14 ac/hr, roughly one third more than the corresponding predictive effective air change of 0.86 based on Qh_SODEM-adj. Figure 4.19 illustrates 'effective' and 'predictive effective' air change at Glenburnie Place and Wardie Place and for electric and gas-heated houses.

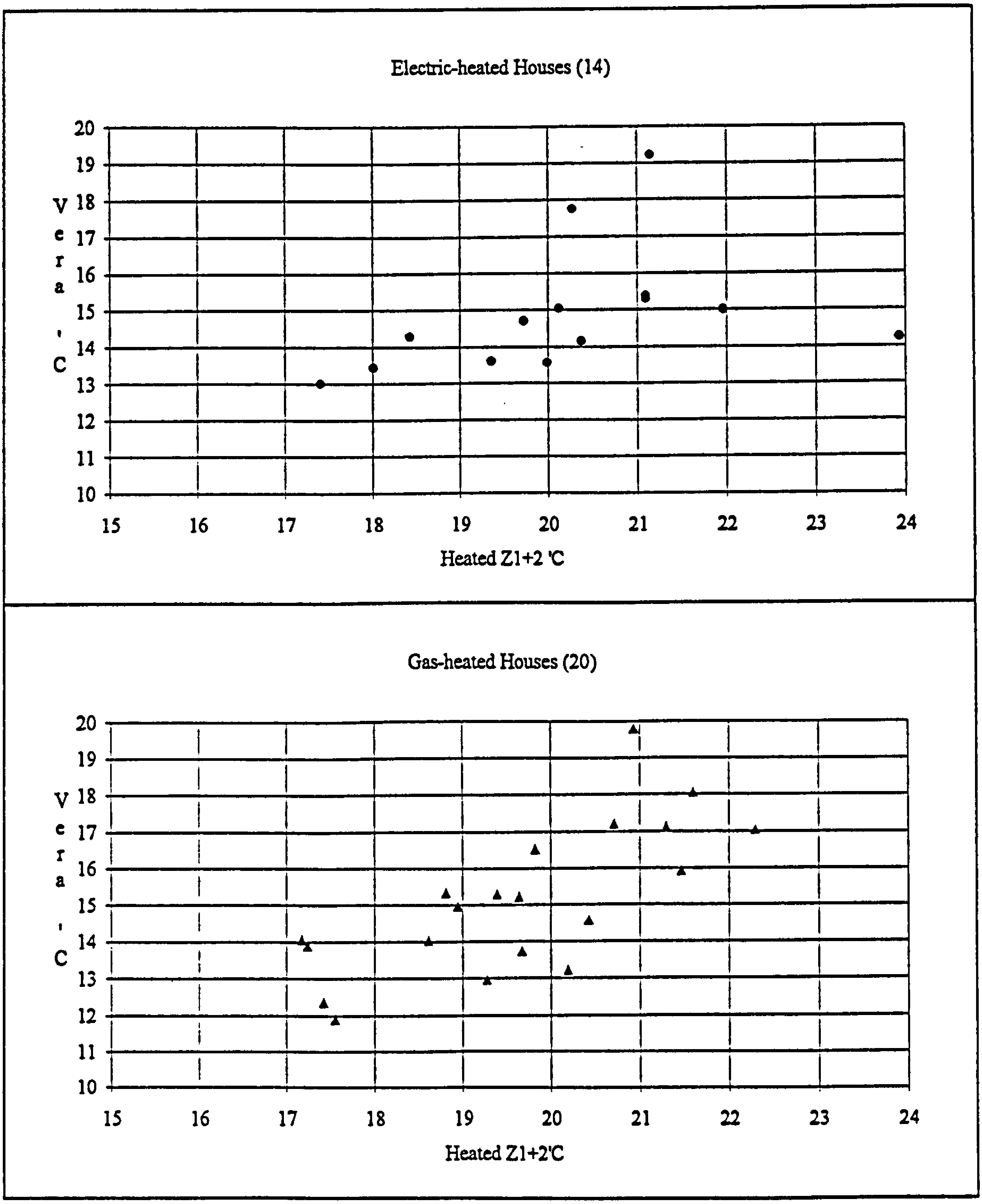
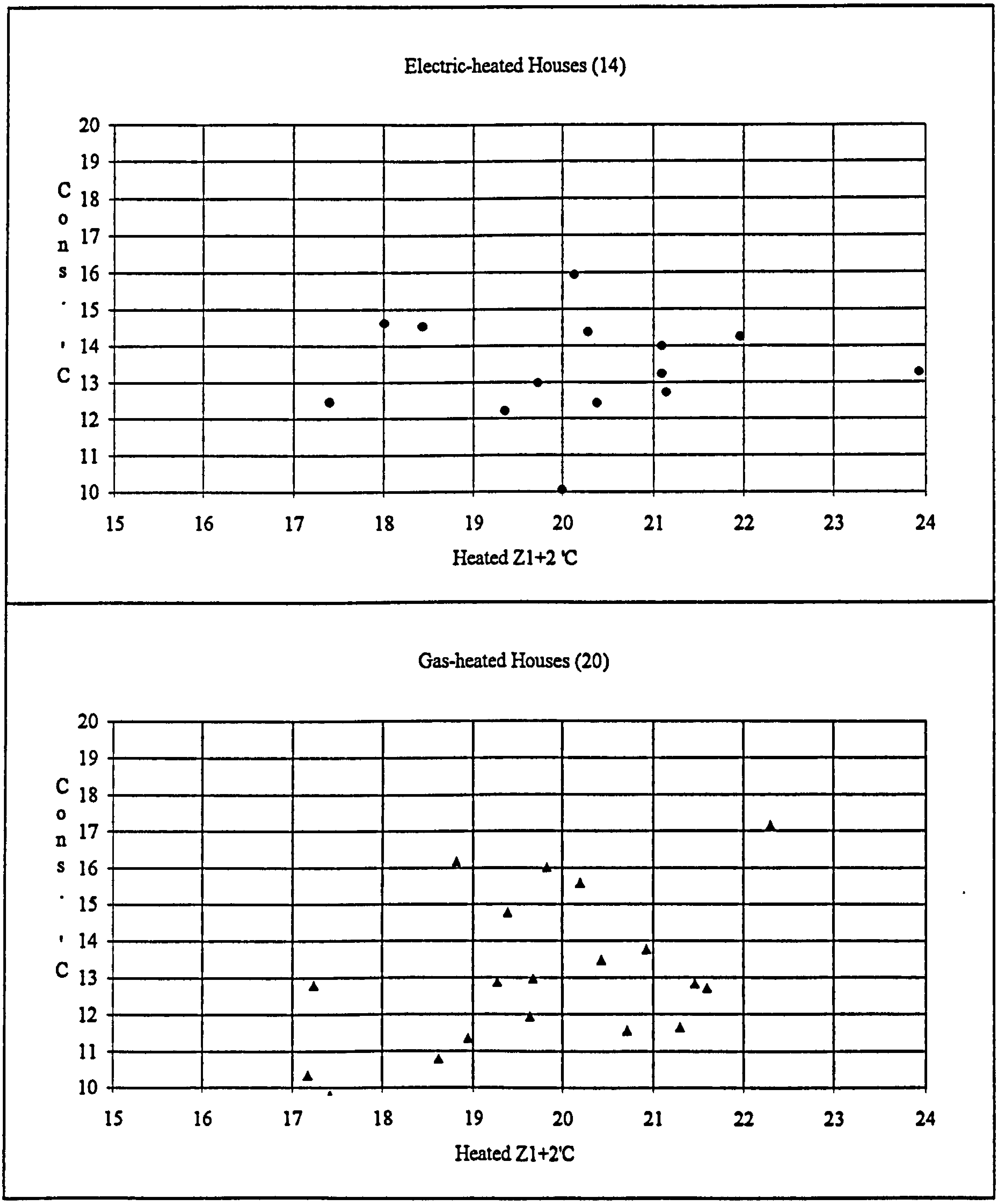


Figure 4.16 Correlation Between Heated Zone and Veranda Temperatures for Electric and Gas-Heated Houses.

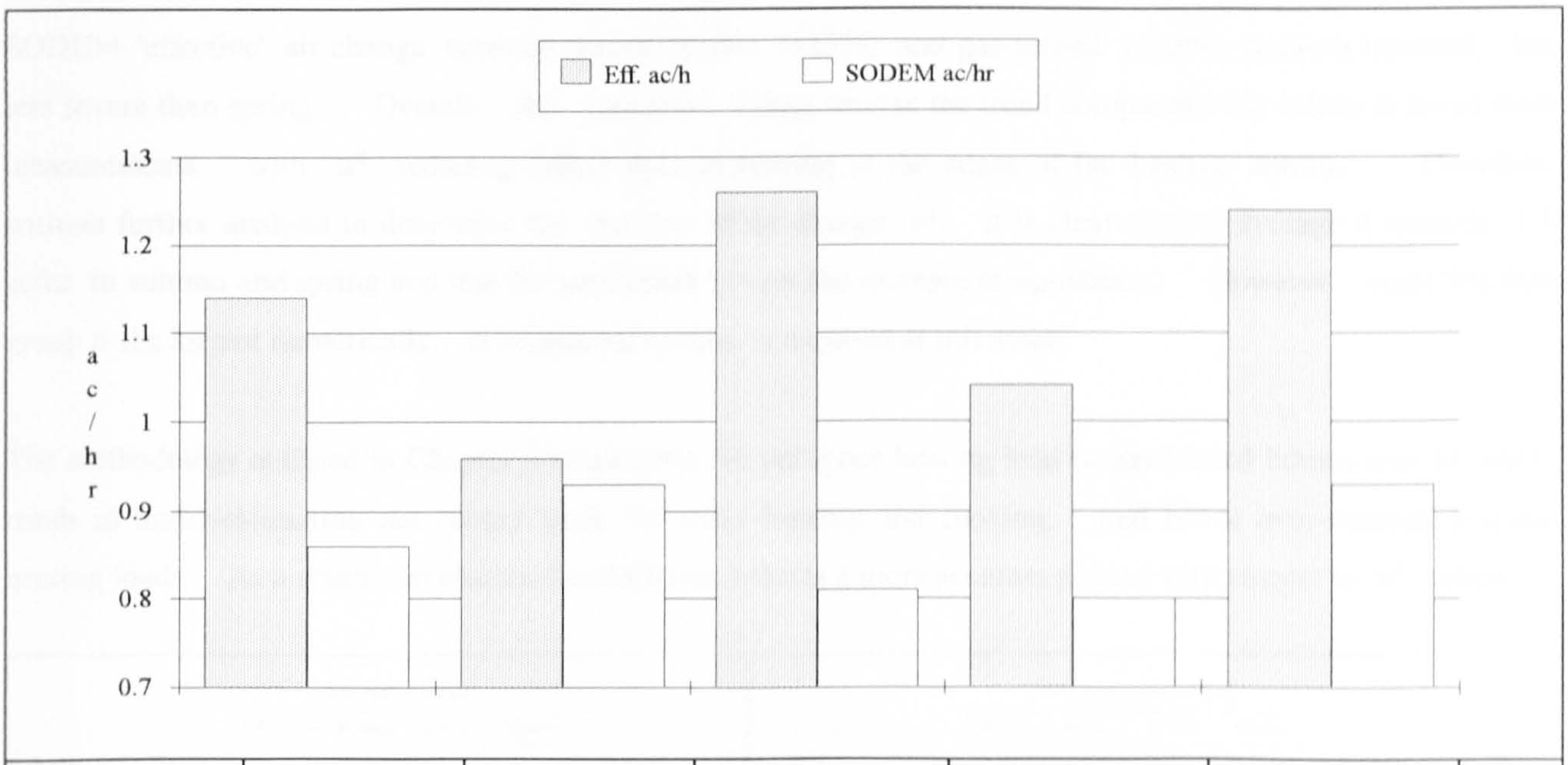


Electric-heated Houses (14)

Gas-heated Houses (20)

Figure 4.17 Correlation Between Heated Zone and Conservatory Temperatures for Electric and Gas-Heated Houses.

Figure 4.18 Mean Monthly Temperatures - Orientations and Heating Fuels.



	All Houses	All Electric	All Gas	All Wardie Rd.	All Glen Pl.
Effective ac/hr	1.14	0.96	1.26	1.04	1.24
SODEM ac/hr	0.86	0.93	0.81	0.8	0.93
Sample No.	(34)	(14)	(20)	(17)	(17)

Figure 4.19 Comparison Between Deducted Effective Air Change and SODEM Predictive 'Effective' Air Change.

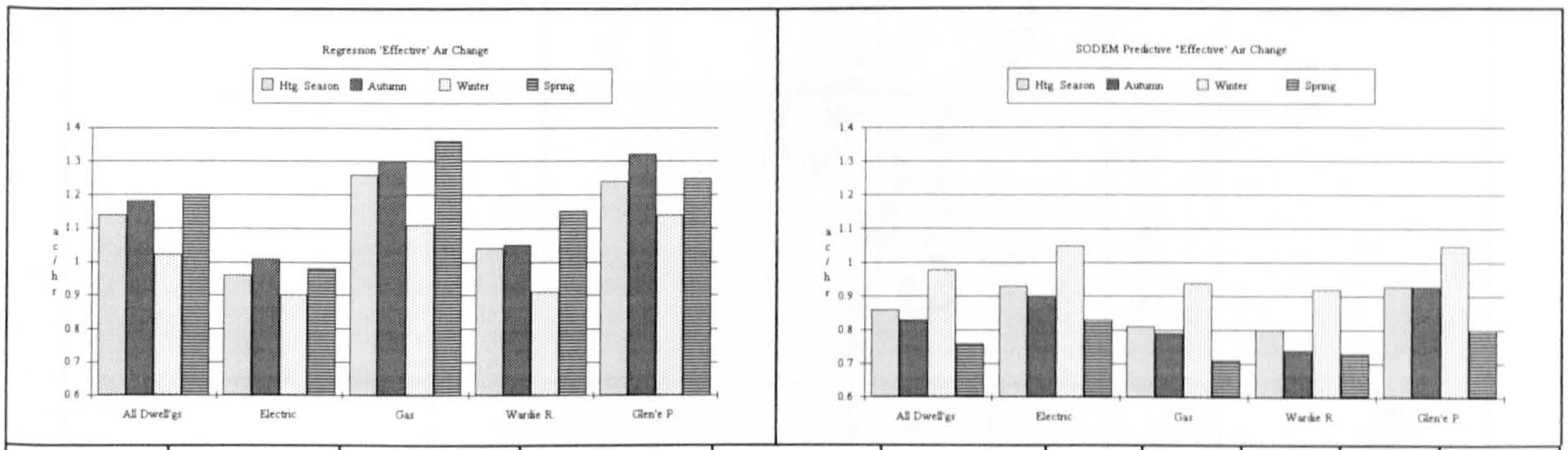
The findings confirm that the effective air change of electric-heated houses (n^c= 0.96 ac/hr) is closely matched with the n^r 1.5 ac/hr 'yardstick' (n^c= 0.93) - a difference of merely 3%. Gas-heated houses not only registered the highest effective air change rate at 1.26, but also the highest margin of +55.6% above 'yardstick'. Solar houses at Glenburnie Place (1.24 ac/hr) recorded a higher effective air change rate than Wardie Road (0.93), both about one-third above 'yardstick' results.

The 'qido' data supports these findings - gas-heated houses acquire a higher level of ventilation, possibly due to the combination of statutory requirement, as well as the family structure, habits and aspirations of occupants. This will be examined more closely in Chapters 5 and 6.

Seasonal analysis confirmed that the mean effective air change rate deduced from measurements, n^c, is somewhat higher in autumn (September - November '92) and spring (March - May '93) supporting the hypothesis that the occupants are psychologically motivated in opening-up sunspaces and/or leaving outer sunspace windows ajar. During the winter months (December '92 - February '93), n^c is much more closely aligned with the corresponding SODEM 'yardstick', as shown in Figure 4.20, in spite of wider margins for fuel type and orientation.

In spring, the difference between deduced and SODEM 'yardstick effective' air change is significant, the former +58% higher than the latter. It is worth noting the difference between electric and gas-heated solar houses - the former is +18% and the latter is +92% above 'yardstick'. This seems to indicate that the occupants in a gas-heated house are more likely to ventilate more liberally than those in an electric house. Similar pattern occurs in autumn, but to a lesser extent resulting in 42% over 'yardstick'; the significant difference over SODEM 'effective' air change between electric-heated (+12%) and gas-heated (+65%) house is repeated, but less severe than spring. Overall, the 'yardstick' values reverse the trend compared with values deduced from measurements, with n^e reducing rather than increasing at the edges of the heating season. Therefore, without further analysis to determine the real rate of air change n^r, it is clear that on average it exceeds 1.5 ac/hr in autumn and spring and that for gas-heated houses the increase is significant. However, since this fuel group is the largest numerically, conclusional caution is required at this stage.

The methodology outlined in Chapter 3 to estimate the net space heating load in gas-heated houses may of course result in under-estimating net energy loads for water heating and cooking, and hence over-estimating space heating loads. As a result, an electric-heated house reflects a more accurate picture with respect to n^e values.



All dwell'g	Electric	Gas	Wardie Rd.	Glen Pl.		All	Elec.	Gas	War.	Glen P
1.14 (33%)	0.96 (3%)	1.26 (56%)	1.04 (30%)	1.24 (33%)	Htg season	0.86	0.93	0.81	0.8	0.93
1.18 (42%)	1.01 (12%)	1.3 (65%)	1.05 (42%)	1.32 (42%)	Autumn	0.83	0.9	0.79	0.74	0.93
1.02 (4%)	0.9 (-14%)	1.11 (18%)	0.91 (-1%)	1.14 (9%)	Winter	0.98	1.05	0.94	0.92	1.05
1.2 (58%)	0.98 (18%)	1.36 (92%)	1.15 (58%)	1.25 (56%)	Spring	0.76	0.83	0.71	0.73	0.8
(34)	(6W/ 8G)*	(11W/ 9G)*	(6e/ 11g)**	(8e/ 9g)**	Sample no	(34)	(14)	(20)	(17)	(17)

Figure 4.20 Comparison Between Seasonal Deduced n^e and SODEM 'yardstick' n^e in ac/hr (figures in brackets shows % of the former above the latter). * W= Wardie Road; G= Glenburnie Place. ** e= Electric-heated; g= Gas-heated Houses.

Figure 4.21 (overleaf) attempts to identify the monthly trend of the n^e values deduced from measurement relative to ambient temperature. Although there are certainly more low n^e values at lower ambient temperatures, the reverse is not the case - i.e. high n^e values do not tend to correspond particularly to higher temperatures. Therefore the higher mean n^e values in autumn and spring previously identified in Figure 4.20, must be due to a relative lack of low n^e values, rather than a surfeit of high ones. A summary of n^e relative to air temperatures for the first and second heating season is included in Appendix 4.4.a-e.

4.4 SUNSPACE WORTH (I): REAL RATE OF AIR CHANGE AND VENTILATION PREHEAT SAVING

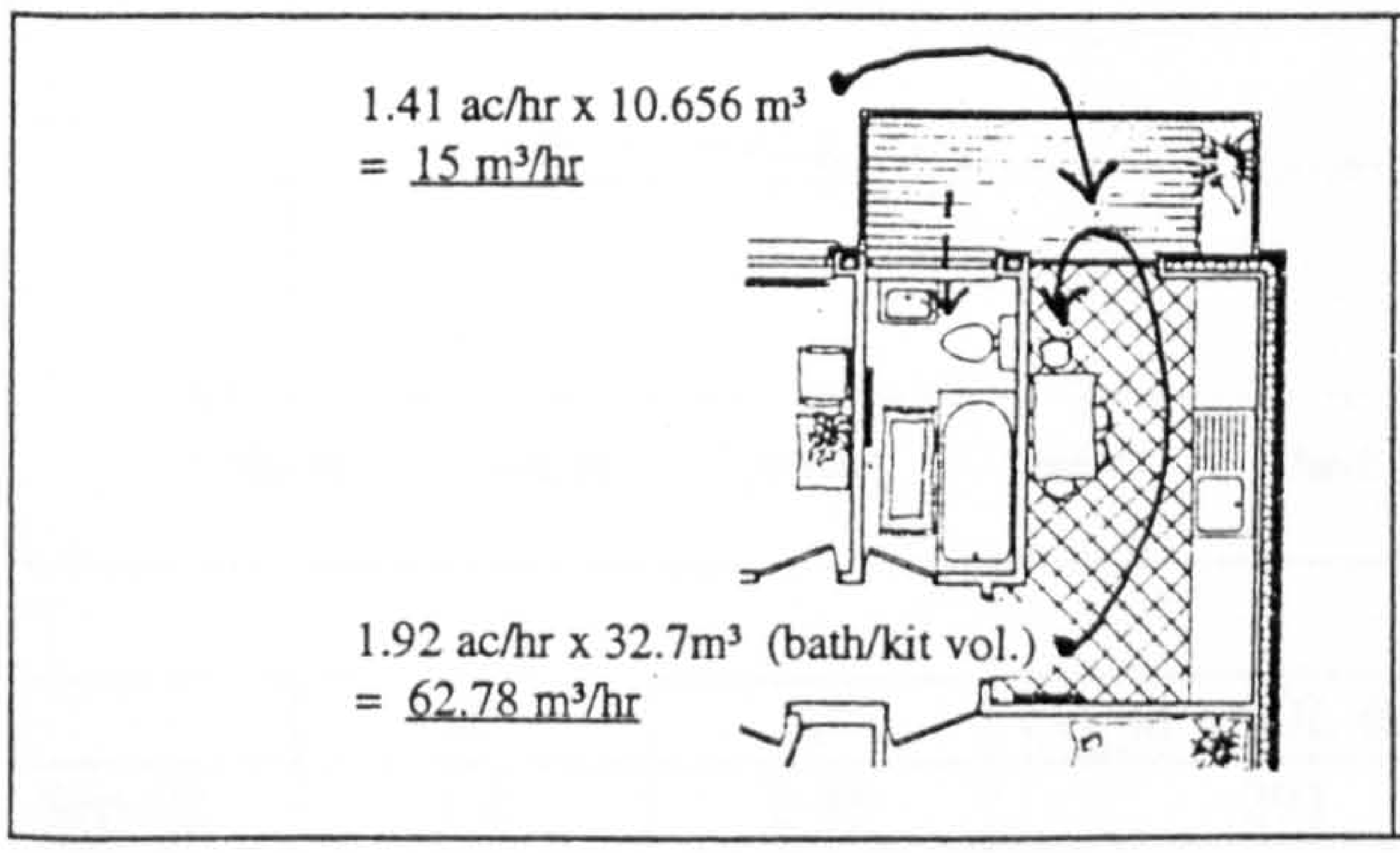
The Passivent Intelligent ventilation system in the kitchen and bathroom guarantees a continuous extraction of air at a rate between 18.33 and 41.67 m³/hour, resulting in a minimum air change of 0.123 - 0.28 air change per hour for Zone 2. In reality, it is likely that most of the air exchange due to the pulling power of the mechanical

Figure 4.21

Figure 4.21 Effective Air Change - September 1992 to May 1993.

ventilation system occurs between the kitchen and conservatory and between the bathroom and the hallway. The hallway in turn connects to living room and main bedroom and so further the design intention of ventilation preheat via the glazed veranda. Therefore it is vital to get a 'feel' of the real rate of air change between the sunspaces and the heated zones, all as outlined in Chapter 3.

Taking the solar house W/16 as an example, the real rate of air change ($n^{S\text{-}cons}$) between the conservatory and the outside air in December 1992 was calculated as 1.41 air change per hour or 15 m^3/hour. This was based on the upper limit of the scenario A, with a real rate of air change ($n^{Z2\text{-}s}$) of 1.92 between the kitchen/bathroom and conservatory. The lower limit of scenario B ($n^{Z2\text{-}s}$ = 0.93) gave an invalid air change of -1.27. Nevertheless, the real air change rate of $n^{Z2\text{-}s}$ of 63m^3/hour was over 4 times higher than the $n^{S\text{-}cons}$'s 15 m^3/hour. The critical component in equation (1) - the conservatory temperature - was raised as a result of opening up the kitchen/conservatory door. This resulted in mixing of air in the kitchen and conservatory as illustrated in Figure 4.22.a.



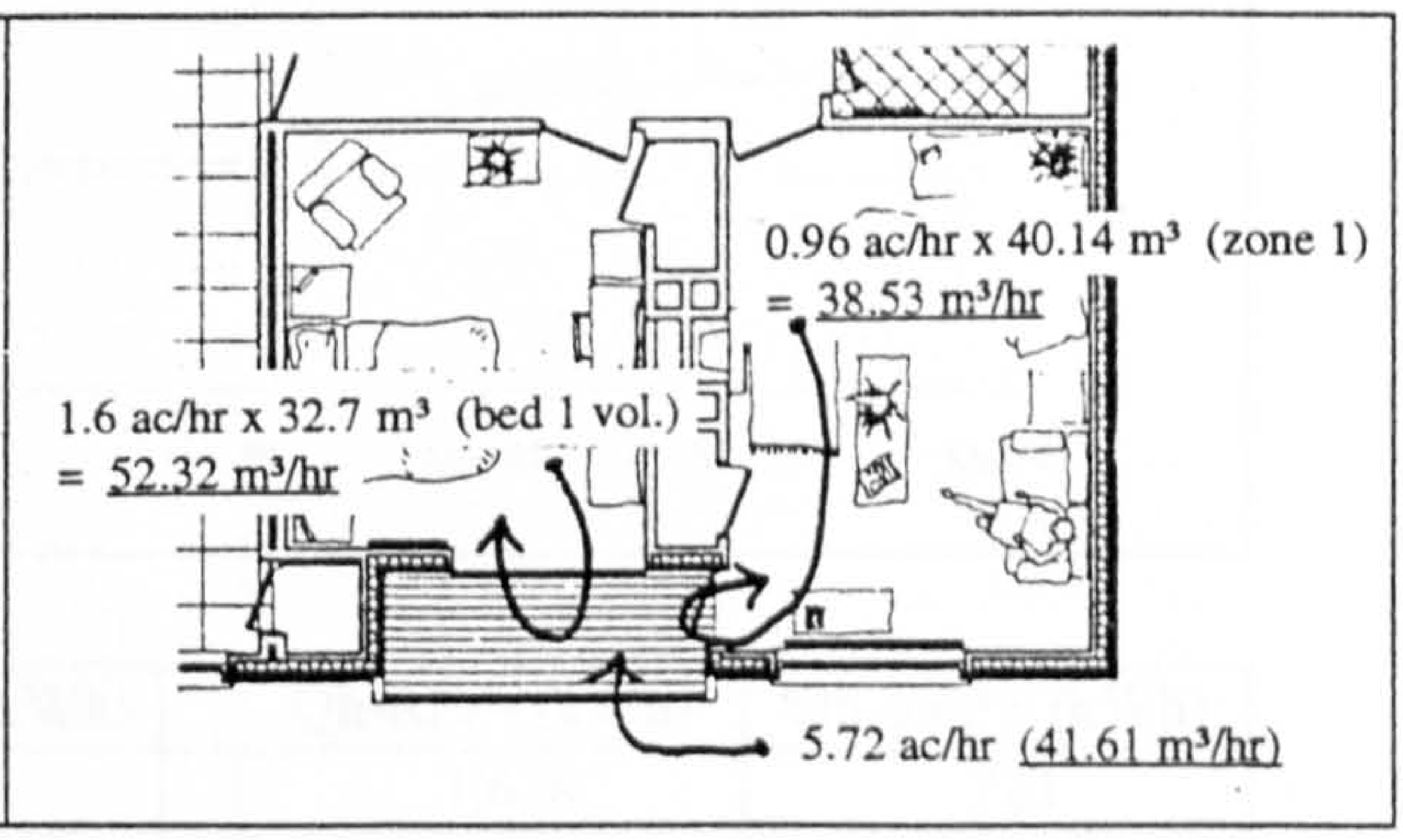
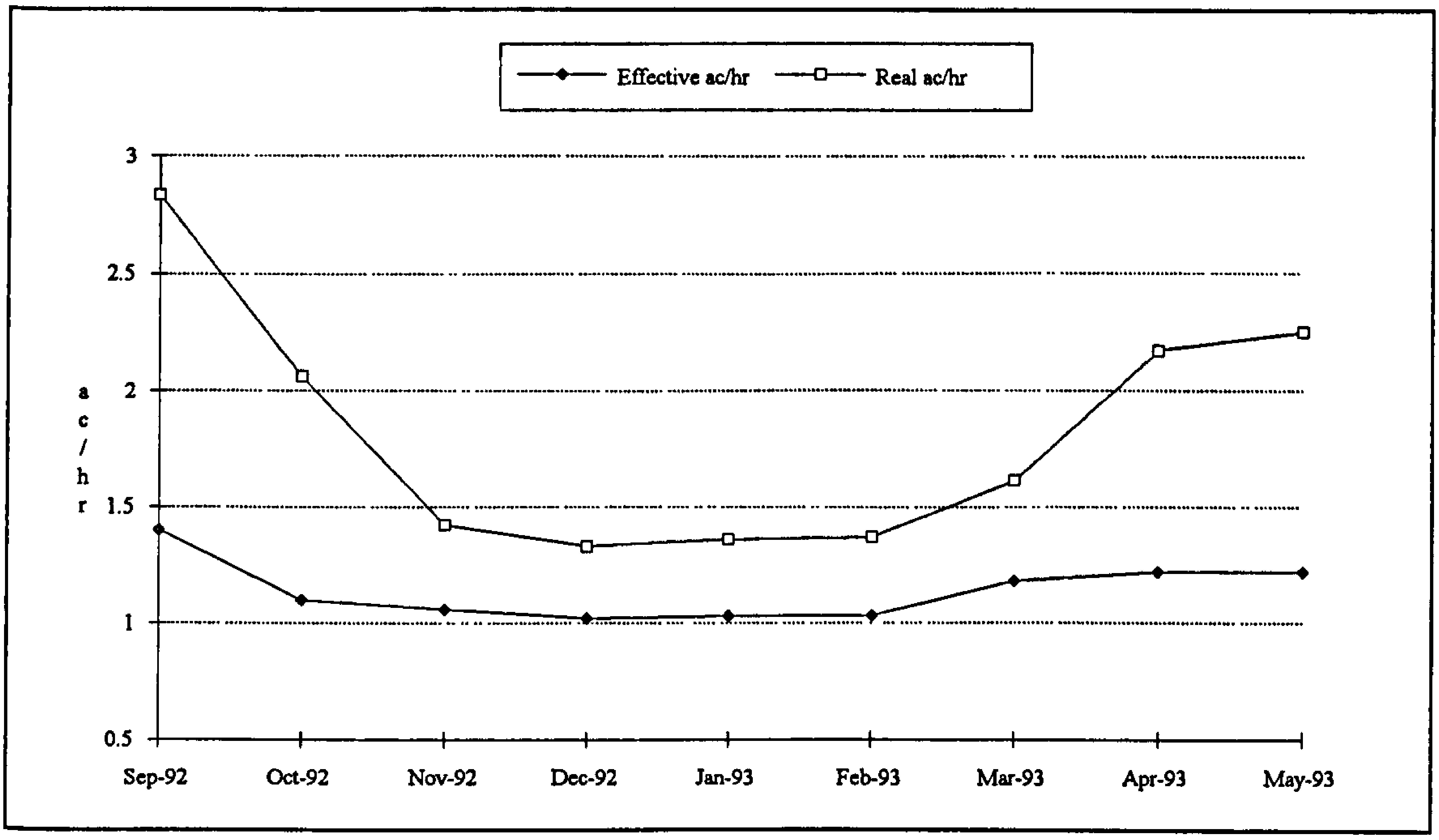


Figure 4.22.a Air Exchange Between Zone 2 and Conservatory. Figure 4.22.b Air Exchange Between Zone 1 & 2 and Veranda.

A higher real rate of air change per hour ($n^{S\text{-}vera}$) of 5.72 or 42 m^3/hour was also found between the veranda and the outside air for the same house and month. Similar to the conservatory, the opening up of the bedroom 1 ($n^{Z1\text{-}s}$ of 0.96 ac/hr) and the living room ($n^{Z2\text{-}s}$ of 1.6) resulted in air mixing within the veranda and the heated zones. The $n^{S\text{-}vera}$ of 42 m^3/hour was insufficient to supply air to satisfy the demand of $n^{Z1\text{-}s}$'s 39 m^3/hour and $n^{Z2\text{-}s}$'s 52, as illustrated in Figure 4.22.b. The prolonged opening up of the heated zone on to the sunspace is graphically illustrated in Figure 4.26.b for W/16 in the later section. Despite this, the robustness of the sunspace in buffer mode had been demonstrated with the net Qh_m of W/16 for the month, just +3% above predicted. It is also worth noting that the relatively generous real air change rate of 1.5 on a 'pro-rata areas' basis was very close to the reality during the winter months. The SODEM adjusted predictions have already taken into account some degree of occupant intervention with respect to ventilation controls.

Mean Monthly n^e and n^r Values

The mean monthly n^e and n^r values of the SOL for the first year and the space heating load for the three models; namely, SOL, REF- and REF+ are summarised in Table 4.7. When heated and ventilated to the same standard as SOL, the theoretical saving is over 70% compared with the baseline reference house (REF-) and just over 30% compared with the REF+. It is worth noting that the contrast of n^r between the fringes and the coldest months is much bigger when compared with the n^e. This indicates that the potential ventilation pre-heat saving is greater at the fringes of the heating season than in the central winter months, and that unheated glazed spaces are effective in reducing the impact of the tendency of users to increasingly open windows in autumn and spring. This will be further highlighted in the four case studies in Chapter 6.



	n^e	n^r	Qh_m - SOL (kWh)		Qh-REF- (kWh)	Qh-REF+ (kWh)
Sep-92	1.4	2.83	291		1,618	723
Oct-92	1.1	2.06	557		2,356	990
Nov-92	1.06	1.42	652		2,282	834
Dec-92	1.02	1.33	946		2,885	1,137
Jan-93	1.03	1.36	893		2,735	1,085
Feb-93	1.03	1.37	708		2,273	874
Mar-93	1.18	1.61	750		2,450	965
Apr-93	1.22	2.17	546		2,168	934
May-93	1.22	2.25	286		1,645	629
Mean	**1.14**	**1.82**	**5,629**		**20,413**	**8,180**
			Saving		**72.4%**	**31.2%**

Table 4.7 Mean Qh For SOL, REF- and REF+.

Note: The mean monthly n^e values, taken in conjunction with the mean transmission loss for all houses and the mean internal temperatures will not necessarily correspond to the mean measured Qh, since distribution of n^e relative to varying transmission loss is relevant. Therefore, the n^e and n^r values have been weighted within each seasonal band i.e. in September - November, December - February and March - May. n^e corresponds to means calculated using equation (1), but values for individual months vary. Similarly monthly Qh totals are at slight variance with mean measured values, but the seasonal total corresponds to the mean for all 34 demonstration houses.

4.5 SUNSPACE WORTH (II): HOW USEFUL AND USABLE ARE THEY TO THE OCCUPANTS ?

The amenity value of the sunspace is widely recognised as described in Chapter 1. Partly determined by heat flowing out from the house and partly by solar gain, the sunspace and its usefulness and usability may be found by examining temperatures of the sunspace relative to the heated zone and information from the 'qido' data.

4.5.1 AIR AND RESULTANT TEMPERATURES

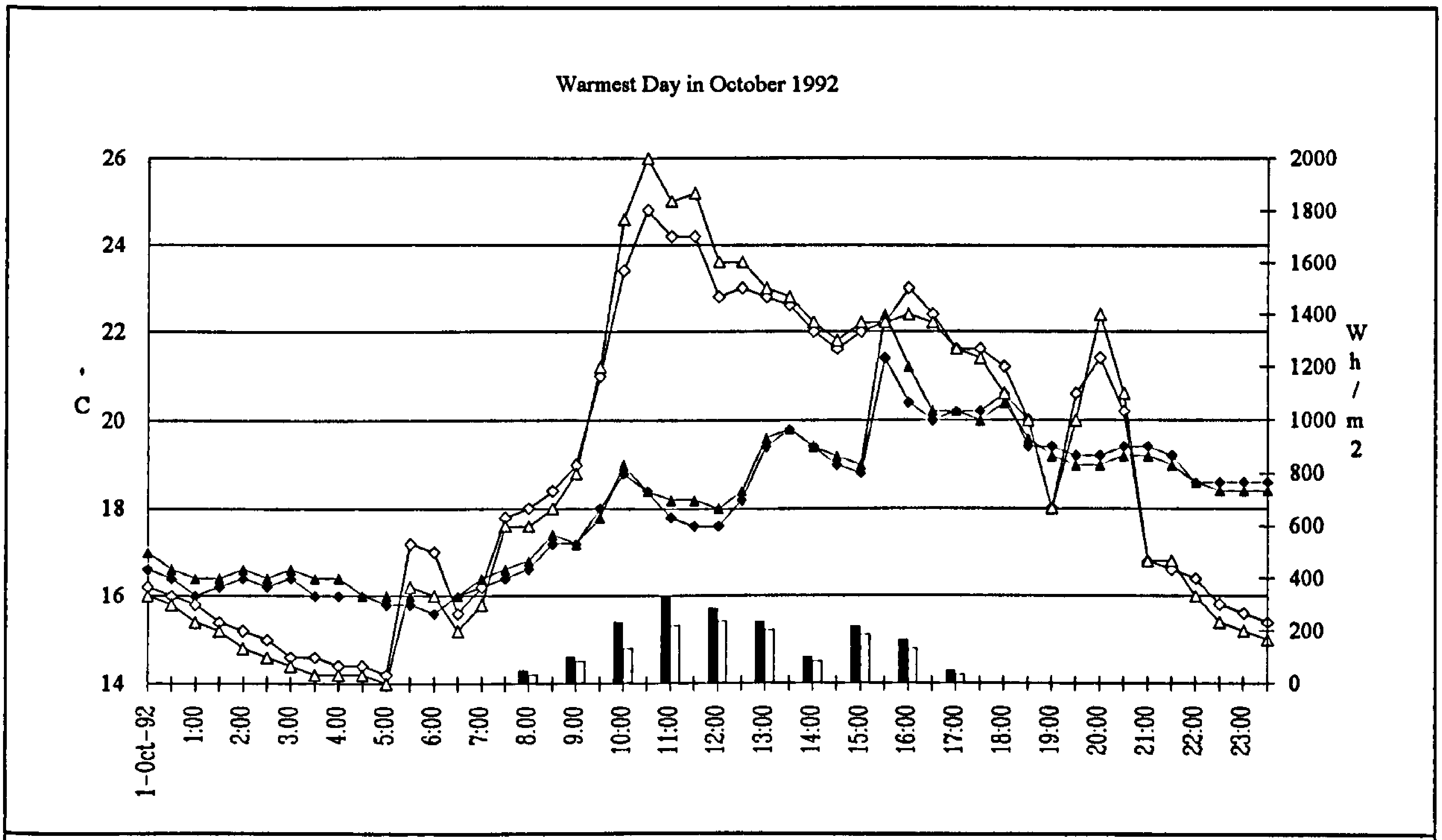
The discrepancy between the mean monthly air and resultant temperature in eight CEC solar houses - where both temperatures were measured - was negligible. The temperature difference in the sunspaces is slightly higher than the adjacent heated zone as in Table 4.8 (air and resultant temperatures, and their monthly difference).

in °C	Veranda	Conservatory	Zone 1	Bed 1
S'92	17 / 17.15 (0.15)	15.66 / 15.54 (0.12)	22.05 / 22.12 (0.07)	20.38 / 20.29 (0.09)
O	13.69 / 13.85 (0.16)	11.58 / 11.6 (0.02)	21.26 / 21.19 (0.07)	18.61 / 18.6 (0.01)
N	12.01 / 12.11 (0.1)	11.05 / 11.02 (0.03)	21.68 / 21.58 (0.1)	18.39 / 18.35 (0.04)
D	11.72 / 11.74 (0.02)	9.83 / 9.83 (0)	22.12 / 21.98 (0.14)	18.26 / 18.22 (0.04)
J'93	10.9 / 11.01 (0.11)	10.62 / 10.59 (0.03)	21.96 / 21.79 (0.17)	17.89 / 17.86 (0.03)
F	13.06 / 13.15 (0.09)	11.95 / 11.89 (0.06)	22.65 / 22.48 (0.17)	18.93 / 18.9 (0.03)
M	13.72 / 13.84 (0.12)	12.35 / 12.36 (0.01)	22.7 / 22.55 (0.15)	19.15 / 19.14 (0.01)
A	15.44 / 16.13 (0.69)	14.27 / 14.96 (0.69)	22.39 / 21.93 (0.46)	19.7 / 19.75 (0.05)
M	17.08 / 17.62 (0.54)	16.15 / 16.79 (0.64)	22.15 / 21.76 (0.39)	20.04 / 20.1 (0.06)
Mean	**13.85 / 14.07 (0.22)**	**22.11 / 21.93 (0.18)**	**12.61 / 12.73 (0.12)**	**19.04 / 19.02 (0.02)**

Table 4.8 Comparison of Air and Resultant Temperatures in Eight Solar Houses (air/resultant/temperature difference).

The difference between the sunspaces' air and resultant temperatures was small during the winter months (mean monthly difference of 0.07°C for veranda and 0.03°C for conservatory), unlike the slightly higher difference in the heated zone (zone 1, 0.16°C). An example is taken for W/6 as in Figure 4.23 and Figure 4.24 (overleaf) - the air and resultant temperatures in the veranda were virtually the same in the selective days in October and December. The conservatory temperatures were however more influenced by incidental gains, i.e. washing and drying clothes, opening up to the kitchen for ventilation whilst cooking and, last of all, solar gains. The wider discrepancy between the air and resultant temperature indicated that air temperatures were more responsive to incidental gains. It is worth noting that the air and resultant temperature was almost the same in Figure 4.23 on 30 October 1992 - the coldest day and with the lowest solar radiation level of the month. Generally the small resultant-air temperature differences in heated zones vindicates the strategy of selective measurement of resultant temperature, with universal measurement of air temperature in these well insulated houses providing a reasonable indicator of thermal comfort.

The mean monthly temperature as shown above, and the maximum, mean and minimum sunspace temperatures over the heating season in Section 4.2.4, do not necessarily indicate the usability of the sunspaces during daytime, say between 09.00 - 17.00 hour, when the occupants are most active. In the absence of movable insulation such as insulated night shutters or thermal-lined thick curtains, the sunspace temperature fluctuates widely between daytime and night-time, especially during the winter months. Hence, it is necessary to examine the daily



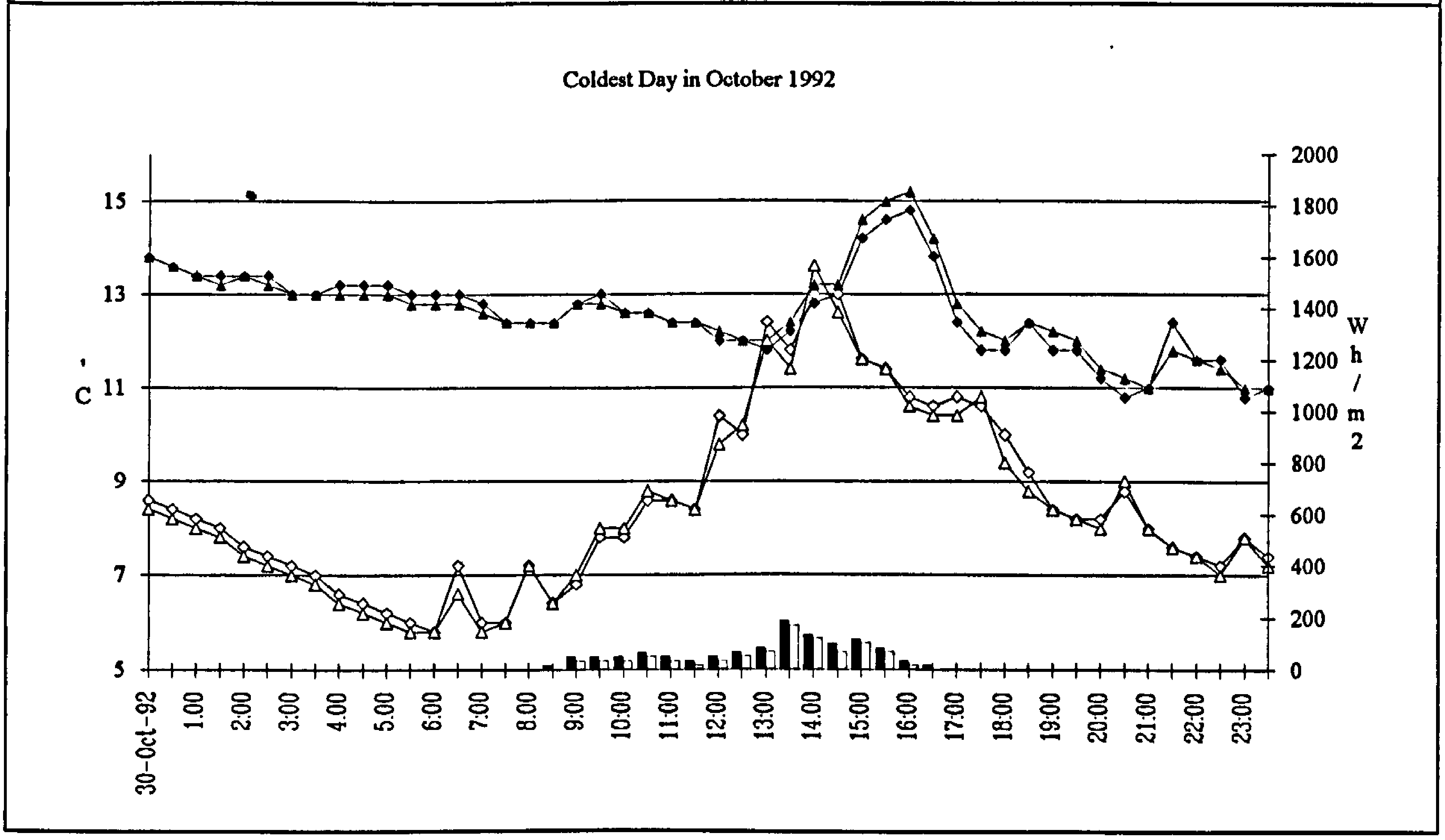
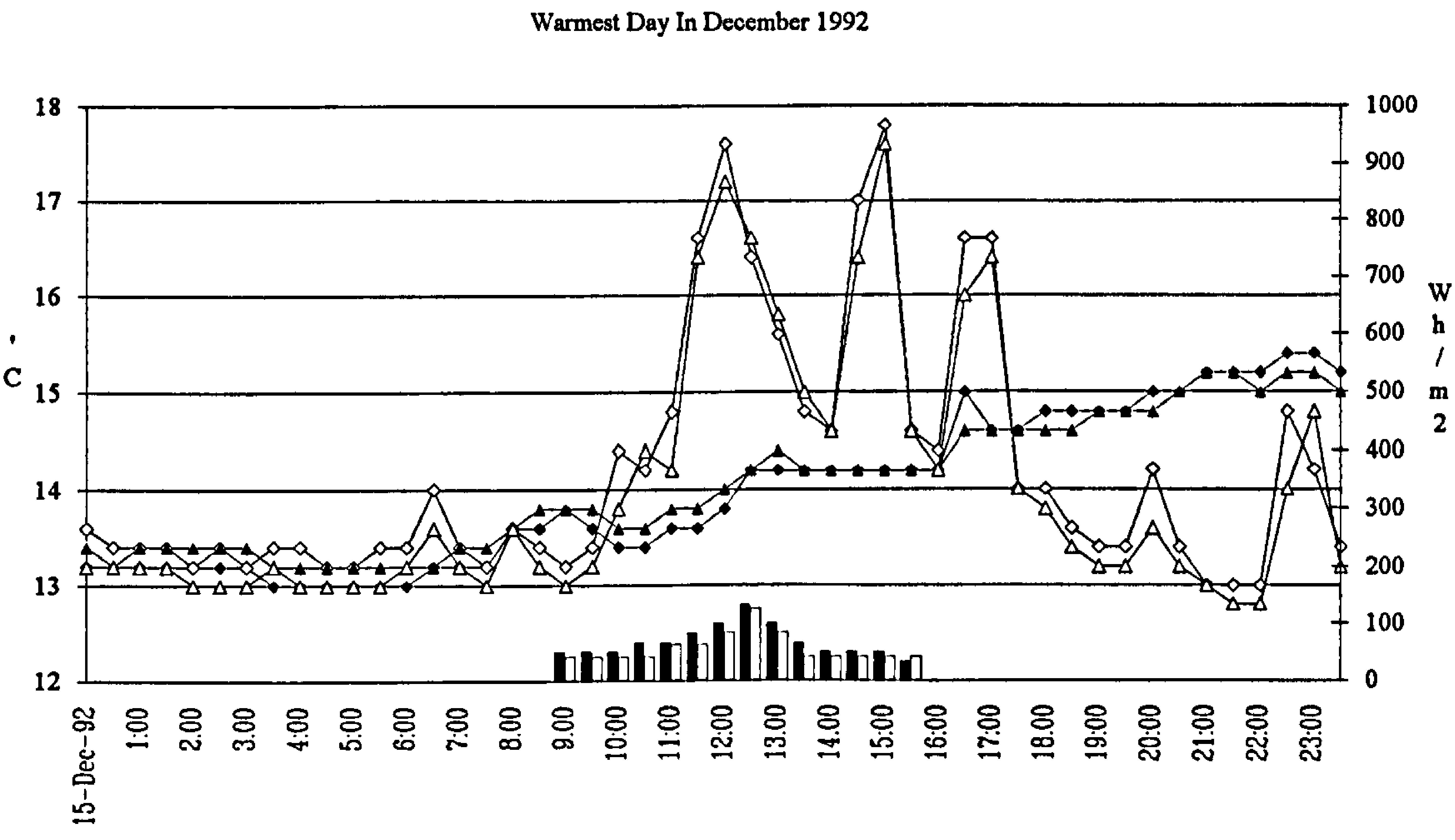


Figure 4.23 Resultant Temperatures cf. Air Temperatures In Both Sunspaces.



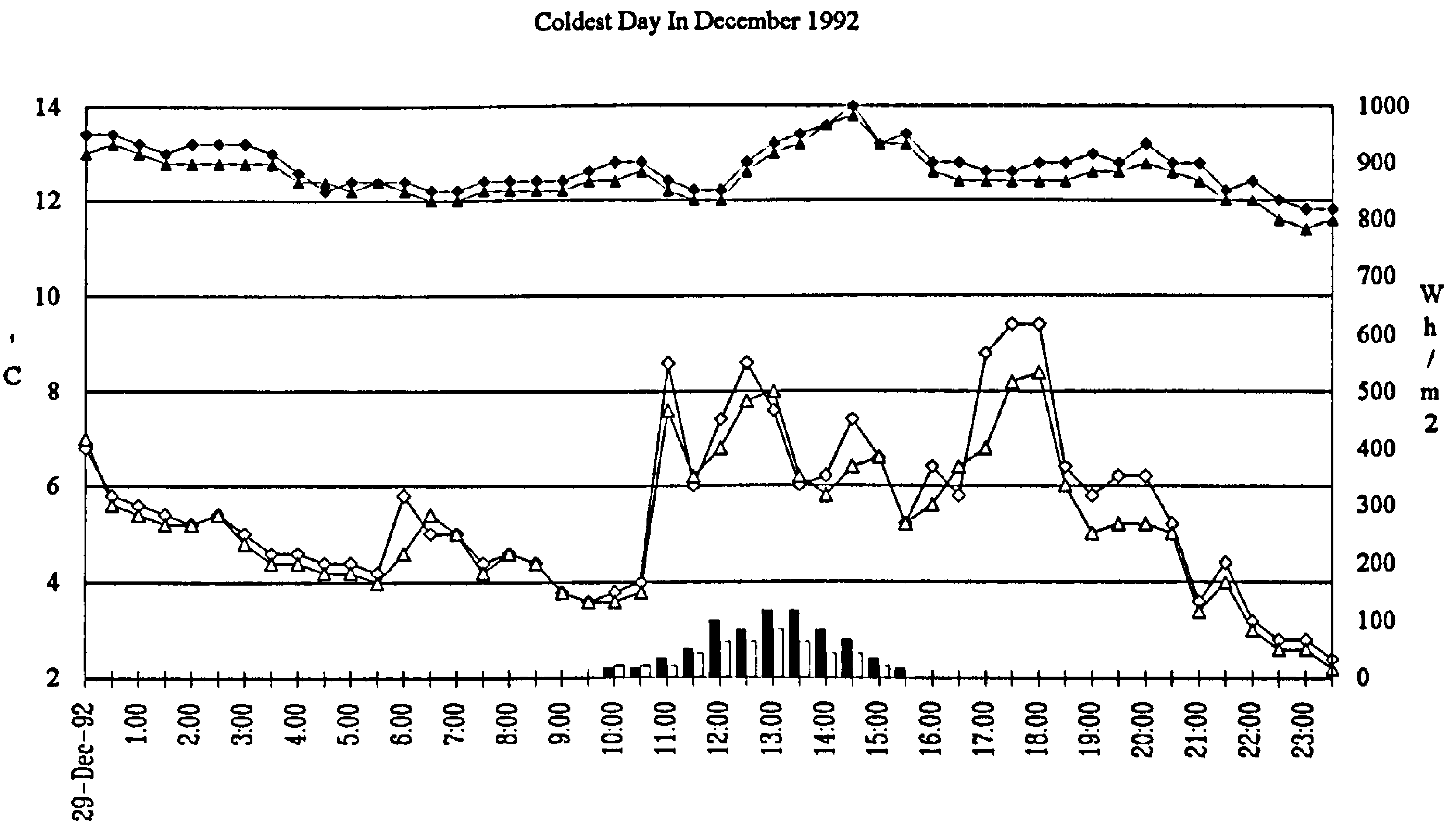


Figure 4.24 Resultant Temperatures cf. Air Temperatures In Both Sunspaces.

temperature profile of a selection of solar houses with respect to both orientations and heating fuels. In order to illuminate the manner in which the sunspaces are being used relative to 'host' rooms and the outside, that is the amount of opening up between heated and unheated spaces and between unheated spaces and outside, it is necessary that the sunspace temperature profile is read in conjunction with the heated zone temperature, ambient temperature and solar gains. In addition to temperature profiles, the uses of both sunspaces in 34 solar houses, as briefly described in Table 4.9 (overleaf), are essentially supported by the 'qido' data. Four solar houses are selected for examination in detail; and the warmest, mean and coldest days are recorded for autumn (October 1992) and winter (December 1992) respectively, see Table 4.10.

	Warmest Day	Mean	Coldest Day
Autumn (Oct. '92)	1 Oct. (11.97°C)	10 Oct.(6.5°C)	30 Oct. (1.98°C)
Winter (Dec. '92)	15 Dec. (10.05°C)	3 Dec. (3.56°C)	29 Dec. (-2.99°C)

	House Code	Location	Qh_m cf. SODEM-adj.
Glen Pl./Electric	G/6	Top Fl. / Mid Ter.	+14.5%
Glen Pl./Gas	G/11	Top Fl. / Mid Ter	-14.93%
Wardie Road/Electric	W/16	First Fl. / Gable End	+30.41%
Wardie Road/Gas	W/15	First Fl. / Mid Ter.	-31.09%

Table 4.10 Selection of the Warmest, Mean and Coldest Days (for house code, see Table 4.4).

The houses selected for this analysis are briefly described in Table 4.4 in Section 4.1.5. Although overall it has been stated that gas-heated houses have higher rates of ventilation and/or more opening-up than those heated by electricity, the opposite appears to be true in this sample - see right hand column of Table 4.10 above which gives the percentage above/below the Qh_SODEM-adj values. Figures 4.25.a-d (overleaf) provide an insight into use and usability, with and without opening up, by virtue of the correction of the temperature profiles during the warmest, mean and coldest day in October 1992 for these four solar houses.

The Warmest, Mean and Coldest Day - October 1992

With regard to the usability of sunspaces, firstly the impact of solar gains on sunspace temperatures in all four solar houses is self-evident. The temperature uplift of the conservatory at Glenburnie Place reflects the east-facing orientation with solar gains peaking in the morning, whereas the west facing veranda benefits from the solar gains in the mid-afternoon. The reverse is true in the case of Wardie Road where the solar gains lift the veranda (south-east facing) temperature in the late morning and have little or no impact to the north-east facing conservatory. On the other hand, there are instances where the erratic nature of sunspace temperatures, closing in on adjacent heated zones during periods without solar input, indicate interventions which may not be in the interests of energy efficiency but do signal use and usability on the part of the occupants. Generally both sunspaces are diurnally within the comfort range, except on the coldest day when the ambient temperature peaks at 7°C.

Electric-heated Houses - October 1992

The temperature profile of the conservatory of W/16 on all three days confirms prominent 'steps' between free-floating buffer periods (e.g. from 0 - 10.00 on October 10th) and periods of opening up to the kitchen (e.g. from 10.00 - 18.00 on October 10th). This contrasts with G/6 where the conservatory is much more

W/5	W/6	W/11	W/12	W/17	W/18
W/3	W/4	W/9	W/10	W/15	W/16
W/1	W/2	W/7	W/8	W/13	W/14

G/5	G/6	G/11	G/12	G/17	G/18
G/3	G/4	G/9	G/10	G/15	G/16
G/1	G/2	G/7	G/8	G/13	G/14

Elevational Key To Solar Houses (W - Wardie Road; G - Glenburnie Place).

House No.	Fuel	Z1'C	Vera'C	Veranda Uses: Winter/Summer	Z2'C	Cons'C	Conservatory Uses	Qh/m3(1)	%_OVER (2)
G/1	electric	21.39	13	Child's Play/Part of Bed 1 & Living Room (All Year)	15.89	12.44	Utilities* (All Year)	31.25	13%
G/2	gas	20.44	12.37	Rarely Used (All Year)	16.27	9.77	Utilities* (All Year)	21.08	-40%
G/3	electric	25.38	15.39	Rarely Used (All Year)	19.44	13.23	Utilities* (All Year)	43.05	12%
G/4	gas	23.64	14.01	Child's Play/Sitting (Summer Only)	16.69	10.82	Utilities* (All Year)	20.77	34%
G/5	gas	22.61	17.04	Sitting/Part of Living Room (All Year)	22.17	17.18	Utilities*/Dog Kennel/Planting (Except Winter)	72.64	114%
G/6	electric	22.61	14.14	Dog Kennel/Sitting/Breakfasting Area (Summer Only)	19.52	12.41	Utilities* (All Year)	35.14	15%
G/7	gas	22.49	15.96	Sitting/Reading (Summer Only)	21.06	12.86	Utilities* (All Year)	71.93	39%
G/8	gas	19.61	15.34	Dog Kennel/Dog Flap on Veranda's Panel (All Year)	18.5	16.21	Utilities*/Pot Planting (All Year)	46.16	83%
G/9	gas	21.64	15.3	Sitting/Reading/Part of Bed 1& Living Room (All Year)	18.54	14.8	Utilities*/Sitting/Reading/Tea (All Year)	31.11	39%
G/10	electric	20.16	14.3	Rarely Used (All Year)	17.75	14.56	Utilities* (All Year)	10.88	-46%
G/11	gas	18.32	13.9	Rarely Used (All Year)	16.83	12.81	Utilities* (All Year)	14.36	-15%
G/12	gas	21.04	14.57	Sitting/Reading/Knitting (Except Winter)	20.2	13.5	Utilities*/Sitting/Reading/Knitting (Mainly In Summer)	36.67	46%
G/13	gas	21.36	13.22	Child's Play/Part of Living Room (All Year)	19.76	15.58	Utilities*/Child's Play (All Year)	80.62	83%
G/14	electric	23.43	14.69	Rarely Used (Except Winter)	18.31	12.95	Utilities* (Rarely Used In Winter)	46.39	-2%
G/15	electric	23.43	15.3	Sitting/Reading/Tea/Pot Planting/TV Watching Except Winter	20.19	14	Utilities* (All Year)	31.44	10%
G/16	electric	21.46	13.45	Rarely Used (All Year)	16.68	14.63	Utilities* (All Year)	15.39	-18%
G/18	electric	23.49	15.06	Dog Kennel/Pot Planting/Sitting/Reading (Except Winter)	18.83	15.94	Utilities*/Pot Planting/Reading/Breakfasting Area (Except Winter)	45.78	56%
W/2	electric	24.11	15.02	Rarely Used (All Year)	21.15	14.26	Utilities*/Lots of Washings (All Year)	41.21	-16%
W/3	gas	23.87	17.22	Rarely Used in Winter	19.5	11.57	Utilities* (All Year)	28.44	13%
W/4	electric	23.73	19.2	Rarely Used (All Year)	20.15	12.7	Utilities* (All Year)	18.86	-35%
W/5	gas	23.72	18.06	Child's Play/Part of Living Room (All Year)	20.78	12.72	Utilities*/Child's Play (All Year)	48.29	65%
W/6	gas	22.41	17.11	Sitting/Reading (Except Winter)	20.88	11.67	Utilities* (All Year)	32.96	7%
W/7	electric	23.11	13.55	Sitting/Reading (Except Winter)	18.8	10.06	Utilities*/Tea Area (Except Winter)	34.4	-20%
W/8	gas	21.6	16.52	Sitting/Reading/Part of Bed 1 (In Summer)	19.14	16.04	Utilities* (All Year)	57.74	75%
W/9	electric	22.32	13.6	Sitting/Reading/Part of Bed 1& Living Room (All Year)	18.22	12.2	Utilities* (All Year)	31.31	30%
W/10	gas	23.05	19.79	Sitting/Reading/Part of Bed 1& Living Room (All Year)	20.11	13.76	Utilities*/Sitting/Tea/Breakfasting Area (All Year)	53.53	221%
W/11	gas	22.82	15.2	Sitting/Reading/Part of Bed 1& Living Room (Summer Only)	18.43	11.97	Utilities*/Sitting/Tea/Breakfasting Area (All Year)	52.21	83%
W/12	gas	20.88	14.96	Rarely Used (All Year)	18.2	11.37	Utilities* (All Year)	15.09	-27%
W/13	electric	25.92	14.26	Occassional Child's Play (All Year)	23.16	13.27	Utilities* (All Year)	61.53	-9%
W/14	gas	21.64	12.96	Child's Play/Access to Front Garden (All Year)	18.36	12.88	Utilities*/Lots of Washing & Drying (All Year)	63.56	71%
W/15	gas	19.47	14.06	Rarely Used (All Year)	16.29	10.35	Utilities*/Rarely Used	14.58	-31%
W/16	electric	22.43	17.75	Sitting/Part of Bed 1 (All Year)	19.45	14.39	Utilities* (All Year)	26.57	30%
W/17	gas	20.48	11.9	Sitting/Reading (Except Winter)	16.44	8.81	Utilities* (All Year)	17.19	-27%
W/18	gas	21.14	13.74	Rarely Used (All Year)	19.11	12.95	Utilities* (All Year)	31.41	6%

Table 4.9 Correlation Between Space heating Load And Household Profile During The Sep. To May Heating Season.

Legends: (1) - net Qh_m in kWh/m3; (2) - Qh_m Comparison with Qh_SODEM-adj.

(Notes: Utilities* refer to washing/ drying only.)

Figure 4.25.a - Warmest, Mean and Coldest Day in Oct. '92 (G/6 - Electric-heated/ Glen Pl.).

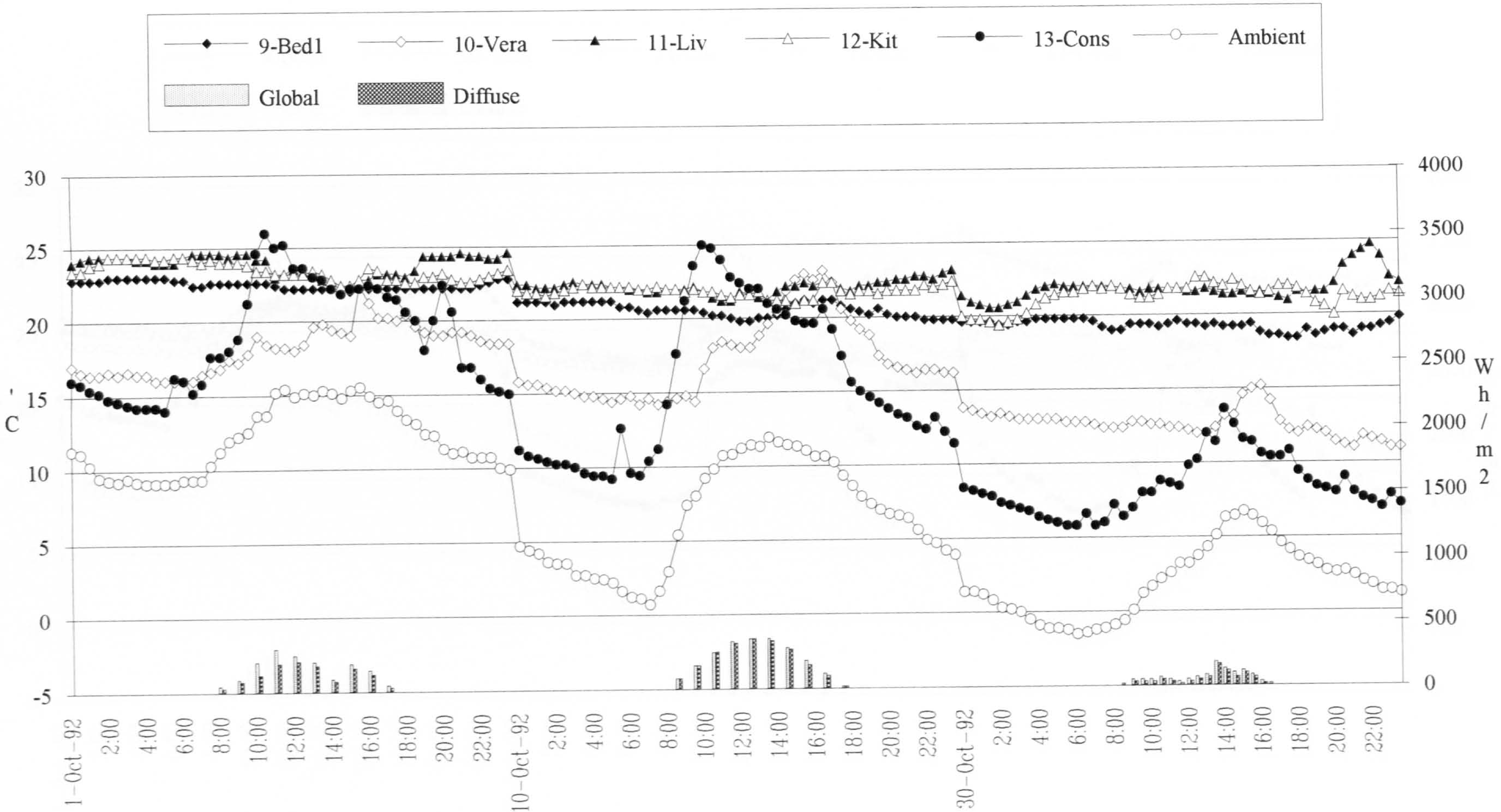


Figure 4.25.b - Warmest, Mean and Coldest Day in Oct. '92 (W/16 - Electric-heated/ Wardie Rd.).

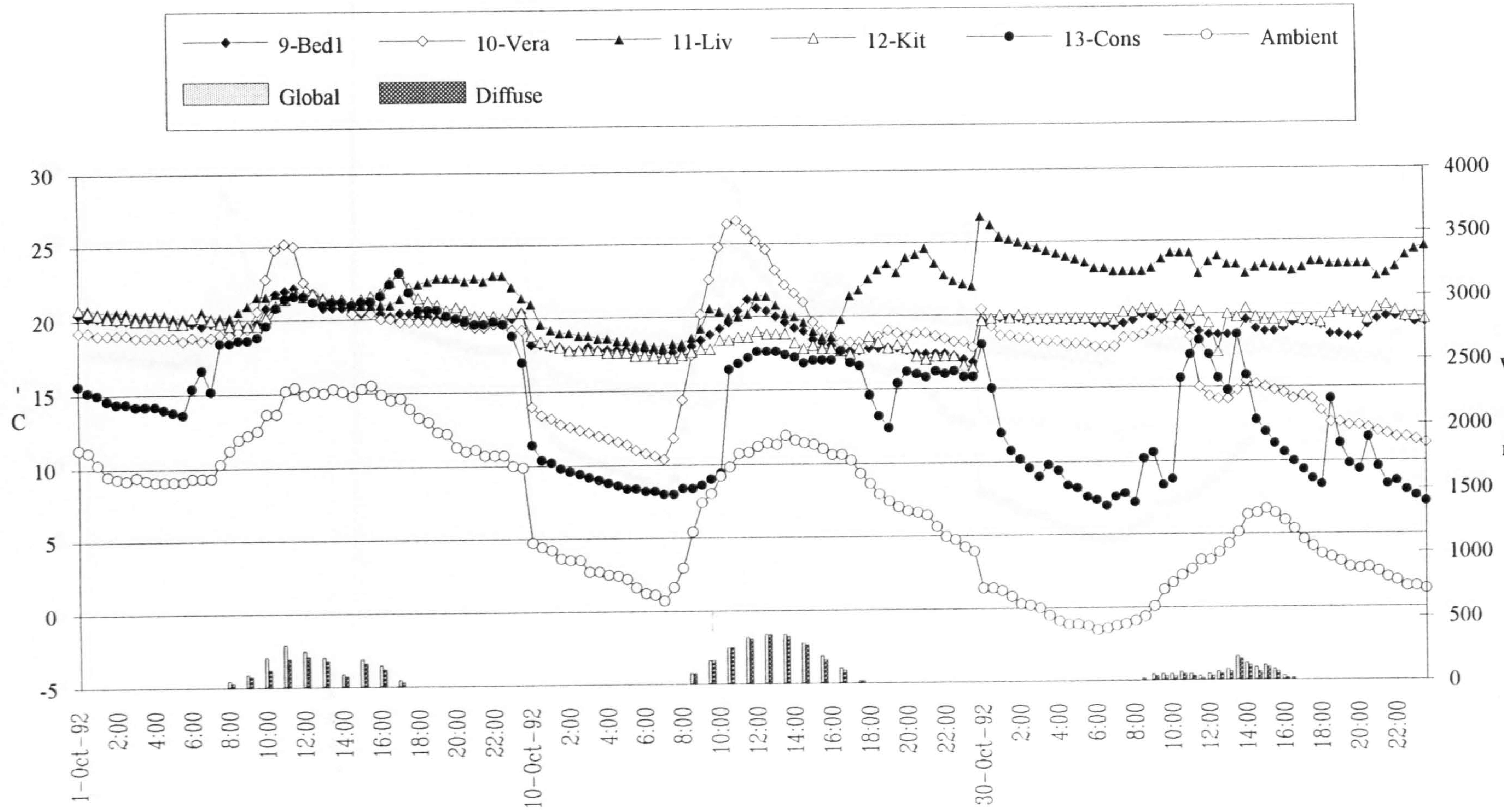


Figure 4.25.c - Warmest, Mean and Coldest Day in Oct. '92 (G/11 - Gas-heated/ Glen Pl.).

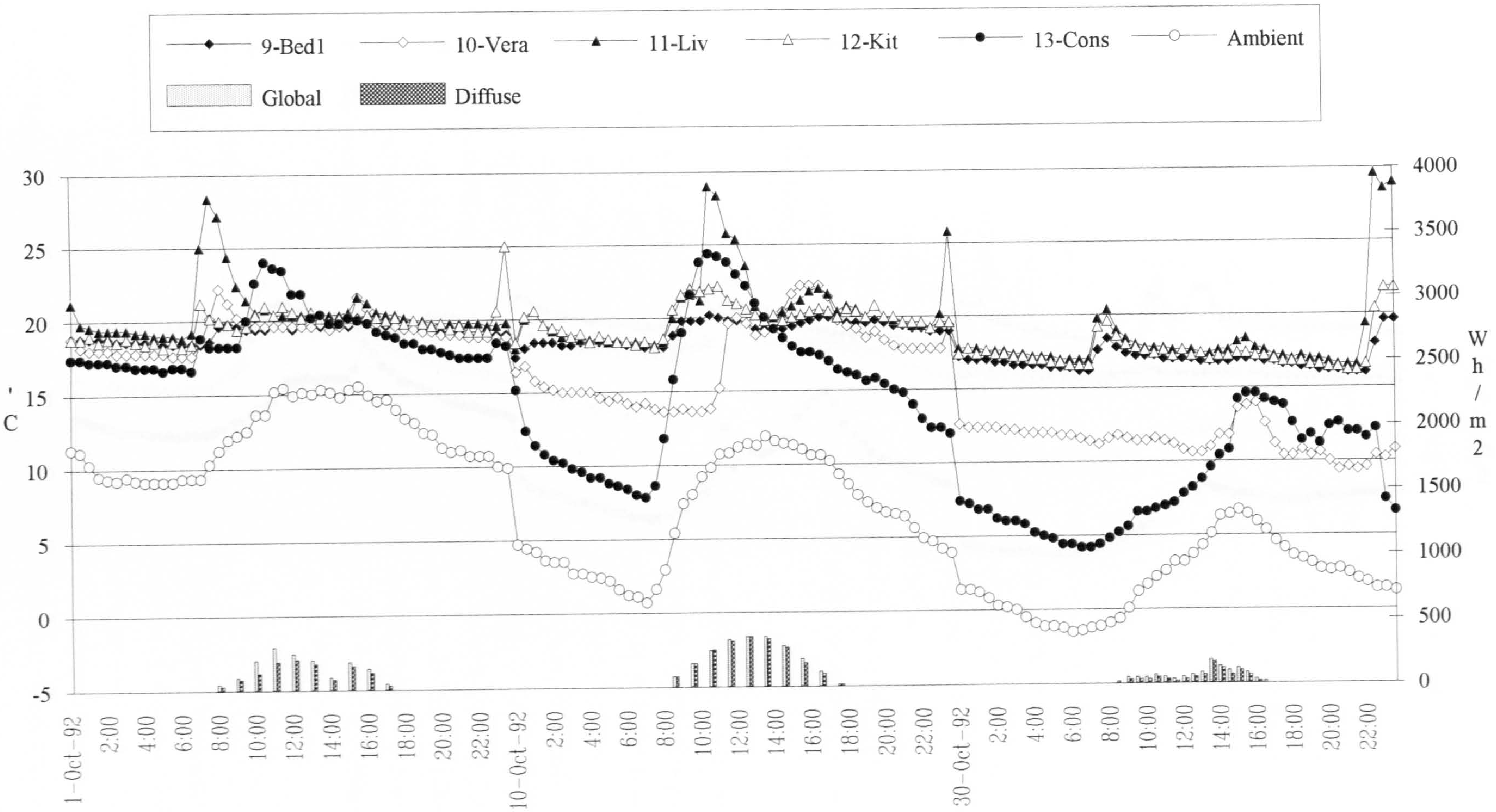


Figure 4.25.d - Warmest, Mean and Coldest Day in Oct. '92 (W/15 - Gas-heated/ Wardie Rd.).

responsive to solar gains (i.e. free-floating) with occasional 'spikes' (e.g. 19.00 - 21.00 on October 1st) due to opening up. W/16's interaction with the veranda is more complex. On the 1st October, opening-up is evident all day with a short solar induced 'spurt' from 10.00 - 12.00 while on the 10th, it appears to free-float at least until 16.00; and on the 30th, it appears to have been opened up until 11.00 and thereafter free-floating. This gain contrasts with G/6. Here the veranda appears to be generally free floating in the 'intended' buffer mode; and consequently where most of the time a temperature difference is maintained between veranda and ambient as well as veranda and heated zones, other than periods of high insolation when merging of temperatures is desirable.

Gas-heated Houses - October 1992

Gas-heated G/11 is remarkably similar to electric G/6, except that heated zones are kept at lower temperatures with occasional boosts, and a specific opening-up of the veranda evident on the 10th from 11.00 onwards. Mr A who worked rota shift as a security guard in a nearby factory ended his night-shift at around 06.00 hour and usually returned home at 06.30 hour. The sudden surge in the living room and kitchen's temperature at around 08.00 hour reflected Mr A's habits - cooking breakfast and watching the morning news before going to bed. The warm weather on 1 October 1992 perhaps led to Mr A leaving both kitchen/conservatory door and bedroom1/veranda doors ajar before going to sleep in the mid-morning; or the sunspaces may simply have balanced out with 'host' rooms which are also free-floating.

W/15's profiles of heated rooms are relatively gentle and the two sunspace profiles respond to solar gains, peaking at the time of the day in accordance with their orientation. Also the 1st and 10th October suggest that opening up of the outer conservatory windows results in merging with the ambient temperature from 10.00 - 16.00; and the subsequent peak perhaps indicates opening up to the kitchen together with a brief spell of insolation. Mrs B, who was widowed and lived alone, spent most weekends with her grandchildren at East Kilbride and was away from home for a substantial period of time throughout the year. Although having a gas centrally heated system, Mrs B hardly used it and mostly heated the living room by using the gas fire only when required. This does mean that the free-floating temperatures of sunspaces are often too low to be comfortably usable, especially the north-west facing conservatory. On the other hand, if it is used for energetic activities such as hanging up clothes to dry, this may not matter; and of course neither has it relevance during periods of absence.

Summary - Autumn/October 1992

The temperature profiles of the four solar houses (G/6, G/11, W/15 and W/16) clearly demonstrate use and usability in thermal comfort for most situations without opening up. The exceptions are the coldest day, which could well belong to January rather than October, and unfavourable orientation such as the north-west conservatories. However, metabolically active use of these spaces will tend to mitigate discomfort. In order to investigate whether the usability of the sunspace extends to beyond the autumn season, temperature profiles for the warmest, mean and coldest day in December are now examined.

The Warmest, Mean and Coldest Day - December 1992

During the winter months, temperature profiles in Figure 4.26.a-d (overleaf) confirm that sunspaces are essentially in buffer mode in reducing the transmission and ventilation loss. However, they are seldom warm enough to be occupied except briefly and for some active purposes, unless they have been opened up - as in the case of W/16 - continuously apart from the last 12 hours on the 29th December in the case of the veranda, and for hours at a time in the case of the conservatory. It may also be noted that solar radiation, now peaking at a maximum of 150 W/m² compared with 375 W/m² in October, no longer impacts on the sunspace profiles.

Glenburnie Place - December 1992

In the case of G/6, the veranda temperature appears to track the heated interior rather than ambient conditions. The effect is marked on the coldest day when the veranda maintains roughly an 8K difference relative to Bedroom 1, similar to the mean day; whereas the veranda-ambient differential increases from about 8K or the mean day to 15K on the coldest. This may be partly due to the cold day being accompanied by an east wind, and would also explain why the east facing conservatory more closely tracks ambient temperature on this day. But it may be partly due to a particular use by Mr and Mrs C, who have a German shepherd called Rocky. The dog is free to wander inside the house and has its kennel near to the living room/veranda door during the winter and in the veranda during early autumn and late spring when the weather is warmer.

Mr A's low, intermittently occupied regime in G/11 results in sunspace temperatures significantly less than those of G/6 - i.e. lacking the input from heated zones. There is an intriguing reversal of veranda profile relative to conservatory on the 29th December. Again this may be partly due to the change in wind direction, but also partly due to some degree of opening up. It is difficult to identify any use for the sunspaces given such low temperatures, unlike G/6 where periodic use is very evident in the conservatory and where at least a dog benefited from the veranda.

Wardie Road - December 1992

As stated above, the electric-heated house of W/16 at Wardie Road undoubtedly opens up the heated zone on to the veranda and, as a consequence, is the only house in this set to achieve adequate warmth to make the space usable at this time. Mr and Mrs D live with their 18-year old daughter. Mrs D, who works as a night-shift nurse, sleeps during the day, usually with the patio door ajar for fresh air. Also, the temperature profile indicated the conservatory was consistently used as a utility room throughout the year - with noticeable spurs signalling opening up for ventilation while cooking and washing clothes.

The relatively low and flat temperature profiles of the gas-heated W/15 confirms that only living room is regularly heated. The sudden surges in the kitchen correspond to a likely pattern of cooking. The profiles of the veranda and conservatory are similar to those of G/6, except that lower conservatory temperatures suggest more opening of outer windows. Again it is probable that there is a fair degree of openness between veranda and bedroom, but not enough to render the space usable for leisurely human activity.

Figure 4.26.a - Warmest, Mean and Coldest Day in Dec. '92 (G/6 - Electric-heated/ Glen Pl.).

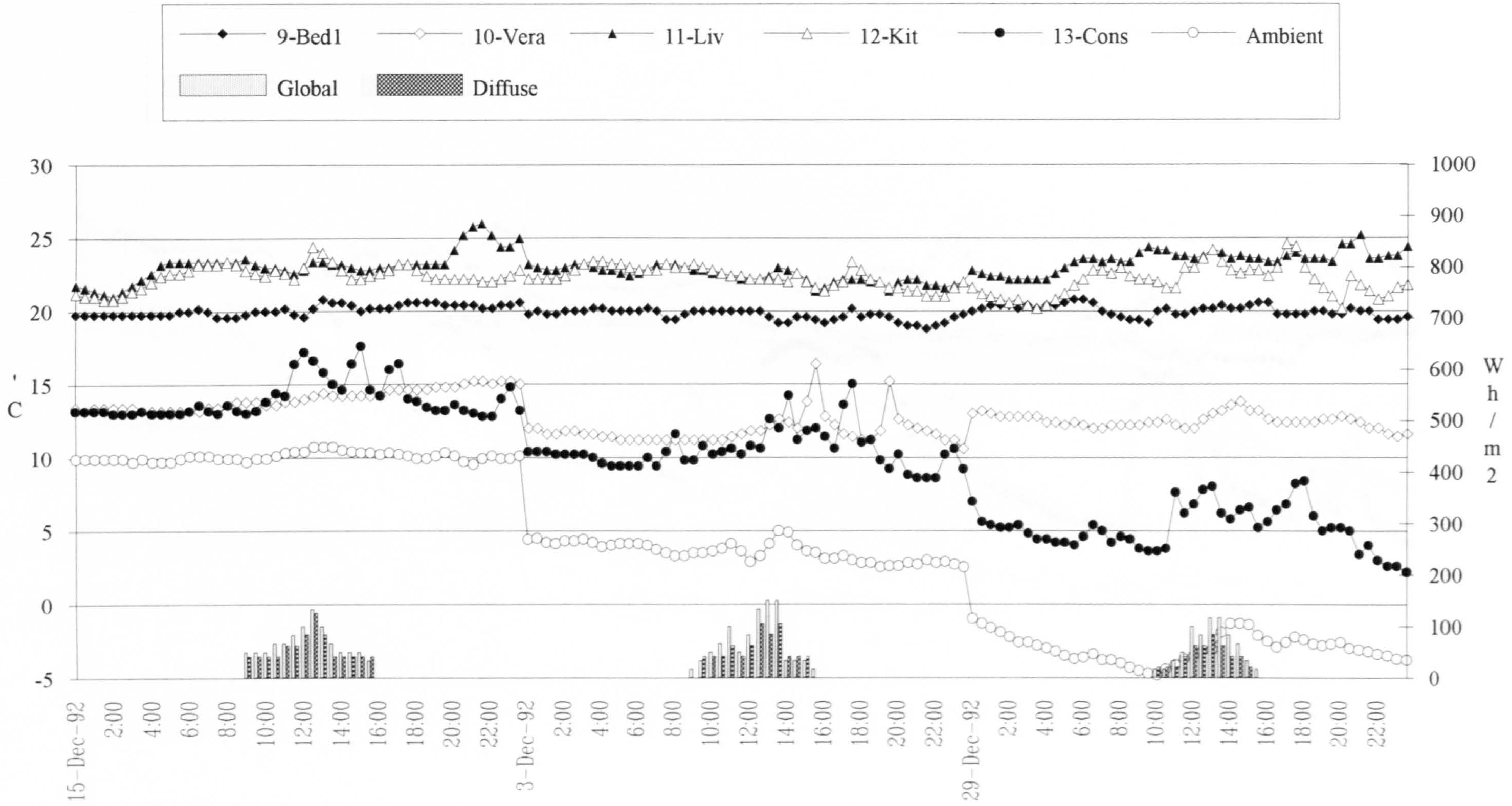


Figure 4.26.b - Warmest, Mean and Coldest Day in Dec. '92 (W/16 - Electric-heated/ Wardie Rd.).

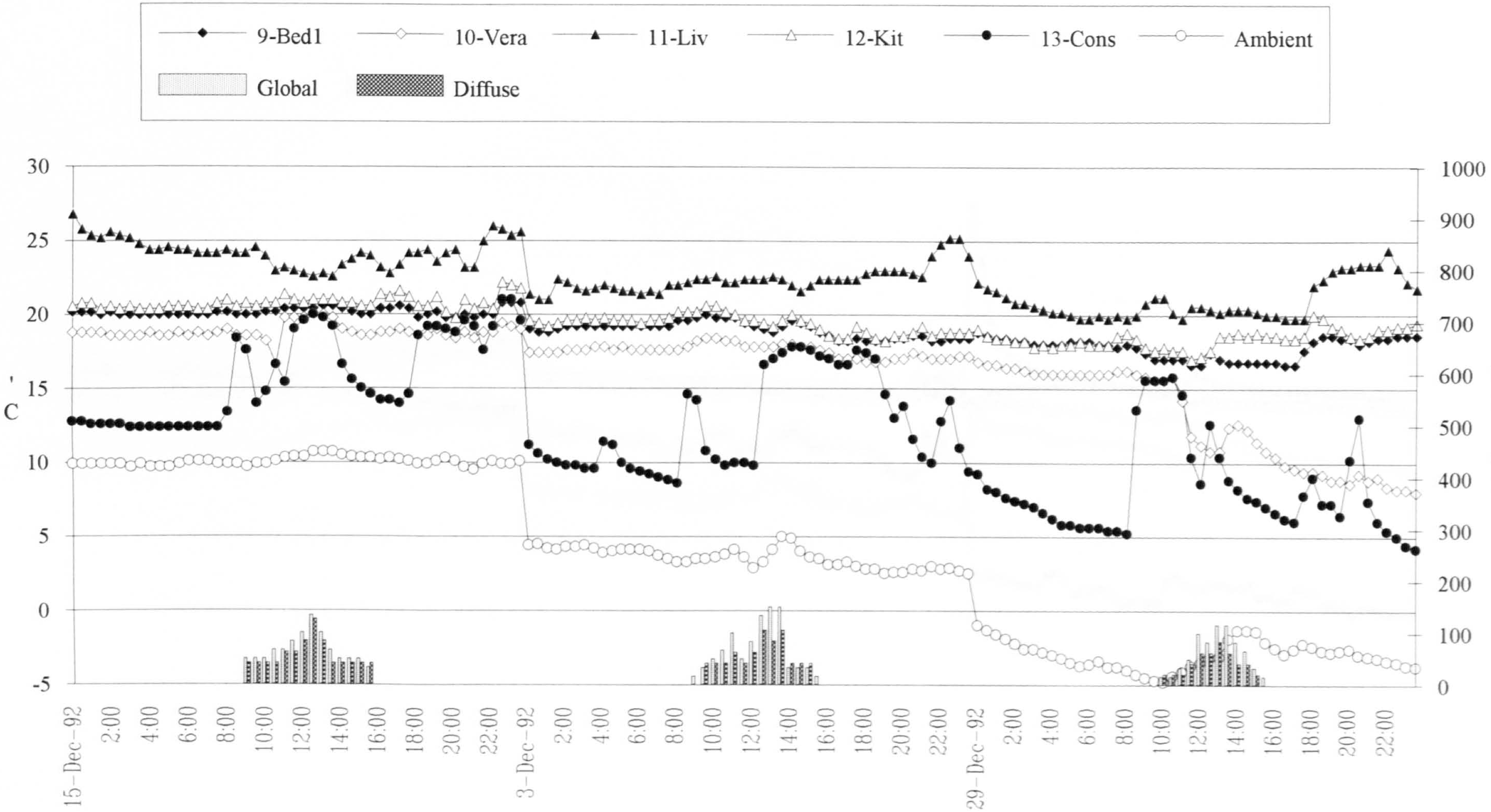


Figure 4.26.c - Warmest, Mean and Coldest Day in Dec. '92 (G/11 - Gas-heated/ Glen Pl.).

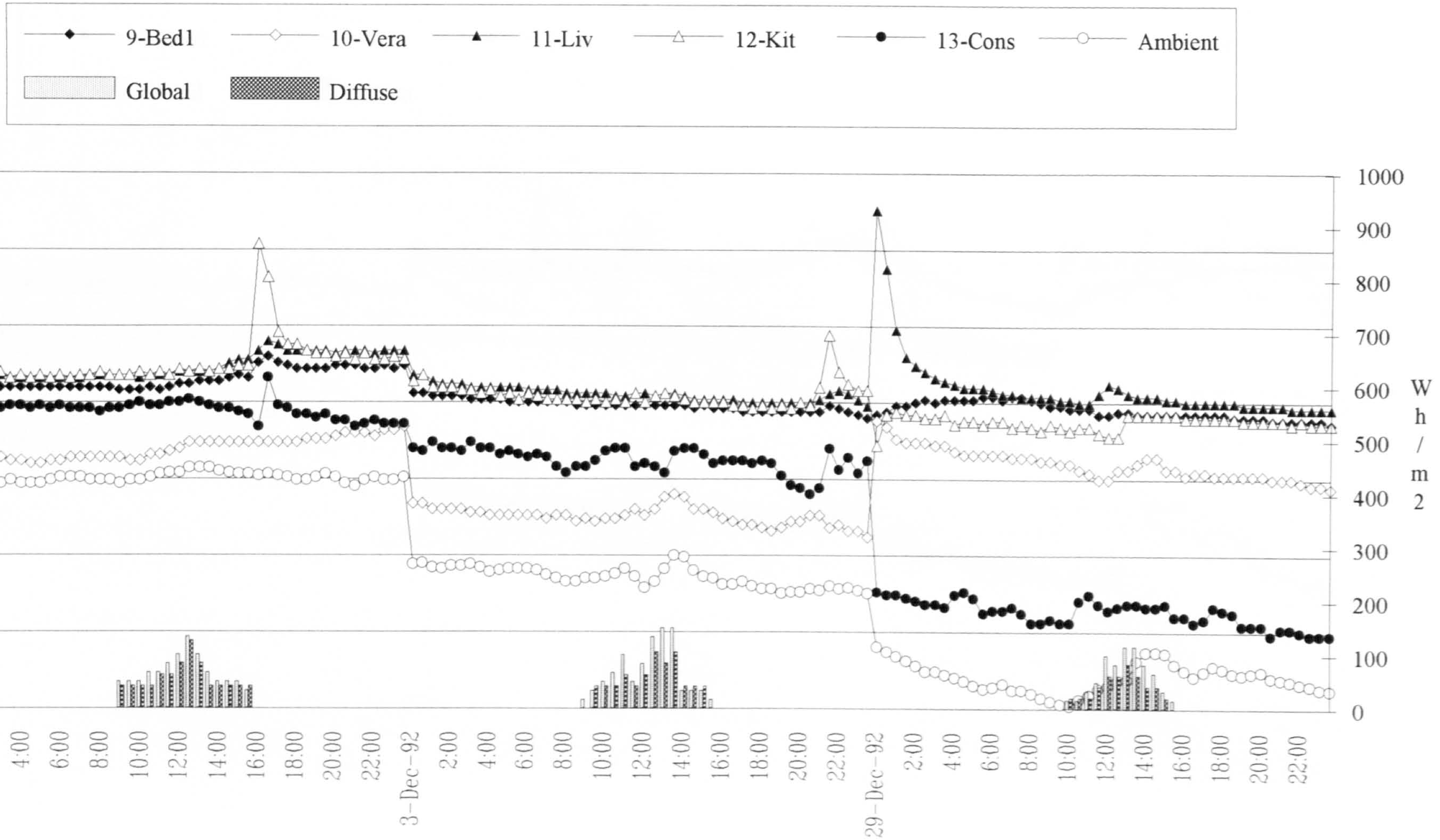
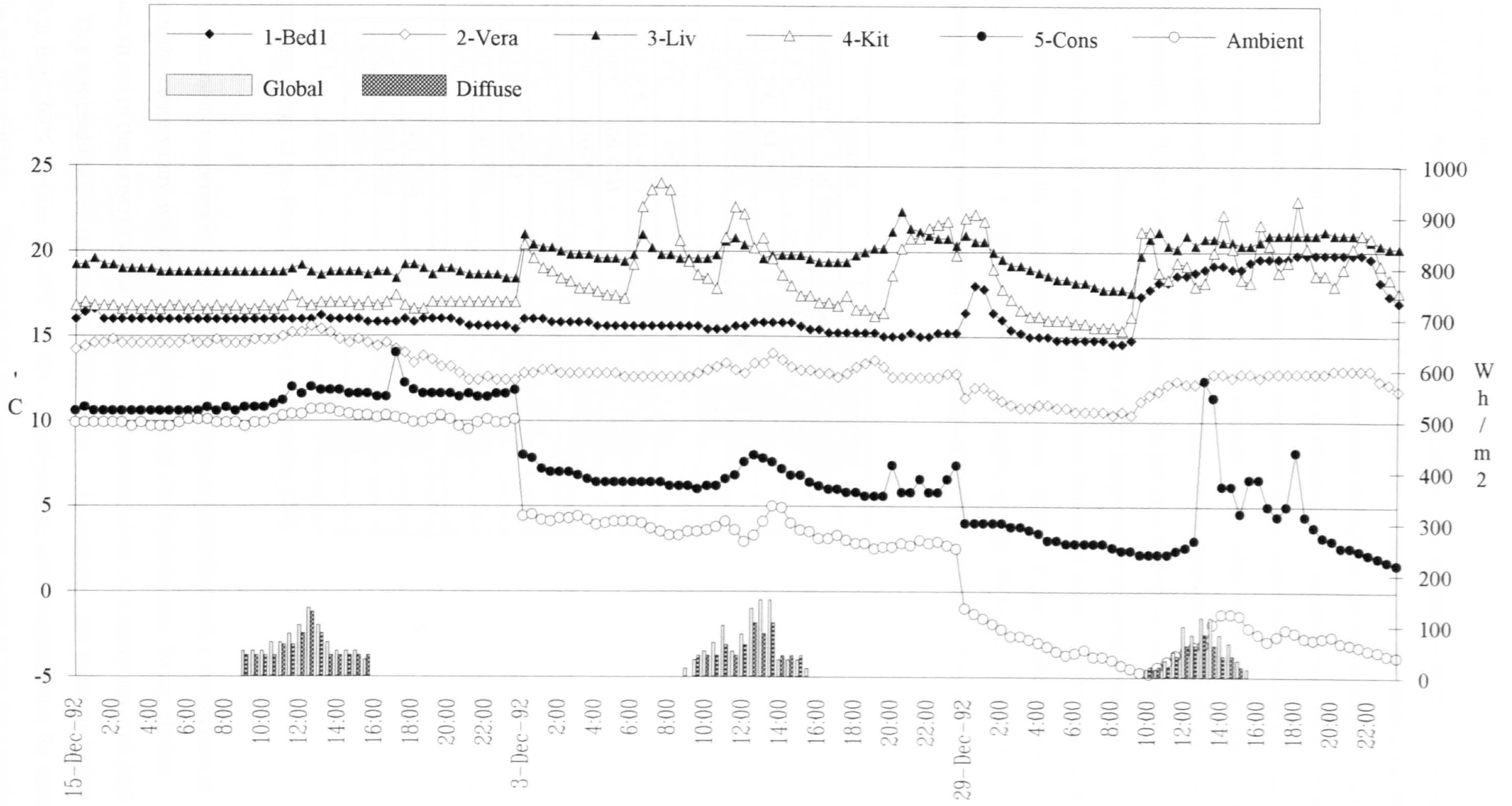


Figure 4.26.d - Warmest, Mean and Coldest Day in Dec. '92 (W/15 - Gas-heated/ Wardie Rd.).



Summary - Winter/December 1992

The sunspaces in all four solar houses largely performed as expected in a buffer mode over the winter months of December, January and February. However, the daily temperature profile of the two electric-heated houses (Figure 4.26.a & b) had ample examples of occupants' interventions throughout the day in respect of opening up of the heated zone on to the sunspaces especially in the case of conservatory - resulting in a larger swing of the daily sunspace temperatures recorded. This renders the comparison of the mean daily sunspace temperature of thirty-four solar houses somewhat less meaningful. For example, the range of sunspace temperatures as in Table 4.11 compares the half-hourly measured sunspace temperatures in the four solar houses for the whole month of December. For example, House G/6 (in bold lettering) has just over half of the month with a conservatory temperature of 10°C or higher. Naturally, most of the higher temperatures occurred during the day when the sunspace temperature was fuelled by both solar gains and loss from the heated zone. The veranda achieved a relatively higher temperature than the conservatory with at least 60% of the whole December having a temperature of 10°C or above at G/11, 90% at W/16 and 100% at both W/15 and G/6. However, the conservatory functioning as utility space recorded a wider range of temperature from 35% to 64% of the time above 10°C.

	Veranda	Conservatory
	Range of °C % of time	Range of °C % of time
G/6 Glen Pl. Electric-heated	>15°C (4.2%)	>15°C (5.6%)
	>12.5°C (54.3%)	>12.5°C (18.9%)
	>10°C (100%)	>10°C (54.9%)
	>5°C	>5°C (84%)
G/11 Glen Pl. Gas-heated	>15°C (0%)	>15°C (1.4%)
	>12.5°C (23.4%)	>12.5°C (14.4%)
	>10°C (60.4%)	>10°C (63.9%)
	>5°C (100%)	>5°C (66.7%)
W/15 Wardie Road Gas-heated	>15°C (3.5%)	>15°C (0%)
	>12.5°C (34%)	>12.5°C (0.9%)
	>10°C (100%)	>10°C (34.7%)
	>5°C	>5°C (71.5%)
W/16 Wardie Road Electric-heated	>15°C (81.9%)	>15°C (27.8%)
	>12.5°C (81.2%)	>12.5°C (44.3%)
	>10°C (89.6%)	>10°C (61.8%)
	>5°C (100%)	>5°C (97.9%)

Table 4.11 Temperature Range of the Four Solar Houses in December 1992.

The relatively low conservatory temperature range (only 3% of time in December with a temperature of 15°C or above) did confirm the conservatory was almost exclusively used for washing and drying clothes. Most occupants would not sit out in the conservatory in such a low temperature even on a sunny day with high level of solar radiation. This was confirmed by results from 'qido' data. In contrast, the relatively higher veranda temperature (with at least 60% of time at 10°C or above) did provide ample opportunities for various uses especially when the sun was shining. Two out of the four occupants were known to use the veranda for pot planting which generally would require a minimum temperature of 10°C and as a tea area (temperature lift by solar gains and loss from heated zone).

Summary - all year round - all houses

The 'qido' data confirms the two sunspaces were well used throughout the year, especially the conservatory as a utility space for washing and clothes drying - 34 out of 36 households had a washing machine installed. At least six households had put a seating bench or small table set in the conservatory and at least two households had used their conservatories regularly as a tea/reading area even in winter. Nevertheless, the uses of the conservatory in most cases were for short periods of time and perhaps in a somewhat routine pattern, say twice a week washing.

The veranda with its proximity to the living room and bedroom 1 had a different and diversified use pattern. Two-thirds of the occupants were using the glazed-in verandas regularly for parts of the heating season. At least three households used the veranda as dog kennels and five households as children' play area during autumn and spring. Due to the nature of the use patterns, occupants may be tempted to open up their verandas for long periods and indeed in some cases extend their living space. The frequent usage of the veranda especially in early autumn and late spring raises the issue of how much interventions with doors, windows etc. compromises the performance - the subject of more detailed study in the next chapter.

4.6 SUMMARY

The Easthall Project compares favourably in both mean total delivered energy and demanded energy with the EPA prototype block at Edderton Place. The running cost was not analysed in the EPA prototype block. Nevertheless, the CEC project's average bill of £364 and £415 as per monitored heating season is thought to be lower (without and with standing charges respectively).

The mean measured heated zone temperature was higher than anticipated. This is thought to be primarily due to full comfort conditions being affordable, rather lack of appropriate control, although the latter is identifiable in some cases. The mean space heating load was almost a quarter above that predicted using a uniform 1.5 ac/hr ventilation rate as a yardstick throughout the heating season, and having adjusted for measured heated zone temperatures. However, the degree of window opening in autumn and spring, which raises real rates of ventilation above 1.5 ac/hr threshold, do correspond to earlier field studies. The diversified sunspace temperatures reflect two factors. Firstly, many of the occupants were opening up early in spring and shutting down late in autumn, relative to an 'energy-optimum' with respect to the potential of solar gains in ventilation preheat mode. Secondly, the effect of occupants is noticeable in most of the houses with respect to temperature profiles in heated and unheated zones.

By deduction from measurements, the effective air change rate, which expresses the preheat/heat recovery effect of the sunspaces, damps down the impact of the relatively high real rates of ventilation in autumn and spring. So, provided each real rates are accepted as a reasonable human response on the part of the users, the saving due to preheat is not compromised. However, having established this principle, the simple expression of house temperatures as a function of space heating loads reveals that the combination of control options available to occupants results in some enjoying better value for money than others. In fact, space heating loads/costs varied widely, with paradoxically some of the lowest consumers apparently 'mis-using' their buffer spaces compared with some of the highest (e.g. with a low temperature difference between Bedroom 1 and the veranda). Also a relatively high house temperature was practically achievable at a low space heating input, and ventilation rate is the most influential variable in this respect together with heating type/regime.

The two sunspaces were particularly well used by the occupants. The conservatory built as a utility space has a distinctive use pattern. Unlike the conservatory, the use pattern of the veranda has a closer relationship with the household profiles, i.e. as child's play areas or dog kennels. Furthermore, the opening up of verandas tends to be more persistent and prolonged. This hypothesis is supported by overall lower space heating loads of households which rarely used their verandas, although as stated above there are apparent 'open-up' exceptions to this rule. The extent of the effect of occupants' interventions relative to a number of physical and social variables is to be examined more fully in the next chapter.

CHAPTER 5 TO WHAT EXTENT ARE OCCUPANTS' INTERVENTIONS AFFECTING ENERGY SAVINGS ?

INTRODUCTION

This chapter aims to disseminate the extent of occupants' interventions affecting energy savings in the CEC project using the research methodology outlined in Section 3.3. The wide variation in measured net space heating load (net Qh_m) mainly reflects varying regimes with respect to demand for warmth, control of ventilation and type/use of heating system. Measured data leaves some 'soft edges' and one gap in the heat balance equation: U-values are calculated, not measured; solar data was not collected on site and use of curtains and blinds, etc. introduces another degree of inaccuracy; incidental gains are computed from measured consumption data; in the gas-heated houses, an assumption has to be made with respect to cooking and hot water consumption and flue losses in order to arrive at the space heating loads; and ventilation rate is the 'gap' or unknown with no air pressure tests to give a value for background infiltration. So to render 'soft' edges around many of the 'knowns' somewhat harder, physical monitoring is supplemented by 'qido' data - a questionnaire completed by most occupants and more detailed logs completed by some occupants; interviews with most occupants; and the author's own observations of most occupants' aspirations, circumstances, etc. made possible by frequent visits into occupants' houses during the two years monitoring period. Thirty-six solar retrofitted houses was statistically small in sample number; nevertheless, 28 out of all 36 (77.8%) households returned questionnaires and were subsequently interviewed.

5.1 SURVEY OF THE CEC PROJECT'S OCCUPANTS

5.1.1 AGE OF HEAD OF HOUSEHOLD

The head of household was defined as the occupant of the solar house in relation to the tenancy taken out with the landlord - Glasgow City Housing . Age was grouped into five categories; namely, below 17, 18- 39, 40-59, 60-69 and 70 or over year old as in Figure 5.1. The category enabled close examination of the characteristics of households with potential special circumstances as well as needs, such as the young, the retired and very old.

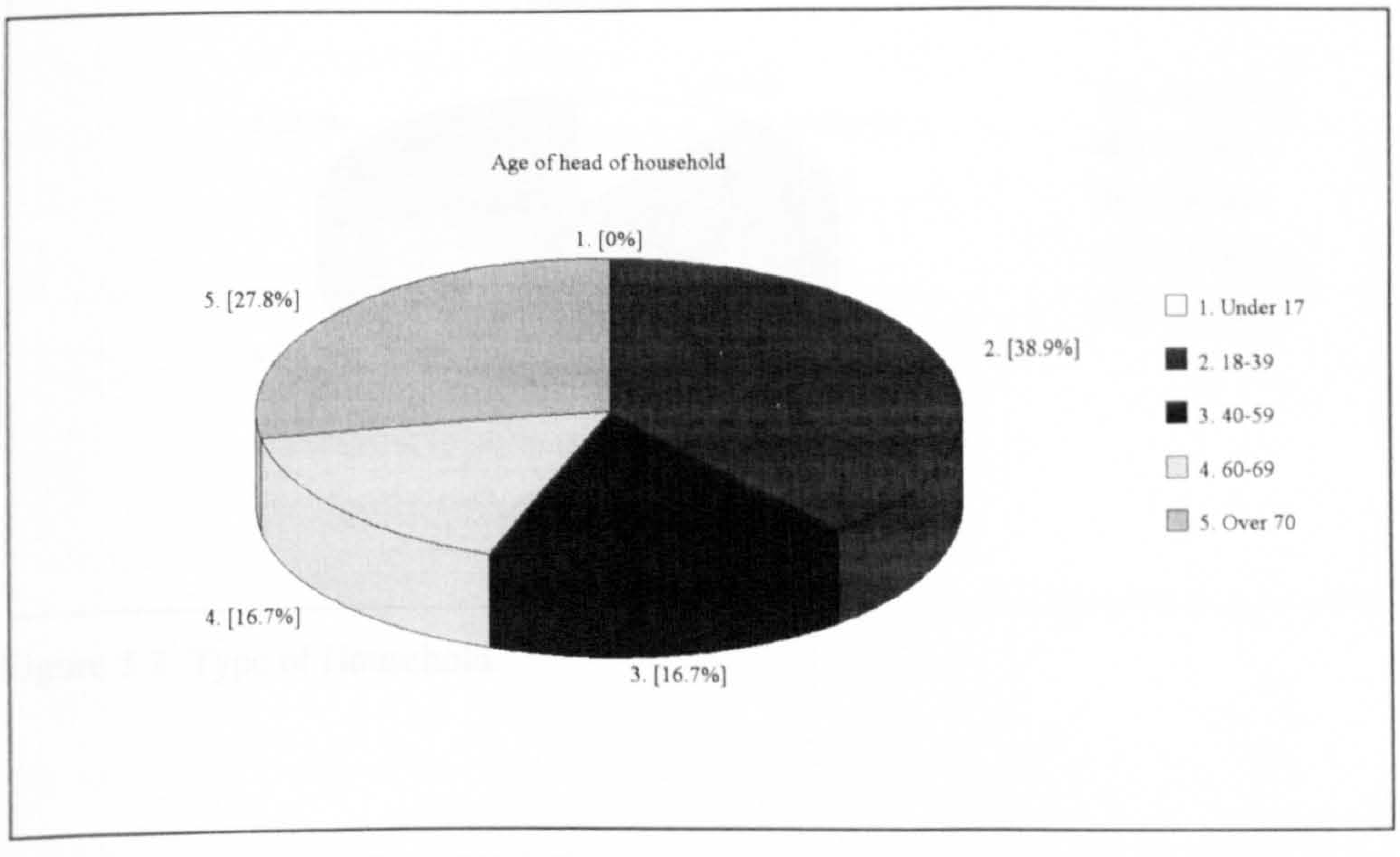


Figure 5.1 Age of Head of Household.

Compared with the Scottish House Condition Survey[1] 1991 value of 34.2%, the Easthall project had a higher concentration of old aged pensioner aged over 60 years. Heads of households aged over 60 years accounted for 44.5% of the sample, within which 16.7% were aged 70 or over. Adults under the age of 40 represented 38.9% compared with 32.3% in the Scottish House Condition Survey 1991.

5.1.2 HOUSEHOLD TYPE

The twenty-eight households interviewed provided the numbers and ages of persons residing in the house. Due to the small sample and one house type (2-bedroomed flat) in the Easthall project, a simplified classification of the English House Condition Survey[2] 1986 was used as follows:

1. single adult household - 1 adult (non-pensionable age) and no children;
2. small household (adult only) - 2 adults (non-pensionable age) and no children;
3. small family household - 1 or 2 adults (non-pensionable age) and with one or more children (including single parent household);
4. single pensioner household - 1 adult of pensionable age and no children;
5. small pensioner household - 2 adults of pensionable age and no children.

Small family households were the largest group (38.9% compared to Scottish average of 41.8%) including more than a quarter (11.1% compared to Scottish average of 4.8%) of small single parent family (1 adult and 1+ children), followed by small pensioner households (27.8%) - see Figure 5.2. Single pensioner households represented 16.7% compared to Scottish average of 15.8%. The other two groups accounted for the remaining 16.7% with no small households with only adults of non-pensionable age. The distribution of household type mirrored the policy of public sector housing allocation in reflecting the needs of disadvantaged groups, i.e. elderly and family.

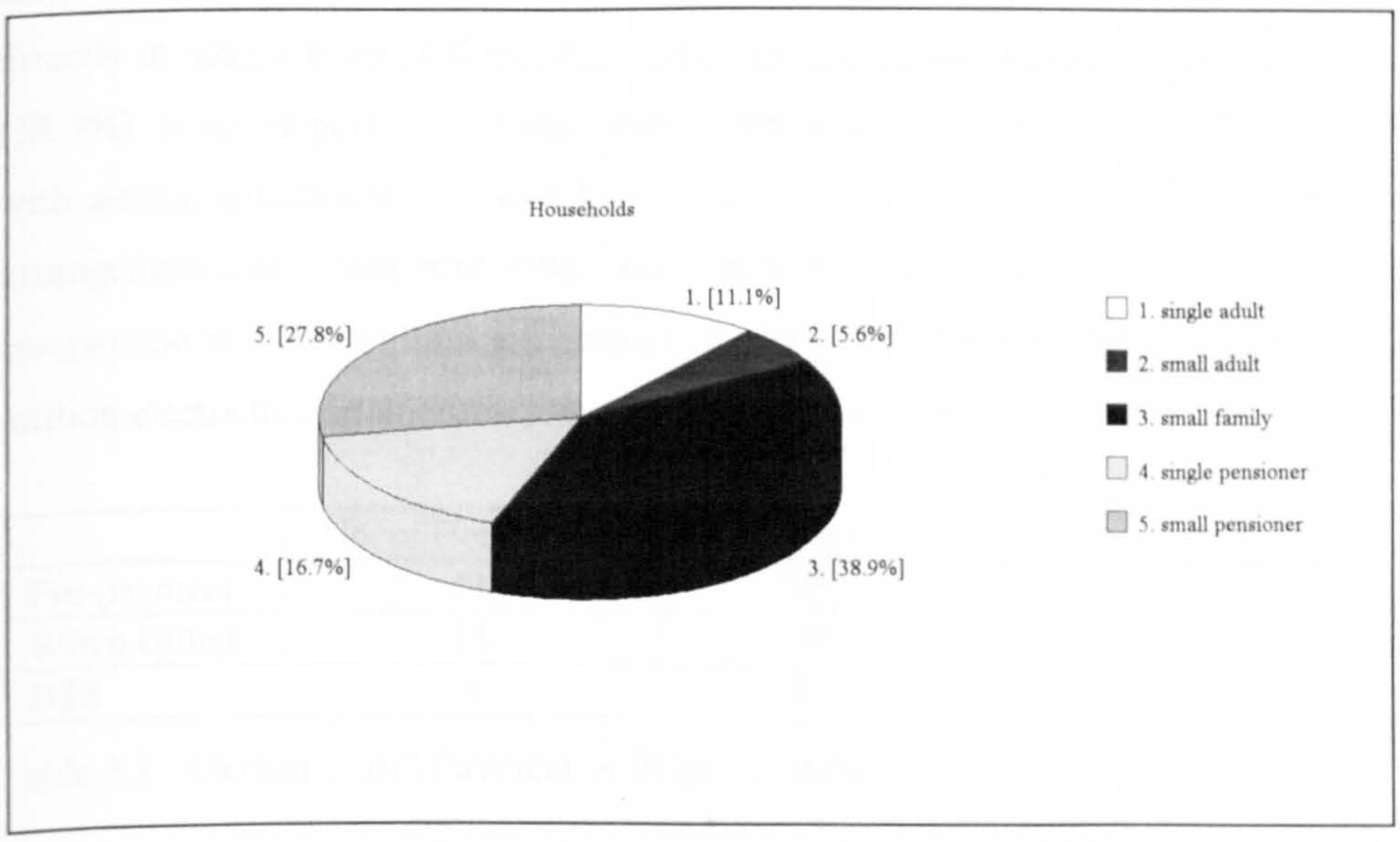


Figure 5.2 Type of Household.

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[1] SCOTTISH HOUSE CONDITION SURVEY 1991, Scottish Homes July 1993.

[2] DEPARTMENT OF THE ENVIRONMENT ENGLISH HOUSE CONDITION SURVEY, 1986. Housing Survey Report Number 13, part 2.

5.1.3 ECONOMIC STATUS

The economic status of all occupants (aged 18 or over) was recorded under six categories as in Figure 5.3 (overleaf):

employed, unemployed, retired, long-term sick/ disabled, full-time looking after the home/ family and 'other' (including training scheme, temporarily sick, maternity leave and full-time education).

Two sets of economic status analyses- heads of household and all adult occupants were used to identify the 'economically inactive' group.

For the head of household only, 47.2% were in either full-time or part-time work; 2.8%, unemployed; 33.3%, retired; 11.1%, long-term sick/disabled, 2.8%, full-time looking after home/family and 2.8%, others. For all adult occupants, just 39.7% were in either full-time or part-time work; 31.7% retired; 6.3% long-term sick/disabled and 14.3% full-time looking after home/family, 4.8% unemployed and 3.2% classified as others. This compares unfavourably with the Scottish average of 52.7% at work; 27%, retired; 5.7%, long-term sick/disabled and 6%, full time looking after home/family. This confirms that the occupants of Easthall project were more 'economically deprived'.

The 'economically inactive' category was higher in the Easthall project mainly as a result of retirement and ill-health in both cases - head of household and all adult occupants. In summary, the Easthall project was more "economically deprived' not by unemployment, but by retirement and ill-health.

5.1.4 INCOME STATUS AND METHOD OF BILL PAYMENT

Household income was not surveyed, but all households were asked whether their energy bills were paid by themselves or through an agency, i.e. 'fuel direct' where payment of fuel, particularly in arrears, was deducted directly at source from DSS benefits - only one household was on 'fuel direct'. Over half of the households (58.3%) were pre-paying their main energy bill either by weekly budget plan or having had a powercard installed with annual adjustment. Table 5.11 illustrates the method of energy bill payment. The level of payment arrangement and prepayment meter installed in the Easthall project was estimated to be higher than average in comparison with 1.9 million gas customers who were on a payment arrangement with British Gas and over 2.5 million electricity customers on prepayment meter nationwide as in 1990[3].

	No. of Households	In Percentage
Pre-payment	21	58%
When Billed	14	39%
DSS	1	3%

Table 5.1 Method of Bill Payment by Project Residents.

Summary

The household profile of the Easthall project portrays a group of occupants who are more likely to be small family households (38.9%) with head of household aged 60 or over years (44.5%) and 'economically inactive'

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[3] BOARDMAN B. 1991 ibid. p.p. 38-40.

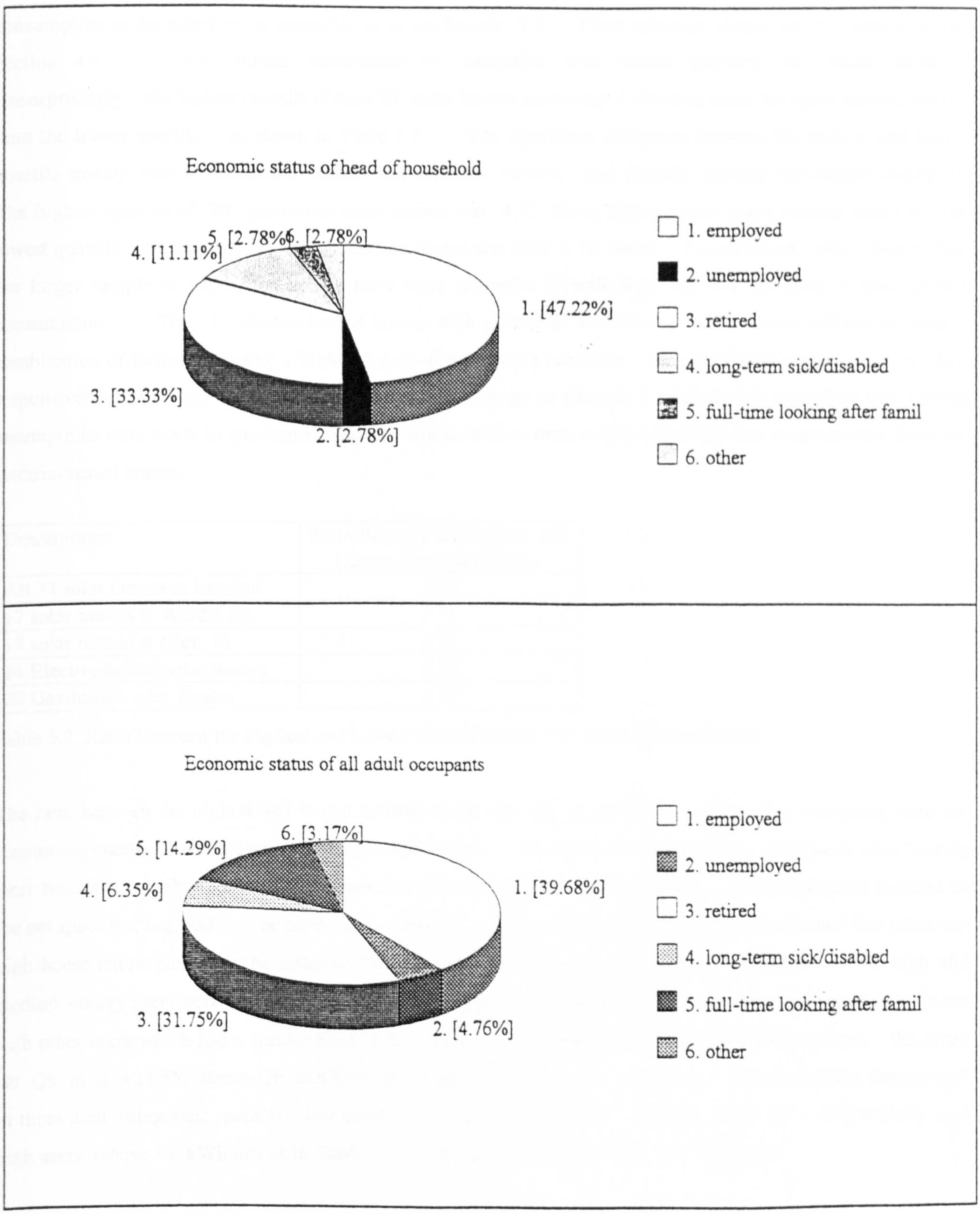

Figure 5.3 Economic Status Of All Head Of Household (Above) and All Adult Occupants (Below).

(60.3%). It is then against their background as a relatively 'economically deprived' group that, the occupants' interactions with heating and ventilation controls and the consequent reduction in potential savings attributable to the sunspaces, are the subject of investigation.

5.2 USER-PERFORMANCE SENSITIVITY: BROAD-BRUSH STATISTICS

The behaviour of the occupants with respect to ventilation and heating controls has undoubtedly affected energy consumption as described in the examples as in the Section 1.5. Their influence already partly explored in the Section 4.5, is now further illuminated by correlation with certain physical and social variables. Unsurprisingly, the highest quartile of the CEC solar houses consumed 3.79 times more net space heating energy than the lowest quartile, as shown in Table 5.2. The significant difference between the highest and lowest quartile mainly reflects ventilation control and achieved warmth, and partially heating fuel/regime employed. The highest quartile of 20 gas-heated solar houses was 4.23 times higher in net space heating load than the lowest quartile; whereas the 14 electric-heated houses was only 2.74 times. On one hand, this indicates that the larger sample of gas-heated houses have more examples of both high and low extremes in term of fuel consumption. The 14 electric-heated houses with a smaller variation of 2.74 times reflects perhaps a combination of factors including a higher degree of monitoring accuracy, the use of split-meters, and the slow responsiveness of storage heating. Research methodology in Chapter 3 has already described that various assumptions were made in gas-heated houses, which renders their results somewhat less accurate than those for electric-heated houses.

Descriptions	Ratio Between the Highest and Lowest Quartile (Times)
All 34 solar houses at Easthall	3.79
17 solar houses at Wardie Rd.	3.51
17 solar houses at Glen. Pl.	4.42
14 Electric-heated solar houses	2.74
20 Gas-heated solar houses	4.23

Table 5.2 Ratio Between the Highest and Lowest Quartile of the Net Space Heating Load.

The ratio between the highest and lowest quartile of the net Qh_m as above confirms that occupants were not consuming energy in accordance with design calculations. As shown in Section 4.2.2, occupants were heating their houses at a higher heated zone temperature than anticipated. Accordingly, a corresponding increase in the net space heating load is to be expected. However, Section 4.2.3 and Figure 4.13 confirmed that relatively high house temperatures can be achieved for a relatively low input of heating fuel. Indeed, some high and medium energy users were not getting value for money with respect to enhanced house temperatures in comparison with other users which had a similar level of fuel input. After adjusting for measured temperatures, the mean net Qh_m is +23.5% above Qh_SODEM-adj as shown in Figure 5.4 (overleaf). The results was summarised in three main categories; namely, low users (less than 25 kWh/m^3), medium users (25 - 45 kWh/m^3) and high users (above 45 kWh/m^3) as in Table 5.3. The mean net Qh_m was 37.75 kWh/m^3.

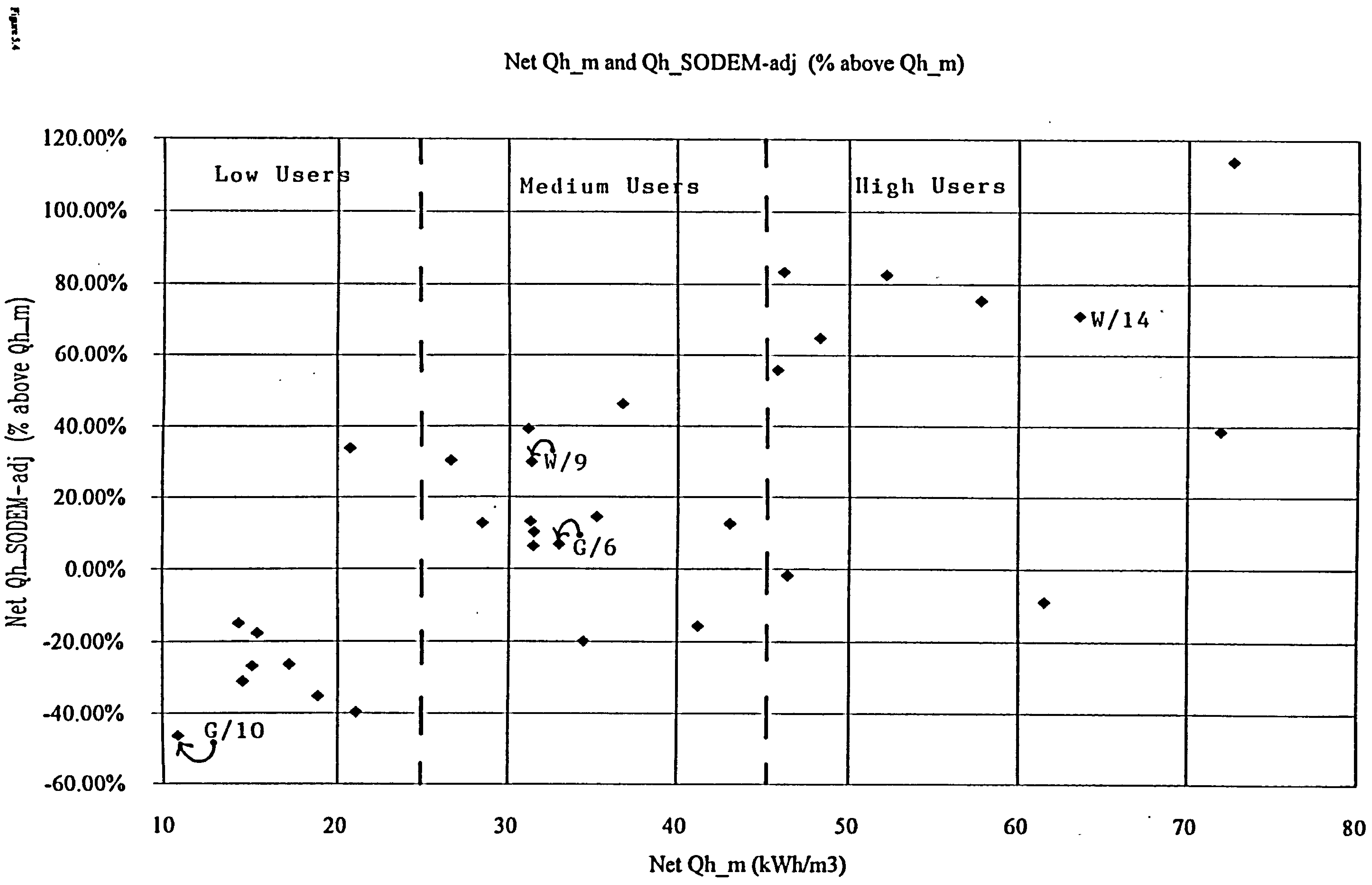

Figure 5.4 Correlation Between Net Qh_m and Qh_SODEM-adj (% above Qh_m).

Category	Qh_m (kWh/m^3)	Mean ± % Above Qh_SODEM-adj
Low Users (9)	16.5	-26.2%
Medium Users (13)	33.5	+10.3%
High Users (12)	58.4	+57.9%
All Users (34)	37.75	+23.5%

Table 5.3 Mean Average Net Qh_m for High, Medium and Low Users all in kWh/m^3 (Number of households in brackets in column 1).

5.3 BENCHMARK AND SUBSET COMPARISON

The research methodology described in Chapter 3 outlined the approach in assessing the occupants' interventions affecting energy saving. The two categories of variable namely, the physical and occupant-related variables, and its subsets are assessed by benchmark and subset comparison using the three sets of key indicators- fuel:warmth ratio, volumetric space heating load and cost:warmth ratio. The benchmark value is the mean periodic value (September 1992 - May 1993) for the whole sample of 34 solar houses (two households did not co-operate with the monitoring programme). The main benchmark values are summarised as follows:

Fuel:warmth Ratio	2.90	(kWh/m^3K) - space heating load per unit heated volume & achieved warmth.
Cost:warmth Ratio	11.68	(£/K) - cost of space heating per unit achieved warmth.
Volumetric Net Qh_m	37.75	(kWh/m^3) - space heating load per unit heated volume only.
Net Qh_SODEM-adj	30.56	kWh/m^3 - ditto, but uniform yardstick ventilation at 1.5 ac/h.
Heated Zone (Z1 + Z2)	19.86	°C - air temperature.
Heated Zone (Z1)	22.21	°C - air temperature.
Heated Zone (Z2)	18.96	°C - air temperature.
Veranda	15.06	°C - air temperature.
Conservatory	13.08	°C - air temperature.

SODEM Predictive 'Effective' Air Change

Autumn 1.18 ac/h - values deduced from measurement, eqn 1.
Winter 1.02
Spring 1.2

For convenience, the two categories of variable and their subsets (as in Table 3.3) are again listed as follows:

Physical Variables
a. **Heating fuel**: a.1 gas; a.2 electric.
b. **Orientation**: b.1 Wardie Road; b.2 Glenburnie Place.
c. **House location**: c.1 gable ground; c.2 gable first; c.3 gable second; c.4 mid-terrace ground; c.5 mid-terrace first; c.6 mid-terrace second.
Occupant-related Variables
d. **Heating regime**: d.1 all-day/whole house; d.2 all-day/Zone 1; d.3 2xday/whole house; d.4 2xday/Zone 1.
e. **Household age profile**: e.1 Infant; e.2 Adult; e.3 OAP.
f. **Smoking habits**: f.1 smoker; f.2 non-smoker.
g. **Pet**: g.1 with pet; g.2 no pet.

5.3.1 SINGLE PHYSICAL VARIABLE - HEATING FUELS

The two subsets of the heating fuel - electric (a.1) and gas (a.2) - appear to be potentially influential physical variables. Although the mean temperature in the electric-heated houses is slightly higher than the gas-heated houses, the 20 gas-heated houses register a higher value than the 14 electric-heated houses in two out of three key indicators - fuel:warmth ratio and volumetric space heating load - as shown in Table 5.4. The cost:warmth ratio is however almost one-third lower due to its substantially lower gas tariff per useful kWh. Thus, two sets of key indicators confirm that although electricity as heating fuel is 'better value' in energy terms than gas, it is the more expensive of the two fuels. Comparisons with other data between the two subsets on heated zone temperatures, sunspace temperatures and 'effective' air change were described in Chapter 4 as part of the overall energy performance of the project. The slightly lower temperatures in both heated zones as in Table 5.5 below confirms gas as a heating fuel is more controllable than electric throughout the autumn, winter and spring, and Table 5.6 illustrates the sunspace temperatures and effective rate of air change. .

	Net Qh_m (kWh/m^3)	Fuel:warmth Ratio (kWh/m^3K)	Cost:warmth Ratio (£/K)
Gas-heated Houses (20)	40.52 (+7.3%)	3.15 (+8.6%)	10.34 (-11.5%)
Electric-heated Houses (14)	33.8 (+10.5%)	2.55 (-12.1%)	13.59 (+16.4%)
Benchmark Value (34)	**37.75**	**2.9**	**11.68**

Table 5.4 Comparison of the Three Sets of Key Indicator - Heating Fuel.

All in °C	Z1 + Z2 °C	Z1 °C	Z2 °C
Subset Value - Gas-heated (20)	19.62	21.61	18.86
Subset Value - Electric-heated (14)	20.21	23.07	19.11
Benchmark Value (34)	**19.86**	**22.21**	**18.92**

Z1 and Z2 in °C	Autumn	Winter	Spring
Subset Value - Gas-heated (20)	19.55	19.42	19.55
Subset Value - Electric-heated (14)	19.68	20.32	19.68
Benchmark Value (34)	**19.6**	**19.79**	**20.2**

Table 5.5 Subsets and Benchmark Comparison of Gas and Electricity as Heating Fuel.

All in °C [Max./Mean/Min.]	Veranda	Conservatory	**n^c Mean** [Aut./Winter/Spr.]
Subset Value - Gas-heated (20)	[19.79/ **15.16**/ 11.9]	[16.04/ **12.88**/ 8.81]	**1.26** [1.3/ 1.11/ 1.36]
Subset Value - Electric-heated (14)	[19.2/ **14.91**/ 13]	[15.94/ **13.36**/ 10.06]	**0.96** [1.01/ 0.9/ 0.98]
Benchmark Value (34)	[19.79/ **15.06**/ 11.9]	[17.18/ **13.08**/ 8.81]	**1.14** [1.18/ 1.02/ 1.2]

Table 5.6 Sunspace Temperatures.

The seasonal subset values of n^c for gas-heated houses are all higher than both benchmark values and subset values of electric-heated houses. This is possibly as a result of the combination of statutory ventilation requirements, as well as the family structure, habits and aspirations of occupants.

5.3.2 TWO VARIABLES CORRELATION - HEATING FUEL AND ORIENTATION

The 18 solar houses at Wardie Road have of course produced a different pattern of solar gains and sunspace temperatures when compared with the same number of houses at Glenburnie Place. This affects the usability and usefulness of sunspaces located at both orientations and ultimately the opening up of sunspaces. Hence, the second physical variable; namely orientation - Wardie Road (b.1) and Glenburnie Place (b.2) - is added to the first search criterion. Table 5.7 illustrates the subset values of gas-heated houses at both Wardie Road and Glenburnie Place. The findings confirm that the 11 gas-heated houses at Wardie Road are very close to the benchmark value with respect to the first two indicators and lower in the third; whereas the first two values in the Glenburnie Place subset are significantly higher.

	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
Subset - Gas/Wardie Rd. (11)	37.73 (0%)	2.96 (+2.1%)	9.75 (-16.5%)
Subset - Gas/Glen. Pl. (9)	43.93 (+16.4%)	3.39 (+16.9%)	11.07 (-5.2%)
Subset - All-Gas houses (20)	40.25 (+6.6%)	3.15 (+8.6%)	10.34 (-11.5%)
Subset - Electric/Wardie Rd. (6)	35.65 (-5.6%)	2.51 (-13.4%)	13.18 (+12.8%)
Subset - Electric/Glen. Pl. (8)	32.42 (-14.1%)	2.58 (-11%)	13.9 (+19%)
Subset - All-Electric houses (14)	33.8 (-10.5%)	2.55 (-12.1%)	13.59 (+16.4%)
Benchmark Value (34)	**37.75**	**2.9**	**11.68**

Table 5.7 Fuel/orientation - Three key Indicators.

In the case of electric-heated houses, although the volumetric space heating load in the subset of electric/Wardie Road is almost 10% higher than the subset of electric/Glenburnie Place, the fuel:warmth ratio is actually lower in the former case than the latter case due to the influence of the higher achieved temperatures (Table 5.8). The higher veranda temperatures in Wardie Road for both gas and electric subsets favour the living room and main bedroom. Whereas the cooler conservatory temperatures in Wardie Road only impact directly in the kitchen and bathroom. The lower n^e values in Wardie Road relative to Glenburnie Place (Table 5.9) also indicate that the more favourable orientation for the veranda is reflected in a higher ventilation-preheat contribution. This all suggests that orientation may influence energy demanded for space heating in general and more severely in gas-heated than electric-heated houses. However, the extent of influence between gas/electric and the two orientations is difficult to assess before inclusion of occupant-related factors.

All in °C	Z1 + Z2°C	Z1°C	Z2°C	Veranda	Conservatory
Subset - Gas/Wardie Rd. (11)	19.69	21.92	18.84	15.59	12.19
Subset - Gas/Glen. Pl. (9)	19.54	21.24	18.89	14.63	13.73
Subset - All-Gas (20)	19.62	21.61	18.86	15.16	12.88
Subset - Electric/Wardie Rd. (6)	21.11	23.6	20.16	15.56	12.81
Subset - Electric/Glen. Pl. (8)	19.53	22.67	18.33	14.42	13.77
Subset - All-Electric (14)	20.21	23.07	19.11	14.91	13.36
Benchmark Value (34)	**19.86**	**22.21**	**18.96**	**15.06**	**13.08**

Table 5.8 Heated Zones And Sunspaces Temperatures (September 1992 - May 1993).

Effective Air Change Per Hour	Mean	Autumn	Winter	Spring
Subset - Gas/Wardie Road (11)	1.13	1.14	0.98	1.27
Subset - Gas/Glenburnie Place (9)	1.41	1.49	1.27	1.47
Subset - All-Gas Houses (20)	1.26	1.3	1.11	1.36
Subset - Electric/Wardie Road (6)	0.86	0.87	0.76	0.95
Subset - Electric/Glen. Pl. (8)	1.04	1.12	1.01	1.00
Subset - All-Electric Houses (14)	0.96	1.01	0.9	0.98
Benchmark Values (34)	**1.14**	**1.18**	**1.02**	**1.2**

Table 5.9 Effective Air Change Per Hour.

5.3.3 TWO VARIABLES CORRELATION - HEATING FUEL AND HOUSE LOCATION

House location (c.1 - c.6) inevitably plays a part in affecting space heating load. For instance, the transmission loss to the bounding surfaces is calculated as 78.45 W/K for a first floor mid-terrace house and 108.9 W/K for a ground floor gable end house. Setting aside other physical and all occupancy-related factors, the three indicators do suggest a fairly consistent influence (Table 5.10). For example, the ground floor mid-terrace location is higher than benchmark, but the ground floor gable-end is higher still in all but the first indicator, which ignores the outside-inside temperature difference. Also 1st and 2nd floor gable-end locations are consistently higher than their intermediate counterparts; while 2nd floor gable locations are also consistently higher than benchmark.

	Fuel	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
0/M (8)	5g/ 3e	51.83 (+37.3)	3.86 (+33.1%)	15.19 (+30.1%)
1/M (8)	4g/ 4e	26.56 (-29.6%)	2.1 (-27.6%)	8.48 (-27.4%)
2/M (7)	6g/ 1e	29.09 (-22.9%)	2.32 (-20%)	8.07 (-30.9%)
0/G (3)	*1g/ 2e*	*47.07 (+24.7%)*	*3.99 (+37.6%)*	*18.75 (+60.5%)*
1/G (4)	*1g/ 3e*	*28.36 (-24.9%)*	*2.16 (-25.5%)*	*9.93 (-15%)*
2/G (4)	*1g/ 3e*	*49.53 (+31.2%)*	*3.54 (+22.1%)*	*13.85 (+18.6%)*
Benchmark (34)	**20g/ 14e**	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.10 House Locations.

(The first number denotes floor level - 0, ground/ 1, first/ 2, second - and the second number denotes house location - M, mid-terrace/ G, gable-end; 'g' for gas-heated and 'e' for electric-heated)

Since heating fuel - particularly gas - has already been established as one of the variables which may affect space heating consumption, Table 5.11 attempts to correlate heating fuel and house location and their impacts on heating demand in all mid-terraced houses on all three floors, constituting a reasonable sample. The other three gable-end subsets are only used as general reference.

	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
0/M - gas (5)	55.51 (+47%)	4.35 (+50%)	14.26 (+22.1%)
0/M - electric (3)	45.71 (+21.1%)	3.04 (+4.8)	16.73 (+%)
1/M - gas (4)	30 (%)	2.42 (-16.6%)	8.06 (-31%)
1/M - electric (4)	23.12 (-%)	1.78 (-38.6%)	8.9 (-23.8%)
2/M - gas (6)	28.08 (-%)	2.27 (-21.7%)	7.47 (-36%)
2/M - electric (1)	*35.14 (-%)*	*2.66 (-8.1%)*	*11.69 (0%)*
0/G - gas (1)	*63.56 (+68.4%)*	*5.24 (+80.7%)*	*16.95 (+45.1%)*
0/G - electric (2)	*38.82 (+2.8%)*	*3.36 (+15.9%)*	*19.65 (+68.2%)*
1/G - gas (1)	*28.44 (-24.7%)*	*2.1 (-27.6%)*	*6.78 (-42%)*
1/G - electric (3)	28.34 (-25%)	2.18 (-24.8%)	10.97 (-6.1%)
2/G - gas (1)	*50.78 (+34.5%)*	*3.55 (+22.4%)*	*11.6 (-0.7%)*
2/G - electric (3)	45.78 (+21.3%)	3.53 (+21.7%)	20.58 (+76.2%)
Subset - all-gas (20)	40.52 (+7.3%)	3.15 (+8.6%)	10.34 (-11.5%)
Subset - all-electric (14)	33.8 (-10.5%)	2.55 (-12.1%)	13.59 (+16.4%)
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.11 House Locations And Heating Fuels.

(The first number denotes floor level - 0, ground/ 1, first/ 2, second - and the second number denotes house location - M, mid-terrace/ G, gable-end.)

Again there is a consistency. Both gas and electric ground floor houses are above benchmark as well as above the respective 'all-gas' and 'all-electric' values for all three indicators. Also the 1st and 2nd floor gable-end electric houses, with a sample of 3 in each case, are consistently higher than the corresponding group in an intermediate location. The 'qido' data confirms four out of five households within the 0/M - gas subset are indeed in the category of high space heating users and have a higher mean effective rate of air change of 1.62 cf. all-gas subset's 1.26. By coincidence all four households have one or more smoker(s) living in the house - with two OAP households, one small adult and one with infant. Within the whole subset, all but one households heat their houses all day and only one household heats the living room only.

This illustrates the importance of 'qido' data. Given that the gas central heating system is more responsive to the occupants' subjective needs for heating, the importance of occupant-related factors is perhaps underestimated. The electric-heated houses may be expected to be less erratic. This subset comparison does then suggest that house locations influence energy demanded for space heating and that this is perhaps more transparent in electric-heated houses where there are fewer occupancy variables - see Section 5.3.5 - 5.3.7.

5.3.4 Two Variables Correlation - Heating Fuel And Heating Regime

The second category of variables starts to examine the human aspects affecting energy demanded for space heating. Four subsets are summarised as in Table 5.12. The social survey in Section 5.1 above portrays a group of occupants who are more likely to be small family households with head of household aged 60 or over years and 'economically inactive'. It follows that many occupants are likely to be home bound, and in fact only 5 out of 36 households heated their houses twice-daily, while over 90% heated their house all day - say from 07.00 - 23.00 hour.

Amongst the five households with twice-daily (2xday) heating regime, four are gas-heated and the remaining one electric-heated. The subset of electric/2xday which also heats the living room (zone 1) is used as reference only (*in italics*) due to its single sample. However, it is worth noting that the heated zone 1 and 2 are 20.16°C and 17.75°C respectively; the fuel:warmth ratio for the same electric house is almost 3 times lower than the benchmark value; and the cost:warmth ratio is almost 2½ times lower than the benchmark. This confirms that these highly insulated solar houses are capable of maintaining a relatively comfortable house temperature for a low heating input. This scenario is mirrored to a lesser extent for the subset of 5 gas/2xday houses (3 households heated the whole house and 1 heated the living room only). All three key indicators are significantly lower than the benchmark value with a mean heated zone temperature of 19.99°C for zone 1 and 18.16°C for zone 2. The relatively small sample again signals caution with respect to drawing any conclusions from this subset.

	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^3K)	Cost:warmth Ratio (£/K)
Subset - gas/2xday (5)	26.76 (-29.1%)	2.29 (-21%)	7.5 (-35.8%)
Subset - electric/2xday (1)	*10.88 (-71.2%)*	*0.96 (-66.9%)*	*4.91 (-58%)*
Benchmark Value (34)	**37.75**	**2.9**	**11.68**

Table 5.12 Twice-daily Heating - Three Key Indicators.

Predictably, since the twice-daily heating subsets are in such a minority, the subset values of 16 gas/all-day heating and 13 electric/all-day heating mirrors the results in the subset of heating fuels as in Section 5.3.1. The subset values of gas/all-day heating are higher in volumetric space heating load and fuel:warmth ratio, but lower in the cost:warmth ratio than the electric/all-day heating - see Table 5.13 and 5.14. Whilst acknowledging that the 16 'all-day' gas houses include more physical and occupancy variants compared with the 5 'twice-daily' subset, the results do seem to indicate that the responsive nature of gas rewards intermittent regimes in such a highly insulated shell.

	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
Subset - gas/all-day (16)	43.97 (+14.5%)	3.37 (+16.2%)	11.05 (-5.4%)
Subset - electric/all-day (13)	35.56 (-5.8%)	2.67 (-7.9%)	14.26 (+22%)
Benchmark Value (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.13 Heating Fuel And All-day Heating - Three Key Indicators

In °C and (aut./winter/spring)	Net Qh_m/ Qh_SODEM-adj/ ±%	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
Subset - gas/all-day (16)	6,556/ 4,409/ +48.7%	19.86/ 22.02/ 19.04	19.79/ **15.33**/ 11.9	17.18/ **12.77**/ 8.81	1.34 [1.36/ 1.23/ 1.44]
Subset - electric/all-day (13)	5,304/ 5,202/ +2%	20.34/ 23.29/ 19.21	19.2 / **14.95**/ 13	15.94/ **13.27**/ 10.06	1.01 [1.06/ 0.93/ 1.03]
Subset all-gas (20)	6,043/ 4,215/ +43.4%	19.62/ 21.61/ 18.86	19.79/ **15.16**/ 11.9	16.04/ **12.88**/ 8.81	1.26 [1.3/ 1.11/ 1.36]
Subset - all-electric (14)	5,041/ 5,047/ ±0%	20.21/ 23.07/ 19.11	19.2/ **14.91**/ 13	15.94/ **13.36**/ 10.06	0.96 [1.01/ 0.9/ 0.98]
Benchmark Value (34)	5,630/ 4,558/ +23.5%	19.86/ 22.21/ 18.96	19.79/ **15.06**/ 11.9	17.18/ **13.08**/ 8.81	1.14 [1.18/ 1.02/ 1.2]

Table 5.14 Heated Zone And Sunspace Temperatures, And Effective Air change.

There are more subtle gas-electric differences relative to regime, which are not brought out by the above comparison of indicators. For example, the influence of electric storage heating compared with intermittent use of a gas fire (W/4 cf. W/15) results in similar space heating loads, but the former having a higher temperature than the latter. In general heating regime is the hardest variable to pin down with any degree of accuracy over a lengthy monitoring period.

5.3.5 Two Variables Correlation - Heating Fuel And Age Group

Having identified the three physical variables, most likely to affect energy demanded for space heating, the first is prioritised relative to the second to fourth occupant-related variable. Orientation differences between Wardie Road and Glenburnie Place have already been discussed in broad terms in Chapter 4, and although respective verandas and conservatories do perform differently, if the sunspaces are treated jointly as a pair, the differences tend to cancel. The third physical variable is known to be relatively minor in terms of fabric loss differentials, but is brought into the analytical discourse as appropriate.

The first occupant-related variable, that of heating regime, is set to one side. Although the influence of electric storage heating compared with intermittent use of a gas fire (e.g. W/14 cf. W/15) may result in one household having higher temperatures than the other, the space heating loads may well be similar.

The analysis therefore moves directly to the second occupancy variable, the household age profile. One particular subset of the age group consistently records a higher than average space heating load as shown in Table 5.15 and Table 5.16.

	Fuel/Orientation	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
Subset - Infant (9)	7g/2e; 6W/3G	46.60 (+23.4%)	3.53 (+21.7%)	13.57 (+16.2%)
Subset - Adult (9)	5g/3e; 2W/6G	33.56 (-11.1%)	2.53 (-12.8%)	10.01 (-14.3%)
Subset - OAP (17)	8g/9e; 9W/8G	35.04 (-7.2%)	2.75 (-5.2%)	11.47 (-1.8%)
Benchmark (34)	20g/14e; 17W/17G	37.75 (±0%)	2.9 (±0%)	11.68 (±0%)

Table 5.15 Age Groups - Three Key Indicators.

(Legend: in col. 2 - fuel: g, gas-heated/ e, electric-heated; Orientation: W, Wardie Road/ G, Glenburnie Place.)

The subset of infant is defined as households with one or more infants under the age of 17. The three key indicators for the infant subset are higher than the benchmark values and all other subsets. The net Qh_m is higher than the benchmark value; this is partly due to a higher house temperature and partly to a higher ventilation rate. The higher ventilation rate is supported by a higher fuel:warmth ratio in kWh/m^{3}K. Given the predominance of 7 gas-heated houses compared to 2 electric-heated houses, the higher than expected cost:warmth ratio at £13.57/K is distorted by an extreme case - an electric-heated house at Glenburnie Place with the highest ratio of £23.97/K. By omitting this extreme example, the cost:warmth ratio reduces to £12.27/K which is still higher than the benchmark and other subset values.

Within the three subsets, the OAP is the closest to the benchmark values. It is worth noting that the OAP subset is comprised of almost even numbers of gas and electric houses and both orientations. Heating fuel is now introduced as a potentially influential physical variable affecting space heating consumption (i.e. kWh/m^3 and kWh/m^{3}K).

	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
Subset - Infant/gas (7)	46.66 (+23.6%)	3.58 (+23.4%)	11.63 (-0.4%)
_Subset - Infant/electric (2)_*	_46.39 (+22.9%)_	_3.35 (+15.5%)_	_20.35 (+74.2%)_
Subset - Adult/gas (5)	36.98 (-2%)	2.84 (-2.1%)	9.19 (-21.3%)
Subset - OAP/gas (8)	37.35 (-1.1%)	2.97 (+2.4%)	9.94 (-14.9%)
Subset - All-Gas (20)	40.52 (+7.3%)	3.15 (+8.6%)	10.34 (-11.5%)
Subset - All-Electric (14)	33.8 (-10.5%)	2.55 (-12.1%)	13.59 (+16.4%)
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.16 Age Group And Heating Fuels.

(Figure in brackets is the percentage comparison with the benchmark value.)

There is no doubt that households with infants have an energy penalty regardless of which heating fuel is deployed. The subset values of infant/electric of which there are only two samples (in italic and marked with *) have to be treated with caution - also due to rather extreme energy users in one household. The energy penalty is more apparent when comparing the infant/gas subset to all-gas houses where all thermal indicators apart from maximum conservatory temperature are higher in the former case than the latter as shown in Table 5.17.

In fact buffer space temperatures as indicators have to be treated with caution as they will tend to be boosted by high temperatures in heated zones and opening up to heated zones, but depressed by high rates of ventilation, particularly if these are induced by opening outer windows to buffer spaces.

	Net Qh_m/ (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
Infant/gas (7)	6,959 (+65.5%) 4,206	20.14/ 22.63/ 19.19	19.79/ 15.57/ 12.96	15.58/ 12.9/ 10.82	1.52 [1.39/ 1.38/ 1.8]
*Infant/electric (2)**	*6,918 (-2.5%) 7,094*	*20.67/ 23.66/ 19.53*	*14.26/ 13.63/ 13*	*13.27/ 12.86/ 12.44*	*1.15 [1.25/ 1.07/ 1.14]*
Adult/gas (5)	5,570 (+21.4%) 4,588	19.54/ 20.49/ 19.18	17.04/ 15.16/ 13.9	17.18/ 14.21/ 11.37	1.2 [1.35/ 1.03/ 1.22]
OAP/gas (8)	5,516 (+51.9%) 3,631	19.22/ 21.42/ 18.38	17.11/ 14.8/ 11.9	14.8/ 12.03/ 8.81	1.06 [1.19/ 0.93/ 1.06]
All-Gas (20)	6,043 (+43.4%) 4,215	19.62/ 21.61/ 18.86	19.79/ 15.16/ 11.9	16.04/ 12.88/ 8.81	1.26 [1.3/ 1.11/ 1.36]
*Adult/electric (3)**	*4,153 (-14.5%) 4,858*	*20.49/ 22.57/ 19.7*	*15.3/ 14.87/ 14.3*	*14.56/ 14.27/14*	*0.76 [0.76/ 0.72/ 0.8]*
OAP/electric (9)	4,920 (+5.7%) 4,654	20.01/ 23.11/ 18.82	19.2/ 15.2/ 13.45	15.94/ 13.17/ 10.06	0.99 [1.04/ 0.92/ 1.01]
All-Electric (14)	5,041 (-0.1%) 5,047	20.21/ 23.07/ 19.11	19.2/ 14.91/ 13	15.94/ 13.36/ 10.06	0.96 [1.01/ 0.9/ 0.98]
Benchmark (34)	5,630 (+23.5%) 4,558	19.86/ 22.21/ 18.96	19.79/ 15.06/ 11.9	17.18/ 13.08/ 8.81	1.14 [1.18/ 1.02/ 1.2]

Table 5.17 Age Group And Heating Fuels Plus Other Thermal Indicators.

Legend: percentage above predictions given in the brackets in the first column.

(* Use this subset result with cautions.)

◆ *Net Qh_m and Net Qh_SODEM-adj*

The mean net Qh_m of the subset infant and both heating fuels (6,950 kWh) was +43.4% higher than the corresponding yardstick value (4,848 kWh). Given the predominance of 7 gas compared with only 2 electric houses, and having established in the previous chapter that gas-heated houses have higher ventilation rates than their electric counterparts (albeit with reservations related to the dominant sample), the net Qh_m of the infant/gas subset was expected to be higher. In fact it was +65.5% higher. This confirms that these particular infant/gas households ventilate their houses more than others, namely adult and OAP of the same heating fuel. The other subset of infant/electric perhaps conveys a confusing result with -2.5% lower than yardstick, see Table 5.17. However, apart from the caution given with respect to the small sample, this does not mean that it represents good value. It has already been shown to perform badly in this respect (Table 5.16). It does indicate that the mean ventilation rate is of the order of 1.5 ac/hr, but also that heating the living room to a mean of almost 24°C entails a heavy cost:warmth handicap. The 'qido' data confirms that the lower than average value (+21.4% relative to the 1.5 ac/hr yardstick, but consistently less than the three benchmark indicators, Table 5.17) of the adult/gas subset was due to 3 out of 5 gas-heated houses having a twice-daily heating regime and one household heating his living room only.

◆ *Heated Zone Temperatures*

A higher whole house temperature was demanded for the subset of infant/gas at 20.14°C, which was higher than adult/gas 19.54°C, OAP/gas 19.22°C and all-gas 19.62°C. The same was also true in both heated zones. Households with young children usually heated their houses to a higher than average temperature and in all five rooms and the hallway. This particular subset heated zone 1 to a mean temperature of 22.63°C and zone 2 to 19.19°C - higher than any other age groups in gas-heated houses. It is also worth noting that the temperature difference between zone 1 and zone 2 (3.44°C) is higher in the infant/gas subset than adult/gas (1.31°C), OAP/gas (3.04°C) and all-gas (2.75°C). From observations, it is more likely that most of the internal doors were ajar during the day when children were playing around the house and the sunspaces, especially the veranda. Coupling with a higher house temperature and a higher ventilation regime, the energy penalty is estimated to be +15% for the subset infant/gas above the benchmark values. In contrast, both adult/gas and OAP/gas subsets is likely to be -8% and -9% below mean average.

◆ *Sunspace Temperatures*

The 'qido' data confirms that the glazed-in verandas are frequently used as a play area especially in autumn and spring. The mean temperature of the veranda (15.57°C) is slightly higher than all other age group/gas subsets (adult/gas, 15.16°C and OAP/gas, 14.8°C) and the all-gas houses (15.16°C). The same subset of infant/gas recorded the maximum veranda temperature of 19.79°C - significantly higher than the adult/gas subset of 17.04°C and OAP/gas subset of 17.11°C, although the difference in mean values is much more modest.

Section 4.2.4 described the diversified uses of the conservatory as a utility room and 2 out 7 of the gas/infant subset were located at the top floor. The more exposed configuration (projected sunspace instead of recessed as the veranda) and glazed roof of the top floor house means that it is not used for any purposes other than washing and drying clothes for most of the winter, late autumn and even early spring. The conservatory temperature profile perhaps partly reflects the composition of each household and different patterns of use. For example, the subset of OAP/gas has a relatively lower maximum, mean and minimum conservatory temperature than the other two age group subsets. This is in line with an expectation, also based on observations, that the OAP group is using the conservatory much less than the other two groups, since there is inherently much less washing and drying.

◆ *Effective Air Change*

Given a higher mean space heating load than predicted, a higher house and sunspace temperatures in the subset of infant/gas, the effective air change is also higher than the other two age groups. It is interesting to find the effective air change is almost identical in autumn and winter for the infant/gas subset - 1.39 cf. 1.38 ac/hr. The effective air change in spring is the highest among all the subsets irrespective of age, heating fuel, orientation and house location. There is a tendency for the infant/gas group to close up their sunspaces late in autumn, ventilate more during the winter months and open up earlier and longer in spring than all other age group living in gas-heated houses. 'Qido' data supports the contention that the higher degree of ventilation for this particular group is a result of children' activities and extra washing and drying. There is also a tendency for parents to leave their children's bedroom door ajar overnight, and work by Etheridge[4] has shown that in conjunction with window opening this will significantly increase ventilation rates compared with a situation where a window is ajar, but the door to this room closed. However, some factors other than those related to infants are also influential, such as smoking, which might also demand a higher than expected ventilation regime. The following section sets out to examine this particular age group in gas-heated houses and its connection with smoking habits.

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[4] ETHERIDGE D.W. NATURAL VENTILATION IN THE UK AND SOME CONSIDERATIONS FOR ENERGY EFFICIENT DESIGN. Proceedings of the 3rd Air Infiltration Centre Conference, London, September 1982 p.p. 38-43.

5.3.6 THREE VARIABLES CORRELATION - HEATING FUEL, AGE GROUP AND SMOKING HABITS

The previous correlation search established that households with infants in gas-heated houses are more likely to heat their houses to a higher temperature, have a higher sunspace temperature by more opening up and have a higher ventilation rate - both effective and real - than gas-heated houses occupied by other age groups. The occupant-related characteristics had a logic in terms of intervention with the system as described above. The air quality perceived by the occupants was also reportedly important in connection with their control of ventilation, and this was much affected by their smoking habits.

Out of the total population sample, only 8 out of 34 households are fully non-smoking. The other three-quarters are households with one or more smoker. The distribution of smokers is of some interest - out of all 26 households with smokers, there are 6 in each of the infant and adult groups, and 14 are in the OAP group. The distribution of heating fuel is more even with 12 gas and 14 electric.

Smokers

All three space heating consumption indicators of the 26 households with smokers are higher than the corresponding benchmark values, as well as the non-smoker subset as in Table 5.18. It is interesting to note that all eight households within the subset of non-smoker were gas-heated, and all but two had an all-day heating regime. The fact that the 8 gas-heated households with non-smokers are substantially lower in all three indicators than both benchmark and the smoker subset strongly suggests that it is the social habit of smoking and/or the incidence of young infants, not the fuel, that has resulted in a prevalence of high gas-heated users. In order to further elicit the influence of smoking, the two subsets of smoker in gas and electric-heated houses are examined in Table 5.19 below.

	Heating Fuel	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
Subset - smoker (26)	12g/ 14e	42.27 (+11.97%)	3.19 (+10%)	13.2 (+13%)
Subset - non-smoker (8)	8g/ 0e	23.06 (-38.9%)	1.97 (-32.1%)	6.74 (-42.3%)
Benchmark (34)	**20g/14e**	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.18 Key Indicators For Smokers And Non-smoker Subset.

	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
Subset - smoker/gas (12)	52.15 (+38.1%)	3.94 (+35.9%)	12.74 (+9.1%)
Subset - smoker/electric (14)*	33.8 (-10.%)	2.55 (-12.1%)	13.59 (+16.4%)
Subset - all-gas (20)	40.52 (+3.3%)	3.15 (+8.6%)	10.34 (-11.5%)
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.19 Heating Fuel And Smoking Habits.

(* - all-electric-heated houses had at least one smoker in the household.)

The results of these two subsets portrays a contrasting picture. The subset of gas/smoker is higher than electric/smoker in two out of three key indicators except cost:warmth where the former's low tariff is in its favour. It is a coincidence that the whole sample of electric-heated houses had at least one smoker in the household. In other words, no direct comparison is available between smokers and non-smokers in the electric-heated houses.

Despite this, there are tale-tell signs in Table 5.18 and Table 5.19 where the subset comparison indicates that a smoking habit is more likely to cause an energy penalty in gas-heated houses than electric-heated houses. Reasons for smokers needing to ventilate more in gas-heated houses to get rid of the stuffy air and carbon dioxide than in electric-heated houses are not apparent. However, gas-heated houses which are dominant with respect to infants and are already confirmed to have caused +23% higher heating load than the benchmark value, may now be added into the analysis.

Gas/Infant/smoker

Since there are only four households falling into this subset in Table 5.20 below, comparisons have to be taken with caution. Nevertheless the subset of infant/smoker/gas records over +60% higher in the first two key indicators and almost +30% higher than in the cost:warmth ratio than the benchmark values. The other subset of infant/smoker/electric also records higher than benchmark values, but not to such an extent as the gas-heated houses in the first two indicators. This suggests that the addition of infants within the subset of smoker/gas leads to an almost +18% rise in space heating load. The energy penalty for this subset is evident in the three main indicators, and other indicators including house temperatures and effective air change all support this hypothesis, as in Table 5.21.

	Net Qh_m kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
Infant/smoker/gas (4)	61.5 (+62.9%)	4.66 (+60.7%)	15.07 (+29%)
*Infant/smoker/electric (2)**	*46.39 (+22.9%)*	*3.35 (+15.5%)*	*20.35 (+74.2%)*
Subset - smoker/gas (12)	52.15 (+38.1%)	3.94 (+35.9%)	12.74 (+9.1%)
Subset - all-gas (20)	40.52 (+7.3%)	3.15 (+8.6%)	10.34 (-11.5%)
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.20 Infant, Smoker And Heating Fuel.

	Net Qh_m/ (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
Infant/smoker/gas (4)	9,172 (+93.5%) 4,740	20.5/ 22.44/ 19.75	19.79/ 16.01/ 12.96	15.58/ 13.74/ 12.72	1.9 [1.69/ 1.79/ 2.22]
*Infant/smoker/electric (2)**	*6,918 (-2.5%) 7,094*	*20.7/ 23.66/ 19.53*	*14.26/ 13.63/ 13*	*13.27/ 12.86/ 12.44*	*1.15 [1.25/ 1.07/1.14]*
All-Gas (20)	6,043 (+43.4%) 4,215	19.62/ 21.61/ 18.86	19.79/ 15.16/ 11.9	16.04/ 12.88/ 8.81	1.26 [1.3/ 1.11/ 1.36]
All-Electric (14)	5,041 (-0.1%) 5,047	20.21/ 23.07/ 19.11	19.2/ 14.91/ 13	15.94/ 13.36/ 10.06	0.96 [1.01/ 0.9/ 0.98]
Benchmark (34)	**5,630 (+23.5%) 4,558**	**19.86/ 22.21/ 18.96**	**19.79/ 15.06/ 11.9**	**17.18/ 13.08/ 8.81**	**1.14 [1.18/ 1.02/ 1.2]**

Table 5.21 Infant, Smoker And Heating Fuel - Other Indicators.

- ***Net Qh_m, House Temperatures, Sunspace Temperatures And Effective Rate Of Air Change***

The apparent high space heating load in the subset of infant/smoker/gas is almost double that of the SODEM yardstick, as well as over +60% above the benchmark net Qh_m (Table 5.20 above), and over +50% above the subset of all 20 gas-heated houses. The high energy demanded for space heating is partly reflected by a higher temperature in both heated zones and partly by a higher than average ventilation rate.

The mean and minimum sunspace temperatures of the subset of infant/smoker/gas are also all higher than the subset of all 20 gas-heated houses. Amongst the four gas-heated houses with infant and smoker, only one house is in a top floor gable-end location, one at first floor mid-terrace, one at ground floor mid-terrace and the remaining one was ground floor gable-end. The lowest conservatory temperature within the subset is at the top floor gable end location. Although by no means conclusive, this indicates that house locations may have an impact on fuel consumption. Of this small group, three are in ground floor and/or gable-end locations where natural infiltration may be expected to be high. However, there is also no doubt that this subset tends to open-up the sunspaces more frequently than other age groups with smokers in gas-heated houses.

High house temperatures do not necessarily signify high rates of air change, although this might be necessary to relieve perception of stuffiness induced by warmth. At any rate the combination does signify high energy consumption and cost. The mean effective air change at 1.9 ac/hr is +67% above the benchmark at 1.14 ac/hr and just over +50% above the all 20 gas-heated houses at 1.26 ac/hr, and each individual seasonal effective rate of air change (i.e. autumn, winter and spring) are all higher than both benchmark and subset values for all twenty gas-heated houses. Moreover, in winter the air change rate is slightly higher than in autumn.

Summary for gas/infant/smoker subset

Despite a small sample of four in the subset of infant/smoker/gas, there are fairly strong indications that the households within this subset ventilate more than other age groups living in either gas-heated or electric-heated houses.

5.3.7 TWO VARIABLES CORRELATION - HEATING FUEL AND PET OWNERSHIP

The 'qido' data confirmed that the sunspaces, and in particular the verandas, tend to be used as a dog kennel or pet corner during early autumn and late spring. All three indicators are found to be higher than the benchmark values in the subset of households with pets as in Table 5.22.

	Heating Fuel	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
Subset - pet (10)	4g/ 6e	45.85 (+21.5%)	3.45 (+19%)	15.47 (+32.4%)
Subset - no pet (24)	16g/ 8e	34.38 (-8.9%)	2.68 (-7.6%)	10.1 (-13.5%)
Benchmark (34)	**20g/14e**	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.22 Households With Pet. (Legend: 'g ' for gas-heated and 'e' for electric-heated.)

In contrast, the 'no-pet' subset is slightly below the benchmark values. After taking the heating fuels into the 'pet' subset as in Table 5.23, a slightly different picture is portrayed by the three indicators for the subset of pet/gas reflecting the characteristics of a gas-heated house with higher values in the first two and a lower value in the third. Again, given the relatively small sample, this comparison is a tentative exploration of impact on space heating requirement.

This accepted, since the pet/electric subset is over 40% of the all-electric subset, and since the latter is well below benchmark for the first two indicators, it must follow that the no-pet/electric subset is even further below benchmark values. This does then seem to support a correlation between pet ownership and increased fuel consumption. Although two households also have infants, as opposed to none of the eight non-pet/electric subset, the fact that all-electric households are 'smokers', but that the eight non-pet subset have a fuel:warmth ratio of 1.89 kWh/m^{3}K, 35% below benchmark strongly affirms 'pet' influence independent of smoking.

	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
Subset - pet/gas (4)	50.99 (+35.1%)	3.81 (+31.4%)	12.33 (+5.6%)
Subset - pet/electric (6)*	42.42 (+12.4%)	3.21 (+10.7%)	17.56 (+50.3%)
Subset - all-gas (20)	40.52 (+7.3%)	3.15 (+8.6%)	10.34 (-11.5%)
Subset - all-electric (14)	33.8 (-10.5%)	2.55 (-12.1%)	13.59 (+16.4%)
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 5.23 Household With Pet And Heating Fuel.

Again, extending the data in Table 5.24 is of particular interest to comparison of the no-pet/electric and pet/electric subsets. Although Z1 + Z2 temperatures are near identical, and mean veranda and conservatory temperatures are somewhat higher in the former case, the significantly lower n^e values is what gives this subset a strong advantage in term of its space heating load.

	Net Qh_m/ (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
Pet/gas (4)	7,605 (+72.1%) 4,420	20.51/ 21.86/ 20	17.77/ **16.17**/ 15.2	17.18/ **14.26**/ 11.67	1.49 [1.57/ 1.37/ 1.52]
Pet/electric (6)*	6,326 (+3.7%) 6,100	20.26/ 23.33/ 19.09	15.06/ **14.12**/ 13	15.94/ **12.85**/ 10.06	1.13 [1.18/ 1.08/ 1.13]
No-pet/electric (8)*	4,077 (-4.2%) 4,256	20.17/ 22.88/ 19.15	19.2/ **15.5**/ 13.45	14.63/ **13.75**/ 12.2	0.84 [0.88/ 0.76/ 0.88]
No-pet/gas (16)*	5,652 (+35.7%) 4,164	19.4/ 21.55/ 18.58	19.79/ **14.91**/ 11.9	16.04/ **12.54**/ 8.81	1.2 [1.23/ 1.05/ 1.31]
All-gas (20)	6,043 (+43.4%) 4,215	19.62/ 21.61/ 18.86	19.79/ **15.16**/ 11.9	16.04/ **12.88**/ 8.81	1.26 [1.3/ 1.11/ 1.36]
All-electric (14)	5,041 (-0.1%) 5,047	20.21/ 23.07/ 19.11	19.2/ **14.91**/ 13	15.94/ **13.36**/ 10.06	0.96 [1.01/ 0.9/ 0.98]
Benchmark (34)	5,630 (+23.5%) 4,558	19.86/ 22.21/ 18.96	19.79/ **15.06**/ 11.9	17.18/ **13.08**/ 8.81	1.14 [1.18/ 1.02/ 1.2]

Table 5.24 Household With Pet And Heating Fuel - Other Indicators.

Summary for heating fuel/pet ownership subset

Therefore, although meaningful relationships are masked in the case of the small gas/pet sample where all four are also smokers, the analysis of the pet versus no-pet subsets in the case of electric-heated houses tends to quite convincingly support the hypothesis that ownership of pets is akin to having young infants. Both lead to more open, airy regimes which carry a penalty in terms of consumed energy.

5.4 SUMMARY OF THE CHAPTER

The analysis in sections 5.3.1 - 5.3.7 yields significant connections between the energy performance and physical and occupant-related factors. Although precise correlations are qualified by the statistically small sample, Table 5.25 provides a useful summary of the energy savings attributable to the sunspaces (mainly ventilation preheat) relative to other variables, using the mean fuel:warmth ratio as a benchmark.

Amongst the physical variables, the correlation analysis between heating fuels and orientations does suggest orientation may influence space heating demand more severely in gas-heated than electric-heated houses. This results in a 5% higher energy saving for gas-heated houses at Wardie Road compared with their counterparts at Glenburnie Place. The correlation analysis between heating fuels and house locations confirms a consistent trend that houses at ground floor locations tend to have a higher space heating demand than first and second floor.

The effect of gable-end compared with mid-terrace locations is not so apparent due to the small sample in the former case.

	Standard Saving [1]	**Savings cf. REF+**	Fuel:warmth (kWh/m^{3}K)
Benchmark	±0%	**31.2%**	2.90
Fuels + Orientations			
Gas/Wardie Road	0%	**31%**	2.96
Gas/Glenburnie Place	-17%	**26%**	3.39
Electric/Wardie Road	+12%	**35%**	2.51
Electric/Glenburnie Place	+12%	**35%**	2.58
Fuels + Locations			
0/M-gas	-49%	**16%**	4.35
0/M-electric	-4%	**30%**	3.04
1/M-gas	+15%	**36%**	2.42
1/M-electric	+38%	**43%**	1.78
2/M-electric	+22%	**38%**	2.27
1/G-electric	+25%	**39%**	2.18
2/G-electric	-23%	**24%**	3.53
Age Group + Fuel			
Infant/Gas	-23%	**24%**	3.58
Adult/Gas	+3%	**32%**	2.84
OAP/Gas	+3%	**32%**	2.97
Infant/Electric	*-17%*	*26%*	*3.35*
Adult/Electric	*+31%*	*41%*	*2.00*
OAP/Electric	+12%	**35%**	2.55
Age Groups/Smoking/Fuels			
Infant/Smoker/Gas	-62%	**12%**	4.66
Infant/Smoker/Electric	*-17%*	*26%*	*3.35*
Pet/Fuel			
No Pet/Electric	+28%	**40%**	2.05
Pet/Electric	-10%	**28%**	3.21

Table 5.25 Energy Worth Of Physical And Occupant-related Variables Relative To Benchmark.
([1] The first column of data refers to percentage above/below the benchmark saving of 31.2%)

After the inclusion of occupant-related factors, the effect of the heating regime on both fuels is almost impossible to isolate especially over a long monitoring period. However, the correlation analysis between age groups and heating fuels yields a consistent trend that households with infant(s) are likely to ventilate more and result in a higher space heating demand - no matter which heating fuels are deployed. When the smoking habit is added into the preceding correlation analysis, the energy penalty is apparent especially in the case of gas-heated houses where the prospective saving is less than half of the electric-heated houses. The last correlation analysis between pet and no-pet ownership in electric-heated houses affirms that 'pet' influence on ventilation demand is akin to having a young infant.

A wide range of prospective energy savings between 12% and 43% relative to REF+, as summarised above, indicates that the combination of physical and occupant-related variables influences the level of ventilation demanded. Despite the statistically small sample of this work, apparent trends relative to the two categories of variable are established. In order to flesh out the correlation between household characteristics and the energy saving, four households in which the author is well acquainted over a monitoring period of two years are selected as detailed case studies.

CHAPTER 6 FOUR CASE STUDIES

The wide variations in energy used for space heating reveals a diversified use of heating and ventilation controls. Despite this, unheated glazed spaces can save at least 30% energy if the occupants use windows, thermostats and ventilators appropriately. This has been demonstrated in that almost one-third of households have a space heating consumption below the predicted 'yardstick' level as described in Chapter 4. Also, in spite of the mean net space heating load of 34 solar dwellings being approximately 25% higher than 'yardstick', with the highest 6.4 times more than the lowest, once a liberal autumn-spring airing regime has been accepted as a legitimate demand or aspiration, the technique of ventilation preheat via sunspaces still yields significant savings compared with a similar house ventilated to the same standard, but lacking the sunspaces. Chapter 5 shows that both physical and occupant-related variables affect energy used for space heating. For instance, heating fuel, house location and orientation all appear to be influential to a certain extent. Certain occupant groups such as households with infants/pets and smokers are seen to use more energy for space heating as a result of opening up the sunspaces and the heated zones for ventilation. In order to define in some detail the way different occupants interact with their heating and ventilation controls, four households within the high (W/14), medium (W/9 and G/6) and low (G/10) energy user categories are selected as case studies.

Three out of the four households agreed to keep a weekly diary commencing in November 1992. Inevitably there are gaps in the diary keeping and only one household completed the entire sixteen months recording period. Nevertheless, the diary, in conjunction with personal observation by the author, forms a valuable part of the 'qido' data regarding to the occupants' physical as well as psychological needs for ventilation and heating, especially in late autumn and early spring.

6.1 CASE STUDY 1 - W/14

6.1.1 HOUSEHOLD PROFILE

Location ground floor, gable-end, Wardie Road.

Heating system gas central heating system with radiators.

Occupants' profile Mr A, Mrs A and a 6 month old baby at the time of taking up tenancy; Mr A works part-time and Mrs A is a housewife; both are aged 30; Mr A is a smoker and Mrs A is a non-smoker; there are no health problems.

Author's observation: High fresh air quality: high level of ventilation, even in winter, late autumn and early spring.

W/5	W/6	W/11	W/12	W/17	W/18
W/3	W/4	W/9	W/10	W/15	W/16
W/1	W/2	W/7	W/8	W/13	W/14

6.1.2 THREE KEY INDICATORS

The household of Mr and Mrs A of W/14 is classified as a high space heating user with an energy load of 9,480 kWh or 63.56 kWh/m^3. All three key indicators are substantially higher than the benchmark, and the all-gas subset values. The research methodology in Section 3.2.2.A sets out the limitations in estimating the net space heating load of gas centrally heated houses. The delivered energy for space heating is calculated by deducting energy for water heating (estimates from the number of persons in the household) and cooking by gas. The residual delivered energy is then estimated pro-rata between space heating by gas fire and hot water radiators in accordance with the 'qido' data which includes author's observations. The net space heating load is obtained by applying respective efficiencies to gas fires (57%) and gas central heating (76%). The estimated delivered energy for water heating has been adjusted for 3 adults. Hot water consumption for households with infants is thought to be higher than an adult household due to increased washing and bathing. In reality, the delivered energy for water heating may have been under-estimated, hence over-estimating the net space heating load. With this in mind, the volumetric space heating is substantially higher than the benchmark (+68%) and the mean of all gas subset value (+57%) as in Table 6.1. The fuel:warmth ratio is also significantly higher than both sets of values confirming that a high level of ventilation rather than exceptionally high house temperature is the main cause. The high use of delivered energy is inevitably reflected in the cost:warmth ratio which is +45% above the benchmark and +64% the gas subset. The three key indicators identify the household of W/14 as one with a high space heating load and, accordingly, incurring high heating costs, the twin generators being relatively high temperatures coupled with an open window regime for several hours daily throughout the heating season.

	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
W/14	63.56 (+68.4%/ 56.9%)*	5.24 (+80.7%/ +66.3%)*	16.95 (+45.1%/ 63.9%)*
Subset - all gas (20)	40.52	3.15	10.34
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 6.1 Three key indicators of W/14. (* ±% above/below benchmark and subset in brackets)

6.1.3 OTHER INDICATORS - HEATING SEASON AND MONTHLY

The other indicators as in Table 6.2 confirms the presence of a high level of ventilation, with the mean veranda temperature (12.96°C) very close to the minimum range. The mean conservatory temperature of 12.88°C is identical to the all-gas subset. This comparison is however masked by the pre-dominance of gas-heated houses (10 out of the 20) being located on the top floor and incurring additional transmission losses through the twin polycarbonate roofing. Taking this factor into account, the mean conservatory temperature of W/14 is effectively somewhat lower than a typical gas-heated house relative to its ground floor location (subset mean 14.09°C). The 'qido' data - the weekly diary - confirms that Mrs A always opened up the outer sunspace windows in the veranda and conservatory in the morning 'to air the house'.

	Net Qh_m in kWh/ (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
W/14	9,480 (+71.2%) 5,537	19.3/ 21.64/ 18.36	12.96	12.88	2 [1.85/ 1.85/ 2.31]
All Gas (20)	6,043 (+43.4%) 4,215	19.62/ 21.61/ 18.86	19.79/ 15.16/ 11.9	16.04/ 12.88/ 8.81	1.26 [1.3/ 1.11/ 1.36]
Benchmark (34)	**5,630 (+23.5%) 4,558**	**19.86/ 22.21/ 18.96**	**19.79/ 15.06/ 11.9**	**17.18/ 13.08/ 8.81**	**1.14 [1.18/ 1.02/ 1.2]**

Table 6.2 Other Key Indicators Of W/14.

The pattern of window/door opening between September 1993 - January 1994 - as extracted from the weekly diary in Table 6.3 - shows a high ventilation demand especially in December and January relative to weather conditions. For example, the cold weather in January did not deter Mrs A from leaving both the living room and veranda outer windows ajar for 2¼ hours and 3¼ hours daily respectively, indeed, just ½ hour and ¼ hour less than the previous month. It is worth noting that there was less opening up of the bedroom 1 door to the veranda, averaging 1½ hour daily between September and January. In contrast, the living room door to the veranda was open for 4½ hours daily for the same period. Bedroom 1 was probably ventilated less as the baby was sleeping in the same room as the parents. Mrs A stated that she usually opened the bedroom 1 door to the veranda for only an hour early in the morning just 'to air the room' whilst she was feeding the baby in the living room. Mrs A usually switched on the gas fire in the living room half an hour in the morning before bathing the baby. After the bath, she spent at least thirty minutes drying, oiling and dressing the baby in the living room. This perhaps explains why the auxiliary gas fire was extensively used between October and January: for 6 - 7¼ hours daily, as in Table 6.4. Mrs A then opened the living room glazed door to 'air the room and get rid of the smell'. There is little doubt in the case of W/14, the presence of a baby has contributed significantly not only to the pattern of opening up the house, in both the living room and bedroom 1, and the veranda outer windows for ventilation, but also the extensive use of the gas fire. In common with most households, the slot ventilators above the bedroom 1 patio door and living room glazed door were opened and not adjusted throughout the year.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR2w
Sep-92	6¼	8¼	24	2½	4¼	5¼	3¼	3
Oct-92	5½	10	24	0	4½	4	3	2½
Nov-92	4¼	6½	24	1½	4¼	4	3	2¾
Dec-92	6½	7½	24	1½	3½	4½	2¾	2¾
Jan-93	9½	11½	24	2	6¼	3¼	2¼	2½
Mean	6½	8¾	24	1½	4½	4¼	2¾	2¾

Table 6.3 Summary Of Opening Windows And Glazed Door From Weekly Diary.

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^{2}w	Bedroom 2 window

Week	Sept.	Oct.	Nov.	Dec.	Jan.
1	-	6	6	10	8
2	-	5	7	6	6
3	3	6	8	7	7
4	3	7	8	6	n/a
Mean	1½	6	7¼	7¼	7

Table 6.4 Use Of Auxiliary Gas Heater In Living Room.

(Monthly mean daily in hours - rounded to the nearest ½ hour).

In the case of the conservatory, the new member of the family also affected the uses of the sunspace and ventilation demand. Washing and drying clothes were carried out on a daily basis as indicated in the diary. Mrs A has no tumble dryer and has to rely on natural ventilation for drying clothes. Use of the outside drying area is not popular due to a high incidence of vandalism in the area. Unfavourable drying conditions perhaps explain the prolonged opening up of the conservatory's outer windows in January for 9½ hours cf. 5½ hours in October. The diary for January indeed records that the outer conservatory windows were open in the early morning and were not closed until night-time. The outer windows were then locked overnight for security reason because of its ground floor location. Such prolonged opening up in the winter was an extreme use of the conservatory extension as a utility space and to some extent compromised its performance as a climatic buffering zone. Moreover, babies are fed at a relatively short and frequent intervals and this is reflected by the extended opening up of the kitchen door to conservatory for ventilation. In addition, the kitchen louvres are in fact never closed throughout the year. Even so, it is interesting to note that the mean conservatory temperature for W/14 is somewhat higher than the mean for gas-heated houses in Wardie Road (Table 6.5), accepted as noted above that the second floor north-west facing conservatories are more disadvantages in winter than W/14. The demand for fresh air for Mrs A also extends to the bedroom 2 with a relatively constant window opening time of 2 hours in the morning throughout the year. The somewhat regular and constant opening up pattern in the bedroom 2 does suggest that Mrs A opens the windows as a matter of routine irrespective of the weather and the actual needs for ventilation.

The extensive opening up of the house has significantly lowered the veranda temperature relative to the gas/Wardie subset, and has caused a space heating load which is 70% more than the mean for the gas/Wardie subset. The seasonal effective rate of air changes for autumn, winter and spring are substantially higher than both benchmark and the all gas subset, and the effective rate of 2.31 air change per hour in spring (cf. 1.85 in autumn and winter) suggests that spring weather prompted the additional opening up of the house to the outside. Also the uniform ventilation rate for autumn and winter corresponds to the high demand for fresh air regardless of the weather conditions recorded in the daily diary. The paradox is that although the openness of this regime carries a substantial penalty in terms of fuel consumed, nevertheless the glazed spaces still significantly soften the impact - i.e. had such a regime been operated in the REF+ model, the fuel bill would have been substantially higher. The analysis also confirms that the loss of performance is mainly attributable to the low veranda temperature coupled with high ventilation, rather than the highly ventilated conservatory, which is much more in accord with other users. Again this reinforces the solar worth of this component on the favourable south-east facade, if used appropriately.

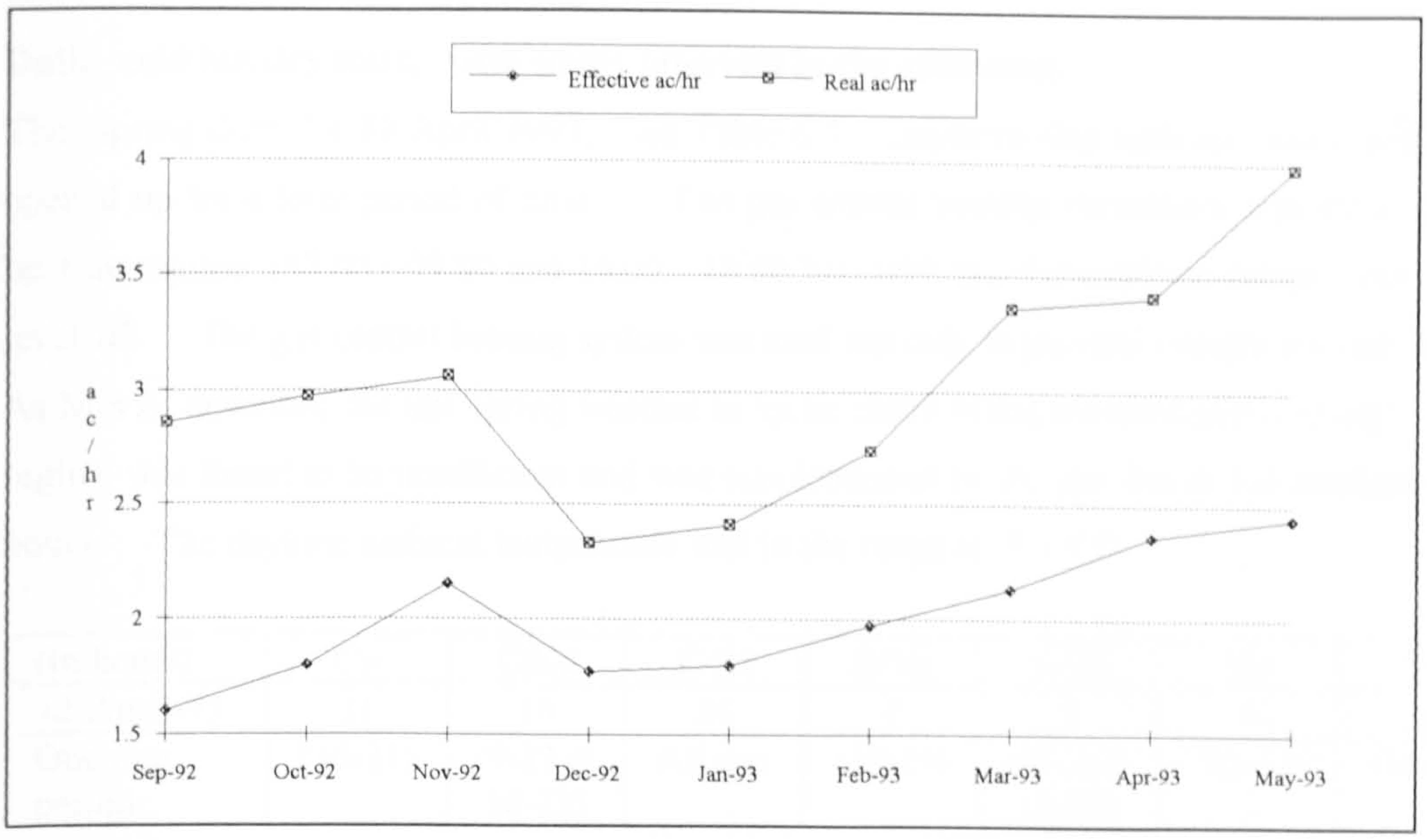
It would appear that need for thermal comfort in relation to the way an occupant interacts with heating and ventilation controls requires more research. In this instance, a combination of specific physical and psychological factors were seemingly significant: the extra moisture generated from bathing and feeding the baby, washing and drying its clothes and the demand for Mrs A to eliminate Mr A's cigarette smoke together with her more subjective needs for fresh air. Mrs A took advantage of the comparatively rapid response gas central heating system to answer her heating and ventilation needs at the expense of optimum energy saving and, accordingly, incurred higher fuel bills.

	Z1	Z2	Veranda	Conservatory	Ambient	Qh_m	Qh_SODEM-adj
Sep-92	21.24 (21.78)	19.18 (19.81)	16.61 (18.64)	15.7 (15.99)	11.56	382 (298)	138 (69)
Oct-92	20.98 (21.46)	17.75 (18.54)	13.47 (15.98)	11.47 (11.46)	6.4	924 (558)	505 (359)
Nov-92	21.14 (21.9)	17.97 (18.28)	11.62 (14.37)	11.88 (10.24)	5.71	1249 (739)	750 (581)
Dec-92	21.52 (22.08)	17.57 (18.3)	9.7 (13.3)	10.49 (9.45)	3.65	1389 (850)	1045 (822)
Jan-93	21.66 (22.14)	17.31 (18.16)	10.27 (13.87)	11.15 (9.56)	4.79	1262 (883)	950 (769)
Feb-93	22 (21.94)	18.5 (18.6)	12.74 (15.31)	12.17 (11)	6.25	1135 (619)	734 (530)
Mar-93	22 (21.75)	18.5 (18.4)	13.11 (15.39)	13.12 (11.04)	6.15	1262 (712)	679 (475)
Apr-93	21.91 (21.89)	18.95 (19.27)	13.48 (15.92)	14.06 (14.21)	8.41	1038 (561)	485 (300)
May-93	22.32 (22.31)	19.53 (20.22)	15.82 (17.77)	16.1 (16.6)	10.34	839 (408)	251 (100)
mean/sum	21.64 (21.92)	18.36 (18.84)	12.96 (15.62)	12.88 (12.17)	7.03	9480 (5628)	5537 (4005)

Table 6.5 Monthly Data Of W/14. (Gas/Wardie Subset values in brackets).

Further comparing the case study with the subset of 11 gas-heated houses at Wardie Road allows a like-for-like comparison, taking into account of the effects of the same heating fuel and orientation in monthly time-steps. The mean monthly zone 1 temperatures show a small variation of just over 1.34K between the highest in May 1993 at 22.32°C and the lowest in October 1992 at 20.98°C. This indicates that the gas central heating system, the use of radiators and gas fires, responded well to the needs of the occupants in the main living space, and this will be further confirmed by the daily temperature profiles examined in a later section. In zone 2 the impact of solar energy in autumn and spring is evident, taking the temperature somewhat higher than required or achieved by Mr and Mrs A in winter. The same effect is seen in the gas/Wardie subset and overall differences in Zone 1 and 2 temperatures between the single house and the group of eleven are slight.

The monthly effective and real rate of air change of W/14 as in Table 6.6 is significantly higher than the mean value of the solar houses. Using the methodology set out in Section 3.3.3, the mean n^r value of 2.0 for the heating season (which is calculated pro-rata for each perimeter condition) is 65% higher than the benchmark (n^r - 1.82 ac/hr for the heating season). This may be broken down into autumn, winter and spring, with W/14 at 2.96, 2.49 and 3.58 again very much higher than the benchmark 2.1, 1.35 and 2.01, and the monthly values in Table 6.6 show that although there is a marked increase in spring, the values remain high throughout the winter period.



Month	Z1 / Z2	$q^s + q^i$ (W)	n^e / n^r	q^h (W)^1	Q^h (kWh)^1
Sep-92	Z1	203	1.6* / 2.86*	530*	382*
	Z2	566			
Oct-92	Z1	215	1.8 / 2.97	1,242	924
	Z2	606			
Nov-92	Z1	184	2.15 / 3.06	1,735	1,249
	Z2	521			
Dec-92	Z1	173	1.77 / 2.33	1,867	1,389
	Z2	469			
Jan-93	Z1	162	1.8 / 2.41	1,696	1,262
	Z2	456			
Feb-93	Z1	178	1.97 / 2.74	1,689	1,135
	Z2	473			
Mar-93	Z1	220	2.13 / 3.36	1,696	1,262
	Z2	542			
Apr-93	Z1	210	2.36 / 3.41	1,442	1,038
	Z2	577			
May-93	Z1	234	2.44 / 3.98	1,128	839
	Z2	630			
		Mean	**2 / 3.01**	**13,025**	**9,480**
				Total (W)	**Total (kWh)**

Table 6.6 Effective And Real Rate Of Air Change With Other Data.
(^{1} - q^h and Q^h as measured and * - estimated q^h, Q^h, n^e and n^r - full monitoring commenced Oct. '92)

The examination of two daily profiles, one for spring (12 April 1993) and one for winter (18 January 1994), in the following section confirms the extensive opening up of the house, and the veranda in particular, and its impact.

6.1.4 DAILY PROFILE - 12 APRIL 1993

Dull, cold but dry start, with sunny intervals in the afternoon.

The spring diary for 12 April 1993, see Table 6.7, confirms that both the house and the two sunspaces were opened up for a long period of time. The gas central heating thermostat was set at 23°C for a twice a day heating regime (07.00 - 09.00 and 16.00 - 18.00 hr) with the thermostatic radiator valve in all the rooms set at level III. The gas central heating system was used not only to provide warmth but also hot water for the family. As Mrs A described the late spring weather as 'quite chilly in the morning and evening', the twice a day heating regime was found to be insufficient and was supplemented by the gas fire at low/medium setting for a total of 6 hours. The daytime ambient temperature was in the range of 5 - 8°C.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR2w
12-April-93	11	10	24	4	8	4	2	n/o*
Opening period	(10-21)	(9-13 & 16-22)	All day	(10-14)	(9-13 & 16-20)	(10-14)	(10-12)	n/o*

Table 6.7 Daily Summary Of Opening Windows/Doors From Diary (Hours open in brackets; * not open).

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^2w	Bedroom 2 window

The diary confirms that the outer windows of the veranda were open for at least 4 hours (10.00 - 14.00 hour), those of the conservatory for 11 hours (10.00 - 21.00 hour) and those of the living room for 2 hours (10.00 - 12.00 hour) on the day. Mrs A explains that she opened the outer veranda windows "to air the house" and the outer conservatory windows to dry washing. For the conservatory, the diary confirms that the occupant did 7 loads of washing within the week, which is not unusual for a family with a baby. As the family has no tumble dryer, the outer windows were opened up extensively for 11 hours.

It is worth noting that although the periods from 9-13.00 and 16-22.00, when the kitchen/conservatory door was open, manifest themselves clearly in Figure 6.1 (overleaf), the corresponding declared interventions with respect to the patio door and outer veranda windows from 10-14.00 are not so transparent. The veranda profile holds a very steady +5K above ambient without peaks. Therefore, although the opening of the outer veranda windows may have inhibited its 'lift', it is still a tangible benefit. On the other hand the profile of bedroom 1 has two peaks. In the earlier case, this might have indicated that the room had received solar energy directly or indirectly via the veranda, but in fact it corresponds to the heating timetable, the thermostatic valves in all rooms set at III, and rather low insolation at that time. The second peak again corresponds to Mrs A's heating timetable, and its less pronounced characteristic may be due to opening of internal doors. The question remaining is that of whether the first larger rise in temperature within bedroom 1 was needed or appreciated.

Figure 6.1 - 12 & 13 April 1993 - W/14

For the living room, as described the use of the gas fire in the morning and late afternoon/evening is clearly shown in the temperature profile which peaks at 27°C at 11.00 hour and again at 17.00 hour. The two periods in which the gas fire in the living room was used (shown by a rapid upsurge of room temperature) overlap with those when the occupants left the glazed door (8 hours in total) and the outer windows (2 hours) ajar. Exactly why the occupant found it necessary to use the gas fire, open the outer windows and leave the glazed door ajar at the same time seems puzzling; but is probably explained by the desire for direct radiant heat for the baby simultaneously with a fresh atmosphere.

There is then an energy conflict between the occupants' physical need for warmth incurring the extensive use of the gas fire and their psychological/physical need to ventilate both the house and the sunspaces. As the house is occupied by someone in part-time employment, a house wife and a baby, it is in use throughout the day, except perhaps for a brief shopping trip to a local store. These findings echo those in Section 5.3.6 that a family with infant and smoker living in gas-heated house is likely to ventilate their houses some two-thirds more than an average solar house (n^r 1.9 ac/hr cf. 1.14).

6.1.5 DAILY PROFILE - 18 JANUARY 1994

Cold and dull day with light drizzle in the late afternoon

Despite the wintry conditions, a similar high level of opening up of the house and the sunspaces is also confirmed in the diary as in Table 6.8. The twice-a-day heating regime was extended for an additional 2 hours in the morning (08.00 - 10.00 hour and 16.00 - 18.00 hour) with the thermostat still set at 23°C. The thermostatic radiator valves were set to level III for the living room, bedroom 1 and bedroom 2 and level II for the kitchen, bathroom and hallway. The gas fire was also used for a total of 7 hours at medium setting because the occupant considered it to be "cold outside". Mrs A stated that "once the house had been heated in the morning and in the evening, the house was very comfortable". This statement effectively concludes that Mrs A was not ventilating the house because of overheating. As the fuel bill was never unaffordably high she was not given cause to reconsider her ventilation habits.

Although the ambient temperature was in the range of 4 - 7°C during the daytime, the outer windows of the veranda and conservatory were open for 3 hours and 11 hours respectively; the outer window of the living room for 2 hours and bedroom 2 for 3 hours. The house was also opened up on to the 2 sunspaces for 2 hours for the patio door, 6 hours for the glazed door in the living room and 12 hours for the conservatory's glazed door. None of the door head ventilators and the louvres in the kitchen were closed at any time.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR^{2}w
18 Jan.-94	11	12	24	2	6	3	2	3
Opening period	(8-19)	(9-21)	All day	(9-11)	(9-15)	(9-12)	(9-11)	(10-13)

Table 6.8 Daily Summary Of Opening Windows/Doors From Diary (Hours of opening in brackets).

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^{2}w	Bedroom 2 window

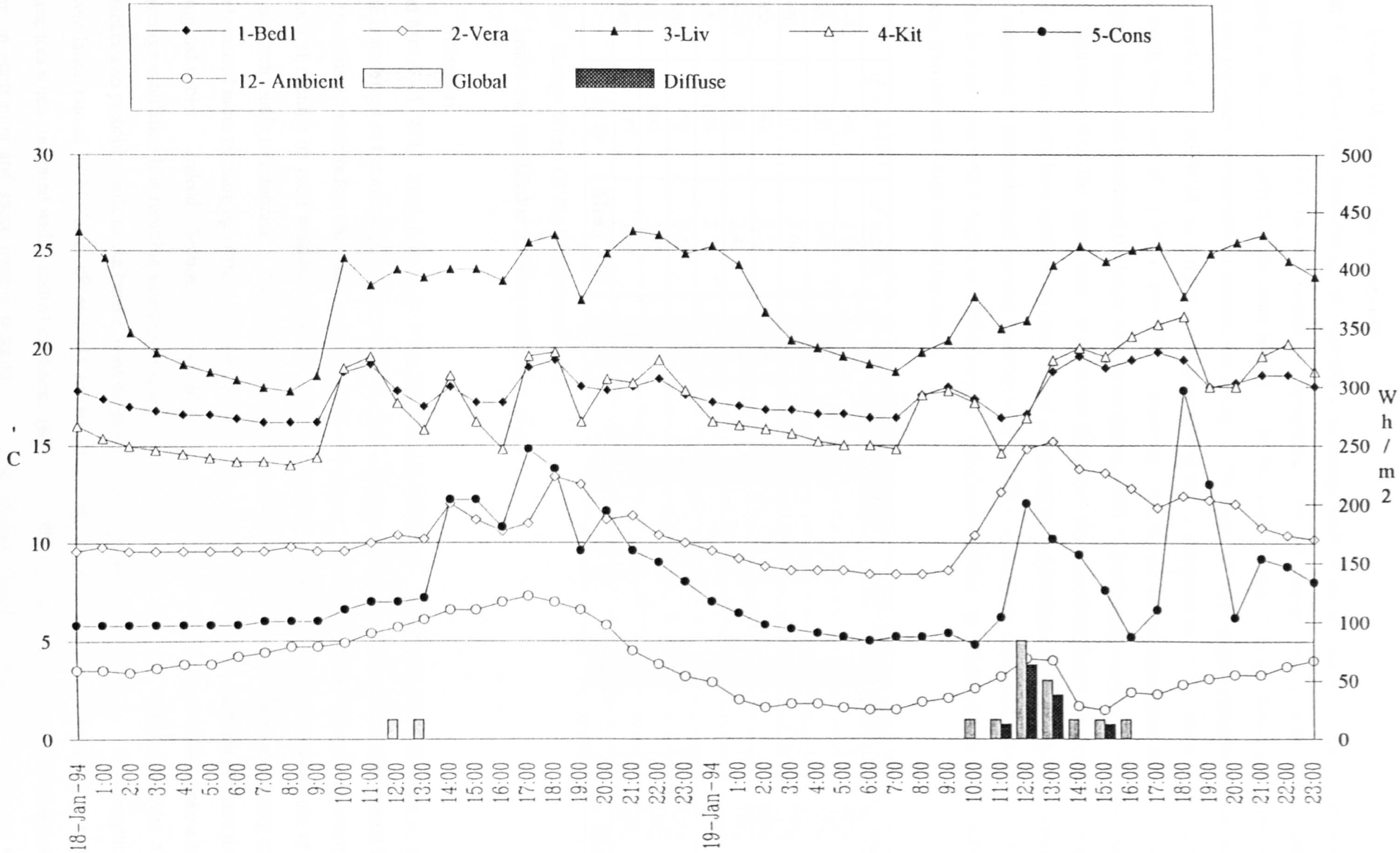
The ambient temperature profile of 18 January 1994 as in Figure 6.2 (overleaf) was only 1 - 2K lower than the spring profile of 12 April 1993 as described in the previous section. The temperature profile of the living room was punctuated with signs of the extensive use of the gas fire. The daytime temperature in the living room was between 23 - 27°C which was somewhat higher than the standard comfort level.

As solar radiation was negligible, the veranda has benefited by heat loss from the house, especially from the living room. However a sharp rise in living room temperature from 10-11.00 is not reflected in the veranda, although the diary states that the glazed door of the living room was open for almost 6 hours from 9-15.00. This suggests little mixing of air between the living room and veranda and/or that the rate of loss from the veranda is such that the veranda temperature maintains a fairly steady profile relative to ambient rather than aligning with the host room. This contrasts with the following day when the solar impact on the veranda profile is evident. It is also contrasts with the main bedroom which, as on the April day, consistently reflects heat inputs. It is also worth noting that the veranda's 'lift' of 5K on the dull 18th January corresponds to that of the 12th April with its dull start; but the sunny 19th roughly doubles the 'lift' for the diurnal period. So even though Mrs A's airing regime raises her fuel bill, but it does not eliminate the ventilation preheat contribution from the veranda.

The conservatory temperature was less than 2K above the ambient in the morning and early afternoon. This again indicates intervention by the occupant leaving the outer conservatory windows ajar, most likely for drying clothes. The diary confirms that the occupant again did 7 loads of washing within the week. The upsurges in the conservatory temperature correspond to the rise of the kitchen's temperature caused by heat gains from cooking. The diary confirms that the glazed door of the kitchen was continuously open for 12 hours from 09.00 - 21.00 hour and the glazed louvres were never closed.

The prolonged opening up of the house for fresh air by the occupants irrespective of the seasonal conditions explains why the house and sunspace temperatures were low when there was a relatively high input of space heating load. The effective rate of 1.8 air change per hour in winter reflects a high ventilation loss as a result of extensive opening up of the house and the 2 sunspaces.

Figure 6.2 - 18 & 19 January 1994 - W/14



6.1.6 ENERGY WORTH OF THE SUNSPACES

Section 3.3.3 sets out the methodology for calculating the energy worth of the sunspaces. The energy worth of W/14 compared to a REF+ house (without no sunspaces, but all thermal improvements and heated and ventilated to the same standard of the solar house) is 28.5% with savings of about 20% during the winter months and increases considerably in autumn and spring. The high n^r only slightly penalises the potential of energy worth/saving of W/14 as a result of the provision of the 2 sunspaces by 2.7% when compared to the energy worth benchmark of 31.2% (Table 6.9). However, this hinges on the assumption that the occupants would have heated and ventilated the house with no sunspaces (REF+) to the same standard as the solar house as built. Information from the 'qido' data, in particular the weekly diary and the author's observations, suggests that the occupants would have operated the same liberal airing regime had the house been built with no sunspaces. This is supported by the prolonged opening up of the outer windows in the living room and bedroom 2. It may therefore be concluded with a degree of confidence that 'ventilation preheat' as a technique is equally valid for occupants who demand a high ventilation regime.

	$q^l + q^s$ (W)	n^r (ac/hr)	q^h (W)	Q^h REF+(kWh)*		Q^{h_m} W/14 (kWh)	Energy worth
Sep-92	788	2.86	1,021	735		382	48%
Oct.	852	2.97	1,918	1,427		924	35%
Nov.	718	3.06	2,313	1,665		1,249	25%
Dec.	646	2.33	2,278	1,695		1,389	18%
Jan-93	623	2.41	2,104	1,565		1,262	19%
Feb.	658	2.74	2,183	1,467		1,135	23%
Mar.	775	3.36	2,494	1,856		1,262	32%
Apr.	801	3.41	2,016	1,451		1,038	28%
May	877	3.98	1,872	1,393		839	40%
	6,739	**Mean 3.01**	**Total**	**13,254**		**9,480**	**Mean 28.5%**

Table 6.9 Energy Worth Of The Sunspaces of W/14.
(*REF+ heated and ventilated to the same standard as W/14)

6.1.7 SUMMARY

Mr and Mrs A of W/14 lived in the same house before it was retrofitted. When interviewed, Mrs A stated that the house smelt in the morning and she was in the habit of opening up most of the windows for several hours to air the house, even before the house was retrofitted with the sunspaces and all the thermal improvements. This habit of opening up most windows by Mrs A has continued even though the thermal performance of their house has been totally transformed. The arrival of the baby and the consequent daily washing and drying clothes certainly caused more opening up of the conservatory-utility as demonstrated by the two daily temperature profiles in spring and winter. Indeed, Section 5.3.5 indicates that households with infants intrinsically invoke a higher than average ventilation loss resulting in a higher space heating load. That Mr A is a smoker but Mrs A is a non-smoker also probably explains the latter's need for fresh air as described in Section 5.3.6. The exceptionally high ventilation rate of W/14 (both n^e and n^r) has no significant penalties with respect to the energy worth of the sunspaces when compared with a theoretical house (REF+). The second heating season almost repeats the patterns in ventilation and space heating demand. This perhaps echoes the findings of previous works referenced in Section 1.5 whereby two-thirds of energy consumption is affected by occupant-related factors, of which only half is capable of re-adjustment over time, the other half being governed by the occupants' habits.

These rather encouraging findings, given the nature of the users' interventions, may now be compared with a household with a more modest space heating and ventilation demand than that of W/14.

6.2 CASE STUDY 2 - W/9

6.2.1 HOUSEHOLD PROFILE

Location first floor, mid-terrace, Wardie Road.

Heating system electric storage heating system and convectors in the two bedrooms.

Occupants' profile Mr B aged 66, retired and a non-smoker. Mrs B aged 67, retired and a heavy smoker. Mr B has health problem and has recently had a heart by-pass operation.

Author's observation fresh air quality, high level of ventilation in early autumn and late spring.

W/5	W/6	W/11	W/12	W/17	W/18
W/3	W/4	W/9	W/10	W/15	W/16
W/1	W/2	W/7	W/8	W/13	W/14

6.2.2 THREE KEY INDICATORS

The household of Mr and Mrs B of W/9 was classified as a medium space heating user with a measured load of 4,669 kWh or 31.31 kWh/m³ for the first heating season. All three key indicators as in Table 6.10 conform to an average household with respect to thermal comfort and the space heating load, especially the fuel:warmth ratio which is very close to the subset mean of 14 electric houses. Given the average space heating load, the slightly lower than average house temperature must be the result of a higher than average ventilation demand. The cost:warmth ratio of £11/K is almost -20% lower than the all electric subset, but is very close to the benchmark. This indicates that Mr and Mrs B used off-peak electricity efficiently for the storage heating system. The occupants hardly used either the electric fire in the living room or the convectors in the bedrooms. Both occupants were very comfortable living in the house, although they complained of air dryness caused by the use of the electric storage heaters.

	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
W/9	31.31 (-17.1%/ -7.4%)*	2.56 (+0.4%/ -11.7%)*	11 (-19.1%/ -5.8%)*
Subset - all-electric (14)	33.8	2.55	13.59
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 6.10 Three key indicators of W/9. (* ±% above/below benchmark and subset in brackets)

6.2.3 OTHER INDICATORS - HEATING SEASON AND MONTHLY

The mean house and sunspace temperatures are slightly below the benchmark and the electric subset (see Table 6.11), corresponding to a relatively high effective rate of air change. The 'qido' data confirms that the outer windows in the living room, veranda and conservatory are ajar for almost 24-hours throughout the year, including the winter months. The slightly lower house temperature (by 0.75K in zone 1 and 0.89K in zone 2 compared with the subset of 14 electric houses) suggests that the fuel:warmth ratio of W/9 would have been lower had the occupants not left all the outer windows ajar day and night. (See Appendix 6.1 - for a cold, but sunny winter day in February and a warm but dull spring day in April.)

	Net Qh_m in kWh (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr • mean [aut./winter/spring]
W/9	4,669 (+30 %) 3,593	19.4 / 22.32/ 18.22	13.6	12.2	1.26 [1.33/ 1.01/ 1.45]
All electric (14)	5,041 (± 0 %) 5,047	20.21/ 23.07/ 19.11	19.2/ 14.91/ 13	15.94/ 13.36/ 10.06	0.96 [1.01/ 0.9 / 0.98]
Benchmark(34)	5,630 (+23.5%) 4,558	19.86/ 22.21/ 18.96	19.79/ 15.06/ 11.9	17.18/ 13.08/ 8.81	1.14 [1.18/ 1.02/ 1.2]

Table 6.11 W/9 - Other Key Indicators.

The veranda temperature of W/9 compares quite closely to the minimum value for the subset of all-electric. Although the conservatory temperature is more likely to be affected by the universal utility function, the temperature of W/9 is 1.16K below the all-electric subset and 0.88K below the benchmark. Also, it is almost 1K below the subset of OAP/electric houses (13.17°C), the same heating fuel and age group. The relatively low sunspace and heated zone temperatures conform to the window opening regime. Indeed, the n^e of W/9 is almost +30% higher than the subset of all-electric and almost +20% above the benchmark. It is also higher than the subset of OAP/electric (the same age group, heating fuel and all with one or more smoker) - autumn, 1.33 ac/hr cf. 1.04; winter, 1.01 ac/hr cf. 0.92 and spring, 1.45 ac/hr cf. 1.01. However, the seasonal n^e for all smoking households as in Table 6.12 shows that W/9 is closer to the mean than the OAP/electric subset. Therefore the smoking habit of Mrs B does have a consistent connection with a higher n^e, though not so much with other pensioners.

(ac/hr)	Autumn	Winter	Spring	Heating season	Sample
Smoking	1.28	1.13	1.27	1.23	(26)
Non-smoking	0.86	0.68	0.98	0.84	(8)

Table 6.12 n^e Of Smoking And Non-smoking Household.

Mr and Mrs B always reiterate their need for fresh air saying that the house is always too warm and dry. The slow-response electric storage heating system appears to have contributed to the higher than anticipated space heating load, a general comment made by many occupants with this type of heating system. This is partly out of the occupants control. The daily temperature profiles of electric-heated houses predictably confirm a higher than needed house temperature between 23.00 and 07.00 hour, although this has the advantage of eliminating thermal inertia relative to particular diurnal demands.

In the case of W/9, the more economic use of off-peak electricity to charge the storage heaters and little use of the electric fire and convectors during the day at a higher tariff have lowered the cost:warmth ratio by 23.5% when compared with the mean value of all electric-heated houses (£11/m^3 cf. £13.59).

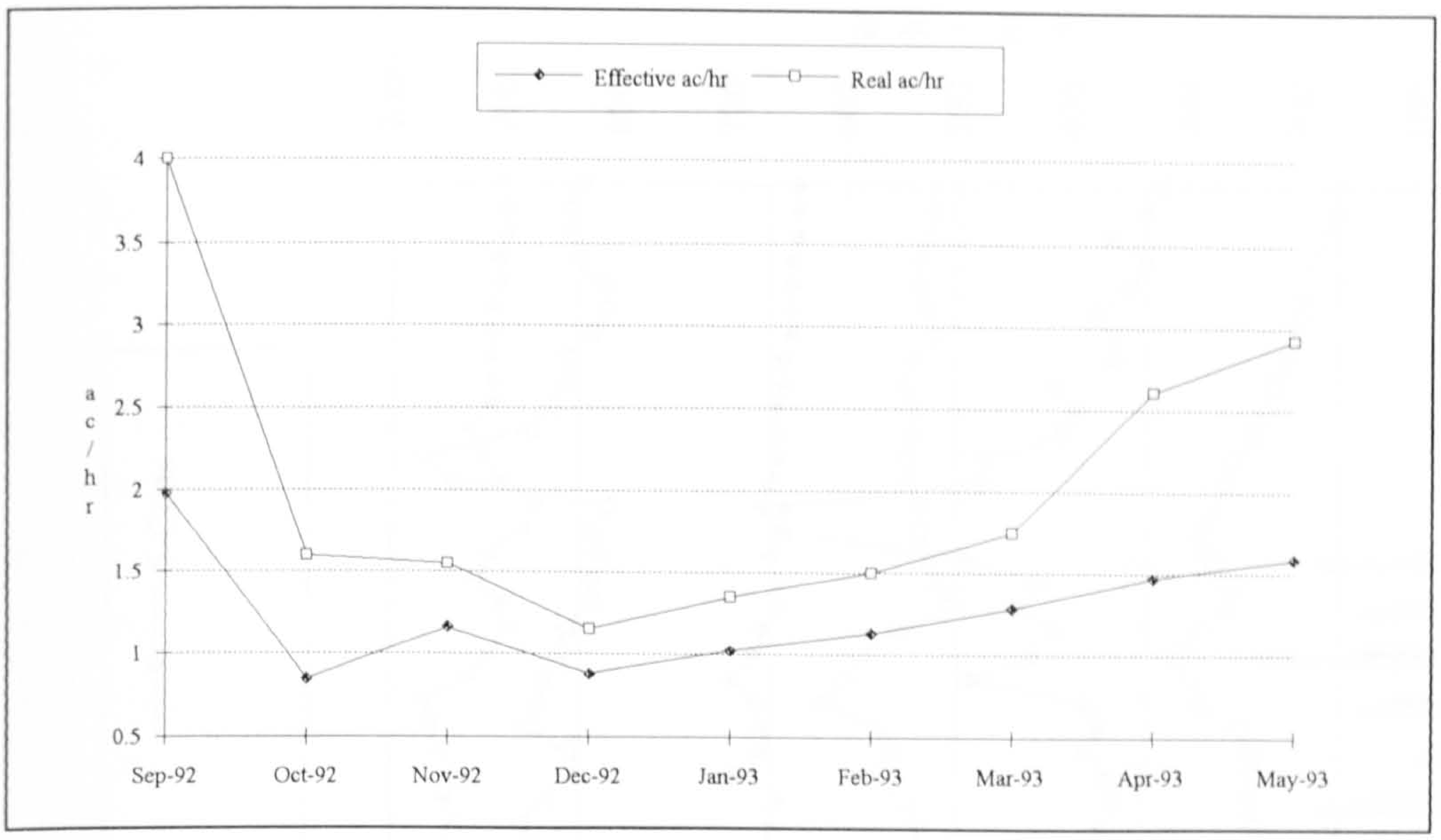
Looking at monthly data, the highest mean zone 1 temperature is in February and the lowest in September giving a maximum-minimum range of 3.19K as in Table 6.13. This inversion suggests that the September value corresponds more to a comfortable 'free-floating' regime (i.e. without much heating), while the winter values are probably somewhat higher than needed due to control difficulties. The mean zone 2 temperature reflects the trend in zone 1. The 'qido' data confirms that the occupants are very satisfied with the retrofit, feel very comfortable and find the house easy to heat.

The mean monthly veranda temperatures are consistently lower than the subset of electric/Wardie. Again the conservatory temperatures are also generally lower, but the difference is fairly insignificant. The temperature difference between zone 2 and the veranda is 2.8K for autumn , 6.15K for winter and 4.84K for spring, the highest occurring in December (7.01K) and the lowest in September (0.45K). There is a similar temperature difference between zone 2 and the conservatory. This apparently indicates that the two sunspaces perform better as thermal buffers in the winter months than in autumn and spring, but the reality of the interaction between solar gain and opening up is complex. Examination of the daily temperature profiles in the following section also confirms the relatively high effective rate of air change in autumn and spring as a result of opening up the sunspaces. However, when the opening up coincides with periods of substantial solar gains this should not be disadvantageous.

	Z1	Z2	Veranda	Conservatory	Ambient	Qh_m	Qh_SODEM-adj
Sep-92	20.26 (22.47)	17.72 (20.29)	17.27 (18.62)	15.59 (16.38)	11.56	239 (253)	0 (164)
Oct-92	21.20 (23.05)	16.31 (19.54)	14.16 (15.91)	11.00 (12.13)	6.4	232 (488)	142 (526)
Nov-92	22.40 (23.68)	17.24 (19.88)	11.17 (14.36)	9.91 (10.78)	5.71	565 (682)	517 (800)
Dec-92	22.08 (23.06)	17.49 (19.64)	10.48 (12.49)	8.77 (10.12)	3.65	652 (712)	745 (1040)
Jan-93	22.93 (24.23)	17.99 (20.05)	12.46 (14.01)	9.58 (10.15)	4.79	702 (909)	714 (1032)
Feb-93	23.45 (24.72)	19.09 (20.49)	13.19 (15.3)	10.61 (11.69)	6.25	629 (715)	590 (775)
Mar-93	22.97 (24.21)	18.89 (20.27)	13.18 (15.29)	11.44 (12.03)	6.15	675 (745)	524 (731)
Apr-93	22.84 (23.63)	19.55 (20.31)	14.91 (16.21)	16.00 (15.07)	8.41	569 (475)	281 (446)
May-93	22.79 (23.39)	19.74 (20.94)	15.57 (17.93)	16.90 (16.97)	10.34	406 (337)	80 (279)
mean/sum	22.32 (23.6)	18.22 (20.16)	13.6 (15.57)	12.20 (12.81)	7.03	4669 (5316)	3593 (5793)

Table 6.13 Monthly Data Of W/9. (6 no. Electric/ Wardie Subset values in brackets).

The mean n^e and n^r of W/9 as shown in Table 6.14 are slightly above the benchmark, and the mean n^r in winter is very close to the benchmark value. In contrast, the difference of 0.28 ac/hr in autumn (2.38 real cf. 2.1 benchmark) and 0.42 ac/hr in spring (2.43 real cf. 2.01 benchmark) confirms that the household of W/9 has opened up the house somewhat longer in comparison to the average, especially in spring and winter. In common with most of the solar houses, the n^r is more pronouncedly lower in winter than in autumn and spring compared with the n^e values, indicating that solar preheat is more effective in these periods - the greater the $(n^r - n^e)$ difference the more preheat. Nevertheless, if both n^e and n^r had been lower in autumn and spring, maintaining the same differential, the preheat effect would not change, but the space heating loads would have fallen.



Month	Z1 / Z2	$q^s + q^l$ (W)	n^e / n^r	qh (W)1	Qh (kWh)1
Sep-92	Z1	172	1.98 / 4	332	239
	Z2	519	*(1.4 / 2.83)*		
Oct-92	Z1	184	0.85 / 1.6	312	232
	Z2	559	*(1.1 / 2.06)*		
Nov-92	Z1	153	1.16 / 1.55	785	565
	Z2	474	*(1.06 / 1.42)*		
Dec-92	Z1	142	0.88 / 1.15	876	652
	Z2	422	*(1.02 / 1.33)*		
Jan-93	Z1	131	1.02 / 1.35	944	702
	Z2	409	*(1.03 / 1.36)*		
Feb-93	Z1	147	1.13 / 1.5	936	629
	Z2	426	*(1.03 / 1.37)*		
Mar-93	Z1	189	1.28 / 1.75	907	675
	Z2	495	*(1.18 / 1.61)*		
Apr-93	Z1	179	1.47 / 2.61	790	569
	Z2	530	*(1.22 / 2.17)*		
May-93	Z1	203	1.59 / 2.93	546	406
	Z2	583	(1.22 / 2.25)		
		Mean	**1.26 / 2.05**	**6,426**	**4,669**
			(1.14 / 1.82)	**Total (W)**	**Total (kWh)**

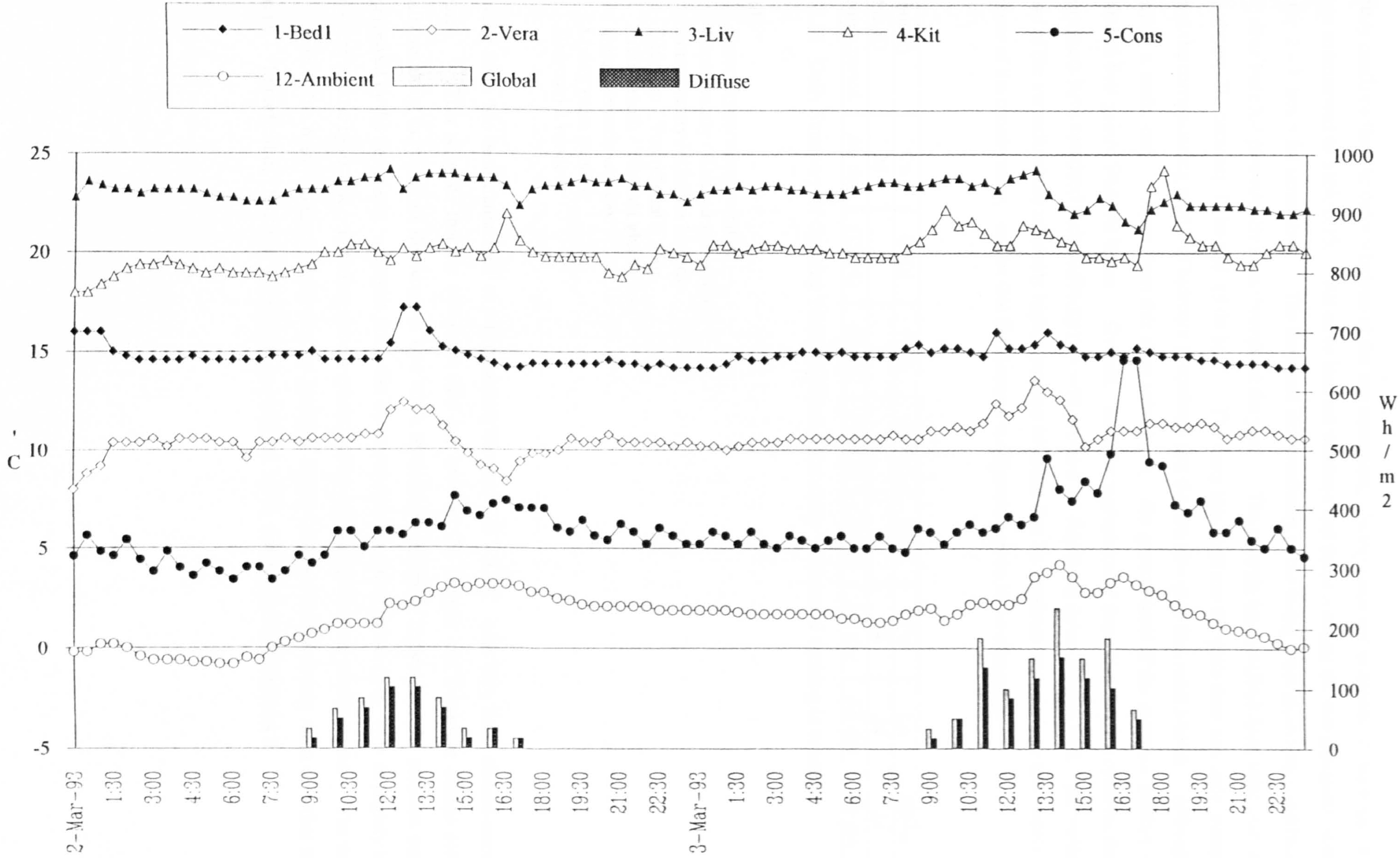
Table 6.14 Effective And Real Rate Of Air Change With Other Data.
(1 - q^h, Q^h as measured and the benchmark value of n^e, n^r in brackets and italics)

6.2.4 DAILY PROFILE - 2 MARCH 1993

Cold but quite sunny spring day

The daily temperature profile of W/9 on 2 and 3 March, as in Figure 6.3 (overleaf), shows an electric-heated house with steady heated zone temperatures. The profiles of the living room, bedroom 1 and kitchen confirm that there is less difference in room temperatures throughout the 24-hour period when compared to W/14 with its gas centrally heating system. This highlights the common criticism of this type of electric storage heater: no thermostat regulated overnight charge control, discharge/damper control or fan-assisted device to disperse heat rapidly. The less controllable and responsive electric storage heater tends to result in a relatively high temperature at night in unoccupied rooms as indicated in the temperature profile.

Figure 6.3 - 2 & 3 March 1993 - W9



The diary confirms that the outer windows of the two sunspaces, living room and bedroom 2 were ajar for 24-hours as summarised in Table 6.15. All other internal windows and doors abutting the two sunspaces were also open for 2 - 3 hours for ventilation. The doorhead slot ventilators in the living room glazed door and bedroom 1 patio door were left permanently open throughout the year. The veranda has benefited from solar gain with a rise of almost 2K between 12.00 and 15.00 hour. The diary also confirms the patio door was open during that time and the corresponding profile of bedroom 1 confirms that the sun also gave that room a boost - although not necessarily a useful one. Apart from this short solar input, the general level of the sunspace profiles is not attributed to heat gained from the house. Overall, the clear segregation of respective profiles confirms that the two sunspaces have sustained their buffering role with pre-heat air displacing space heating load, particularly in the case of the veranda whose relatively higher position indicates that its windows were perhaps less widely open than those of the conservatory, and/or that the recessed configuration gives its an advantage.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR^{2}w
2 Mar.'93	24	2	3	3	3	24	24	24
Opening period	All day	(12-14)	(9-12)	(12-15)	(12-15)	All day	All day	All day

Table 6.15 Daily Summary Of Opening Windows/Doors From Diary (Hours of opening in brackets).

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^{2}w	Bedroom 2 window

The living room has been maintained at a temperature between 23 - 24°C with very little diurnal-nocturnal difference. This suggests that the occupants may not have set the damper and overnight charge controls optimally resulting in premature discharge of heat and a temperature relatively higher than the assumed comfort level perceived by the designers. Despite this, the measured living room temperature of W/9 is slightly below the subset of electric by 0.75K - reflecting the occupants' policy of leaving the outer windows ajar. The weekly diary, as in Table 6.16, also confirms that no auxiliary heater was used in the living room or either of the bedrooms. In particular, bedroom 1 balanced out at about 15°C which suited Mr and Mrs B.

	L/fire	L/st	Kit/st	Bath/st	Hall/st	B1/con	B2/con
Heater setting	not used	3	3	not used	3	not used	not used

Table 6.16 Summary Of Uses Of Heating System.

Legend:

L/fire	Living room / electric fire
L/st	Living room / storage heater
Kit/st	Kitchen / storage heater
Bath/st	Bathroom / storage heater
Hall/st	Hallway / storage heater
B1/con	Bedroom 1 / electric convector
B2/con	Bedroom 2 / electric convector

The solar influence is also apparent during the following day. Note particularly that the burst of sunshine from 16-17.00 hour gives the conservatory a sharp boost for a short period just prior to the evening cooking surge in the kitchen.

6.2.5 DAILY PROFILE - 20 SEPTEMBER 1993

Warm, sunny early autumn day

The effects of the Indian summer are shown by the temperature profiles clustering together as in Figure 6.4 (overleaf). This indicates that both the two sunspaces and the heated volume are open extensively and have had their temperature boosted significantly by solar gain. For instance, the temperature difference between bedroom 1 and ambient is less than 1°C at 15.00 hour and the value of 20°C is considerably higher than that required by Mr and Mrs B as indicated by the spring day above, although not so high as to cause inconvenience. The conservatory temperature is equal to that of the kitchen for at least 4 hours between 13.00 - 17.00 hour with the 16.00-17.00 surge corresponding to the late afternoon sunshine on the projecting conservatory. The two-periods of temperature upsurge at 12.00 and 17.00 hours also coincide with the occupants' lunch and tea time. Overall, the diary as in Table 6.17 confirms extensive opening up of all the windows and doors, but not necessarily to the disadvantage of the passive solar system, given the weather.

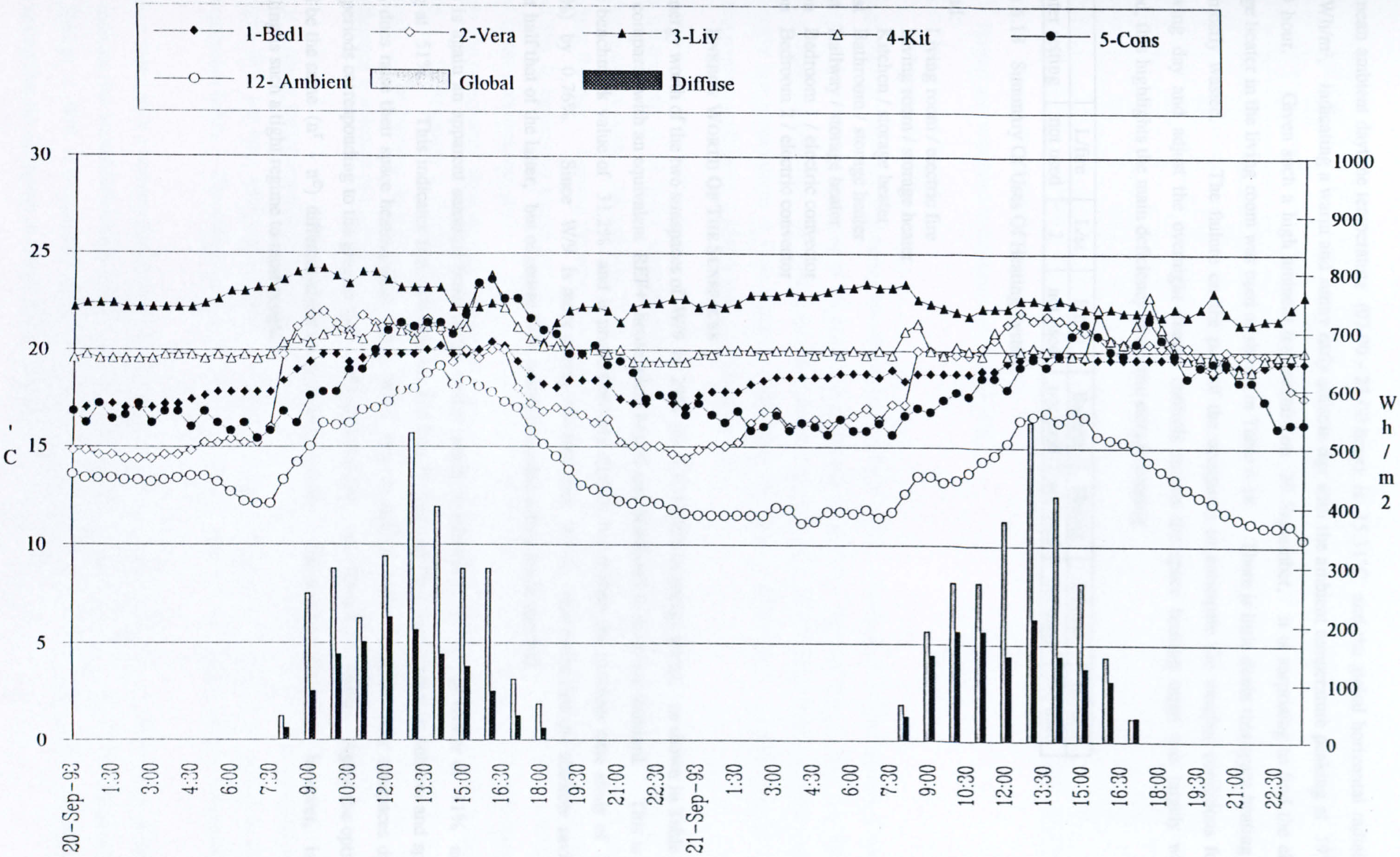
(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR^{2}w
20-Sep-93	24	9	9	9	9	24	24	24
Opening period	All day	(9-18)	(9-18)	(9-18)	(9-18)	All day	All day	All day

Table 6.17 Daily Summary Of Opening Windows/Doors From Diary (Hours of opening in brackets).

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^{2}w	Bedroom 2 window

Figure 6.4 - 20 & 21 September 1993 - W/9



The mean ambient daytime temperature (07.00 - 23.00 hour) is 15.31°C and the global horizontal radiation is 2.8 kWh/m², indicating a warm and sunny early autumn day with the ambient temperature peaking at 19°C at 15.00 hour. Given such a high ambient temperature on 20 September, it is surprising to find the electric storage heater in the living room was used as shown in Table 6.18. There is little doubt this space heating input was mostly wasted. The failure on the part of the occupants to anticipate the weather conditions for the following day and adjust the overnight charge controls means the space heating input was largely wasted. Indeed, this highlights the main deficiency of electric storage heating.

	L/fire	L/st	Kit/st	Bath/st	Hall/st	B1/con	B2/con
Heater setting	not used	2	not used	not used	not used	not used	not used

Table 6.18 Summary Of Uses Of Heating System.

Legend:

L/fire	Living room / electric fire
L/st	Living room / storage heater
Kit/st	Kitchen / storage heater
Bath/st	Bathroom / storage heater
Hall/st	Hallway / storage heater
B1/con	Bedroom 1 / electric convector
B2/con	Bedroom 2 / electric convector

6.2.6 ENERGY WORTH OF THE SUNSPACES

The energy worth of the two sunspaces of W/9 is 29% (or 1,931 kWh in energy term), as shown in Table 6.19, when compared with an equivalent REF+ house when heated and ventilated to the same standard. This is close to the benchmark value of 31.2% and is proportionately slightly better than the previous case study of W/14 (28.5%) by 0.76%. Since W/9 is more energy efficient than W/14, this mean that the absolute saving is almost half that of the latter, but of course W/9 is still rewarded with a lower fuel bill.

There is again an apparent seasonal trend in the energy worth in autumn at 41%, in winter at 11% and in spring at 51%. This indicates that although Mr and Mrs B open up their house more in autumn and spring, which does raise their space heating load, like W/14 they do achieve better value for their sunspaces during these periods corresponding to the greater (n^r - n^e) differentials - see Table 6.14 above. Again the optimum would be the same (n^r - n^e) differential but lower absolute values. The question this poses, however, is how appealing is such a tight regime to most people ?

	$q^l + q^s$ (W)	n^r (ac/hr)	q^h (W)	Q^h REF+ (kWh)		$Q^{h}\_^{m}$ W/9 (kWh)	Energy worth
Sep-92	788	4	903	650		239	63%
Oct-92	852	1.6	594	442		232	47%
Nov-92	718	1.55	914	658		565	14%
Dec-92	646	1.15	959	714		652	9%
Jan-93	623	1.35	1068	795		702	12%
Feb-93	658	1.5	1077	724		629	13%
Mar-93	775	1.75	1108	825		675	18%
Apr-93	801	2.61	1345	969		569	41%
May-93	877	2.93	1108	824		406	51%
	6,739	**Mean 2.05**	**Total**	**6600**		**4669**	**Mean 29.3%**

Table 6.19 Energy Worth Of The Sunspaces of W/9.

(REF+ Heated and ventilated to the same standard as W/9)

6.2.7 SUMMARY OF W/9

Although the diary was only kept during March and September of 1993, it gives a feel of the ventilation demand, the extent and pattern of opening up of the house and the sunspaces of W/9. Mr and Mrs B certainly ventilate the two sunspaces extensively, by leaving the outer windows ajar day and night throughout the year and resulting in relatively low temperatures in these spaces, particularly the utility conservatories, as demonstrated in the daily temperature profiles on 2 March and 20 September 1993.

Unlike Mr and Mrs A of W/14 who 'actively and consciously' ventilate the house by opening up several hours each day to air the house, Mr and Mrs B of W/9 'passively' leave all the outer windows ajar most of the time throughout the year. Leaving the outer windows ajar for 24 hours throughout the year had been the practice of Mr and Mrs B before they moved into the retrofitted solar house. Their high demand for fresh air is somewhat similar to the previous case study of W/14, but the first floor location of W/9 does not make it necessary to 'actively and consciously' close the outer sunspace windows, the living room and bedroom 2 windows at night for security. Subsequently it does not occur to them to close these windows when there is a change in the weather or season. The opening up of the heated volume on to the two sunspaces is less severe in W/9 than W/14. The difference is reflected in a lower net space heating load and n^r for W/9 when compared to W/14.

There is a strong indication that the high demand for fresh air is fulfilling the occupants' psychological needs. Although W/9 has been totally transformed into an energy efficient house the occupants are unable to change their ventilation habits. The difference is that these habits, comfort and affordability are all now compatible.

A smoker living with a non-smoker in an OAP group raises another interesting issue. The findings in Section 5.3.6 indicate that households with a smoker are likely to ventilate more than others. Here the effective rate n^e of air change of W/9 is consistently higher than the subset of smoker/electric as in Table 6.20, although it is worth noting that the difference in winter is less significant.

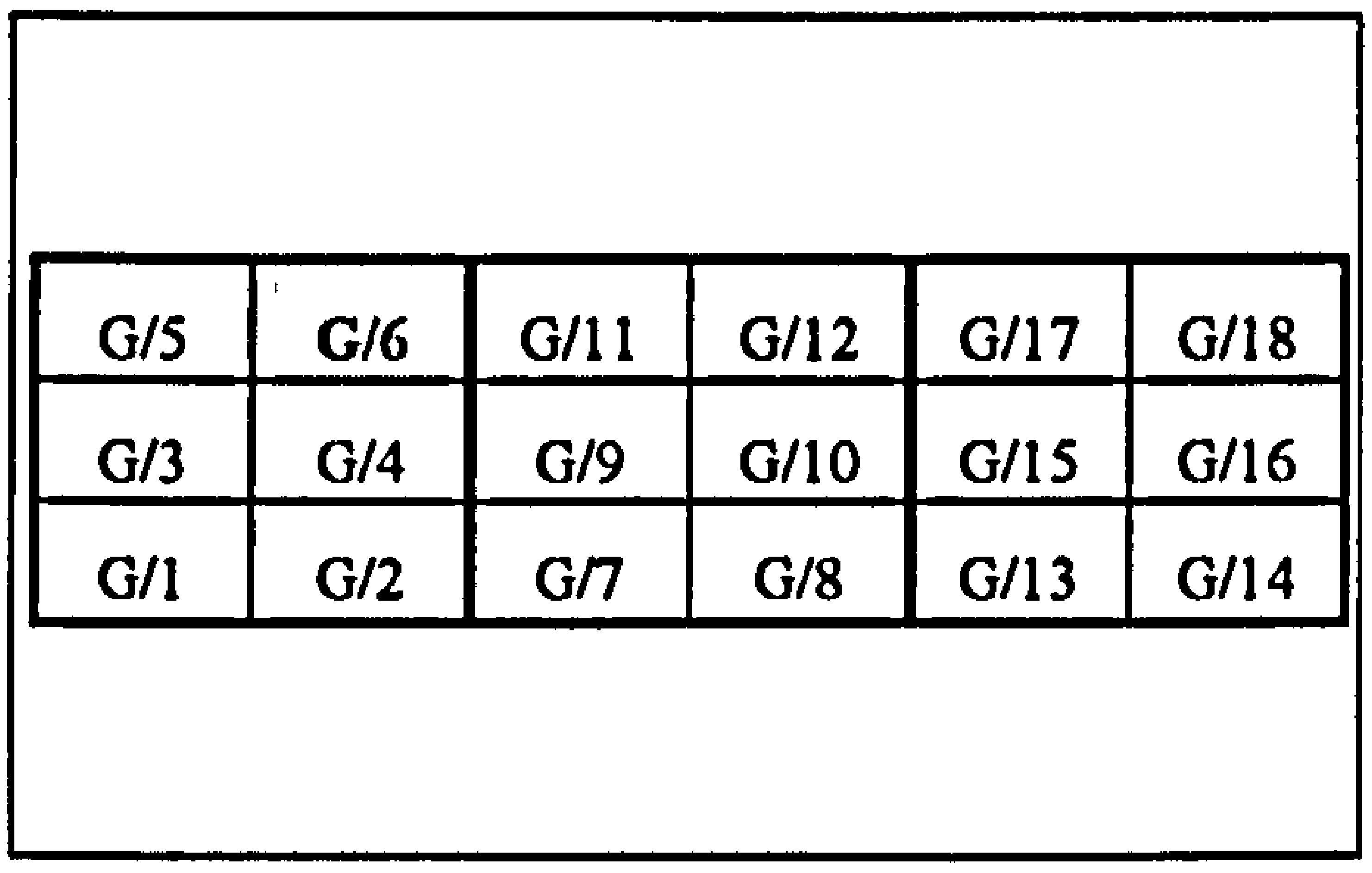
n^c (ac/hr)	Autumn '92	Winter '92	Spring '93	Htg. Season	Sample
W/9	1.33	1.01	1.45	1.26	1
Smoker/electric	1.01	0.9	0.98	0.96	14
Non-smoking/both fuels	0.87	0.68	0.98	0.84	8
Benchmark	**1.18**	**1.02**	**1.20**	**1.14**	**34**

Table 6.20 Effective Rate Of Air Change.

On the basis of the hypothesis that household characteristics such as a smoking habit affect the n^r significantly, the next case study examines another household with similar characteristics, i.e. OAP/smoker living in an electric-heated house.

6.3 CASE STUDY 3 - G/6

6.3.1 HOUSEHOLD PROFILE



G/5	G/6	G/11	G/12	G/17	G/18
G/3	G/4	G/9	G/10	G/15	G/16
G/1	G/2	G/7	G/8	G/13	G/14

Location second/ top floor, mid-terrace, Glenburnie Place.

Heating system electric storage heating system and convectors in the two bedrooms.

Occupants' profile Mr C aged 67, retired, smoker. Mrs C aged 69, retired, smoker. No health problems. A 5-stone German shepherd, 'Rocky'.

Author's observation normal air quality; improvement in ventilation and heating controls in the second heating season.

6.3.2 THREE KEY INDICATORS

Mr and Mrs C's weekly diary for the duration of the monitoring period confirms the pattern of closing up late in autumn and opening up early in spring. Glenburnie Place has a different pattern of solar gain comparing to the two previous case studies and is also exposed to the prevailing westerly wind. Furthermore, its second (top) floor location incurs a higher transmission loss in the conservatory extension as described in Section 4.2.4. The volumetric space heating load and the fuel:warmth ratio are very close to the subset of 14 electric-heated house as in Table 6.21. Like W/9, the household has been making economic use of the off-peak electricity to re-charge the storage heaters overnight with minimal use of electricity during the daytime, the electric fire in the living room and convectors in both bedrooms being rarely used. This results in the cost:warmth ratio of G/6, almost -14% below the subset of all electric.

	Net Qh_m (kWh/m^3)	Fuel:warmth (kWh/m^{3}K)	Cost:warmth Ratio (£/K)
G/6	35.14 (-6.9%/ +4%)*	2.66 (-8.3%/ +4.3%)*	11.69 (±0%/ -14%)*
All electric (14)	33.8	2.55	13.59
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 6.21 Three Key Indicators of G/6. (* ±% above/below benchmark and subset in brackets)

6.3.3 OTHER INDICATORS - HEATING SEASON AND MONTHLY

The house of G/6 is heated to the mean temperature of 20.35°C, slightly higher than the subset of all-electric, especially in zone 2 as in Table 6.22. However, the mean veranda temperature of G/6 is marginally below the subset mean. The mean conservatory temperature is also slightly lower than the subset and the subset of all 5 top floor houses at Glenburnie Place (15.15°C) by more than 2K. The effective rate of air change, n^c, is also higher than that of the all-electric subset. The combined effect of a slightly higher house temperature, but lower conservatory temperature and higher n^e is almost +15% higher net space heating load than both 'yardstick' (SODEM-adj) and the all-electric subset.

	Net Qh_m in kWh/ (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
G/6	5,241 (+14.5%) 4,577	20.35 / 22.67/ 19.46	14.81	12.88	1.13 [1.41/ 1.01/ 0.95]
Benchmark (34)	5,630 (+23.5%) 4,558	19.86/ 22.21/ 18.96	19.79/ 15.06/ 11.9	17.18/ 13.08/ 8.81	1.14 [1.18/ 1.02/ 1.2]
All Electric (14)	5,041 (± 0 %) 5,047	20.21/ 23.07/ 19.11	19.2/ 14.91/ 13	15.94/ 13.36/ 10.06	0.96 [1.01/ 0.9 / 0.98]

Table 6.22 Other Key Indicators Of G/6.

Frequent opening up of the heated volume in autumn and spring, but relatively less in winter is confirmed by the 'qido' data. Mr C kept the weekly diary for the whole 12-month period. This gives a relatively complete insight to the ventilation and heating controls of G/16 throughout the year as in Table 6.23.

As shown, there are more opening of the outer sunspace windows in autumn (4¼ hours daily for the conservatory and 3 hours for the veranda) and spring (5 hours for both conservatory and veranda) than in winter when they are mostly closed. Similar ventilation patterns emerge for most of the ventilation devices from the house on to the sunspaces: again, a longer period of opening in autumn and spring than in winter. Similar to the previous case study, the doorhead ventilators in the living room glazed door and bedroom 1 patio door were never closed throughout the year. The only exception is the glazed door and louvres in the kitchen where the opening up hours are consistent, presumably as cooking takes place whatever the weather.

Rocky's presence resulted in most internal doors being open much of the time. Furthermore, the veranda with seating and pot plants is used for at least part of the heating season. Interestingly, the auxiliary electric bar heater in the living room was used from October till March on average between 2 and 5.5 hours daily as in Table 6.24. Mr and Mrs C stated that they liked to see the effects of a visible fire, and that most of the time the electric fire was only set on minimum This view is held by a number of other occupants who like to have a visible source of heat in order to feel warm.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR2w
Sep-92	7	5¼	10½	14¼	9¾	6¼	9	7½
Oct-92	6	3	6	4½	3	3	1½	0
Nov-92	0	3¼	2¼	0	1¾	0	0	0
Aut. mean	4¼	3¾	6¼	7½	4¾	3	3½	2½
Dec-92	0	0	6	0	0	0	0	0
Jan-93	0	6	6	0	0	0	0	0
Feb-93	0	1	7½	3½	0	0	0	0
Winter Mean	0	2¼	6½	1	0	0	0	0
Mar-93	2½	4¾	6	4¾	4¼	2½	2½	2½
Apr-93	6½	7	6¼	4½	5	6¼	2¼	3
May-93	6	10	10	10	10	6	6	10
Spr. Mean	5	7¼	7½	12½	6½	5	5	5
Mean	3	4½	6¾	4½	3¾	2½	2¾	2½

Table 6.23 Summary Of Opening Windows And Glazed Door From Weekly Diary.

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^{2}w	Bedroom 2 window

Week	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1			4	3½	4	3½	3½		
2		4	4	3½	4	3½	3½		
3		4	4	3½	4	7½	5½		
4			4	3½	3½	7½			
Mean	0	2	4	3½	4	5½	3	0	0

Table 6.24 Use Of Auxiliary Electric Heater In Living Room.

(Monthly mean daily in hours - rounded to the nearest ½ hour).

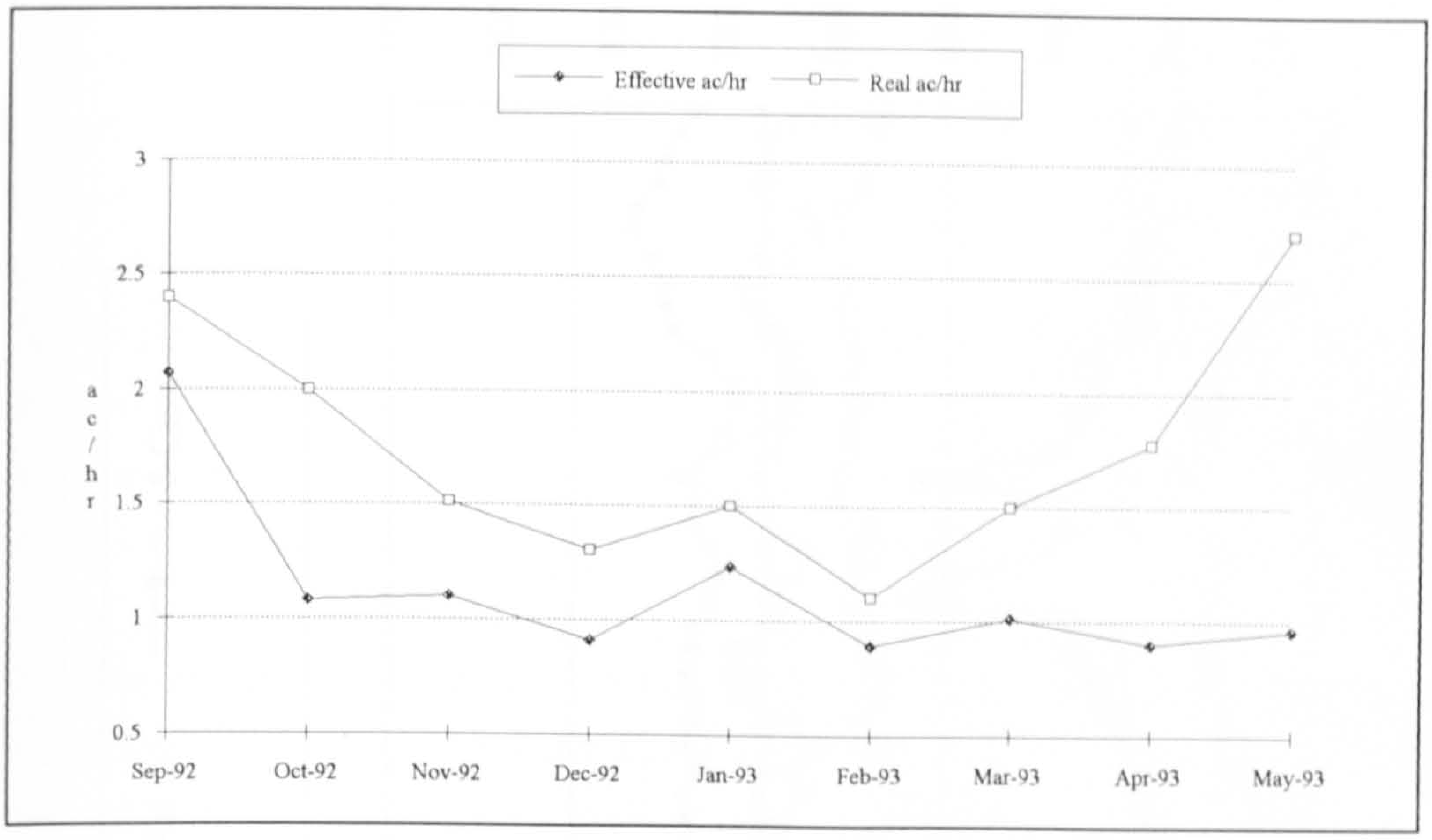
Comparing monthly data for the case study of G/6 with the subset of 8 electric-heated houses at Glenburnie Place, all with the same heating fuel and orientation, as in Table 6.25, a range of 2.48K is found in the mean zone 1 temperature, with the highest temperature recorded in February and the lowest in May. This variation is slightly higher than the subset of Glenburnie/electric (2.07K). The zone 2 temperature however shows a smaller variation than the subset. Mr and Mrs C stated that the house is very comfortable and easy to heat. However both occupants complained of draughts from the main entrance door (via communal hallway and stair) and the two sunspaces. In the first case, the draughts are caused by the badly fitted draught-proofing sealants and in the latter case, it is probably due to its top floor location with the west facing veranda opening on to a playground and the east facing conservatory incurring additional loss via the glazed roof.

	Z1	Z2	Veranda	Conservatory	Ambient	Qh_m	Qh_SODEM-adj
Sep-92	22.42 (21.62)	19.1 (18.3)	20.12 (17.59)	16.59 (17.65)	11.65	466 (192)	156 (85)
Oct-92	21.92 (21.57)	19.6 (17.22)	15.17 (14.42)	13.69 (12.74)	6.56	563 (367)	380 (324)
Nov-92	21.89 (22.19)	18.74 (17.66)	12.1 (12.36)	11.22 (12.45)	5.72	673 (683)	647 (641)
Dec-92	23.32 (22.8)	19.51 (18.18)	12.78 (12.77)	9.42 (10.8)	3.57	889 (785)	909 (889)
Jan-93	23.22 (23.03)	19.2 (18.27)	10.69 (10.98)	10.74 (12.59)	4.76	974 (961)	944 (923)
Feb-93	23.93 (23.64)	19.92 (18.67)	12.62 (13.4)	11.23 (13.57)	6.38	626 (647)	728 (664)
Mar-93	23.38 (23.57)	19.54 (18.18)	14.1 (14.03)	12.19 (13.77)	6.75	617 (627)	593 (586)
Apr-93	22.49 (23.57)	19.64 (19.17)	17.06 (17.36)	13.98 (15.26)	9.02	310 (397)	220 (308)
May-93	21.45 (22.05)	19.9 (19.28)	18.61 (18.51)	16.83 (17.05)	10.74	123 (176)	0 (66)
mean/sum	22.67 (22.67)	19.46 (18.33)	14.81 (14.6)	12.88 (13.99)	7.24	5,241 (4,835)	4,577 (4,486)

Table 6.25 Monthly Data Of G/6. (Electric/Glenburnie Place Subset values in brackets).

The mean monthly veranda temperature is almost always in line with the subset values, resulting in a seasonal difference of less than 0.2K. The extra transmission loss of the conservatory extension of G/6 because of its top floor location may have contributed to its temperature being below that of the subset. The net Qh_m of G/6 is +8.4% above the subset of Glenburnie/electric. This reflects the consistently higher zone 2 temperature, as well as the generally lower conservatory temperature, and its higher effective rate of air change, n^e, with a mean seasonal value of 1.13 for G/6 compared with 1.04 for the Glenburnie/electric subset. The seasonal pattern of the n^e and n^r is shown in Table 6.26.

The n^e and n^r of G/6 are even closer than W/9 to the benchmark values of 1.14 and 1.82 ac/hr respectively, although higher than the subset of all electric and Glenburnie/electric. Again, the n^r values confirm that although the 'yardstick' assumption of 1.5 air changes is not too far off the mark from November to March. The n^r for the rest of the heating season tends to be considerably higher, reflecting the occupants' proclivity to open windows.



Month	Z1 / Z2	$q^s + q^i$ (W)	n^e / n^r	q^h (W)^1	Q^h (kWh)^1
Sep-92	Z1	201	2.07 / 2.42	647	466
	Z2	550			
Oct-92	Z1	213	1.08 / 2.02	757	563
	Z2	589			
Nov-92	Z1	183	1.1 / 1.51	935	673
	Z2	481			
Dec-92	Z1	162	0.91 / 1.33	1,195	889
	Z2	439			
Jan-93	Z1	156	1.23 / 1.51	1,309	974
	Z2	424			
Feb-93	Z1	163	0.89 / 1.14	932	626
	Z2	439			
Mar-93	Z1	197	1.01 / 1.56	829	617
	Z2	505			
Apr-93	Z1	208	0.9 / 1.78	431	310
	Z2	561			
May-93	Z1	238	0.96 / 2.7	165	123
	Z2	634			
		Mean	**1.13 / 1.77**	**7,199**	**5,241**
				Total (W)	**Total (kWh)**

Table 6.26 Effective And Real Rate Of Air Change With Other Data.
(^{1} - q^h and Q^h as measured)

6.3.4 DAILY PROFILE - 12 APRIL 1993

Dull, cold but dry start, with sunny intervals in the afternoon

Examination of daily temperature profiles on 12 April 1993, Figure 6.5 (overleaf), the date also used in case study 1, confirms a completely different pattern of ventilating and heating. G/6 has a very steady heating profile corresponding to the storage heating, compared to that of W/14. The veranda's profile is similarly steady to that of W/14, but much higher at around 17.5°C compared with 11°C. This is likely to be partly due to the generally 2K higher temperature in bedroom 1 together with steadier living room profile, but also partly due to the extent to which windows and glazed doors have been opened. Significantly, solar gains in the

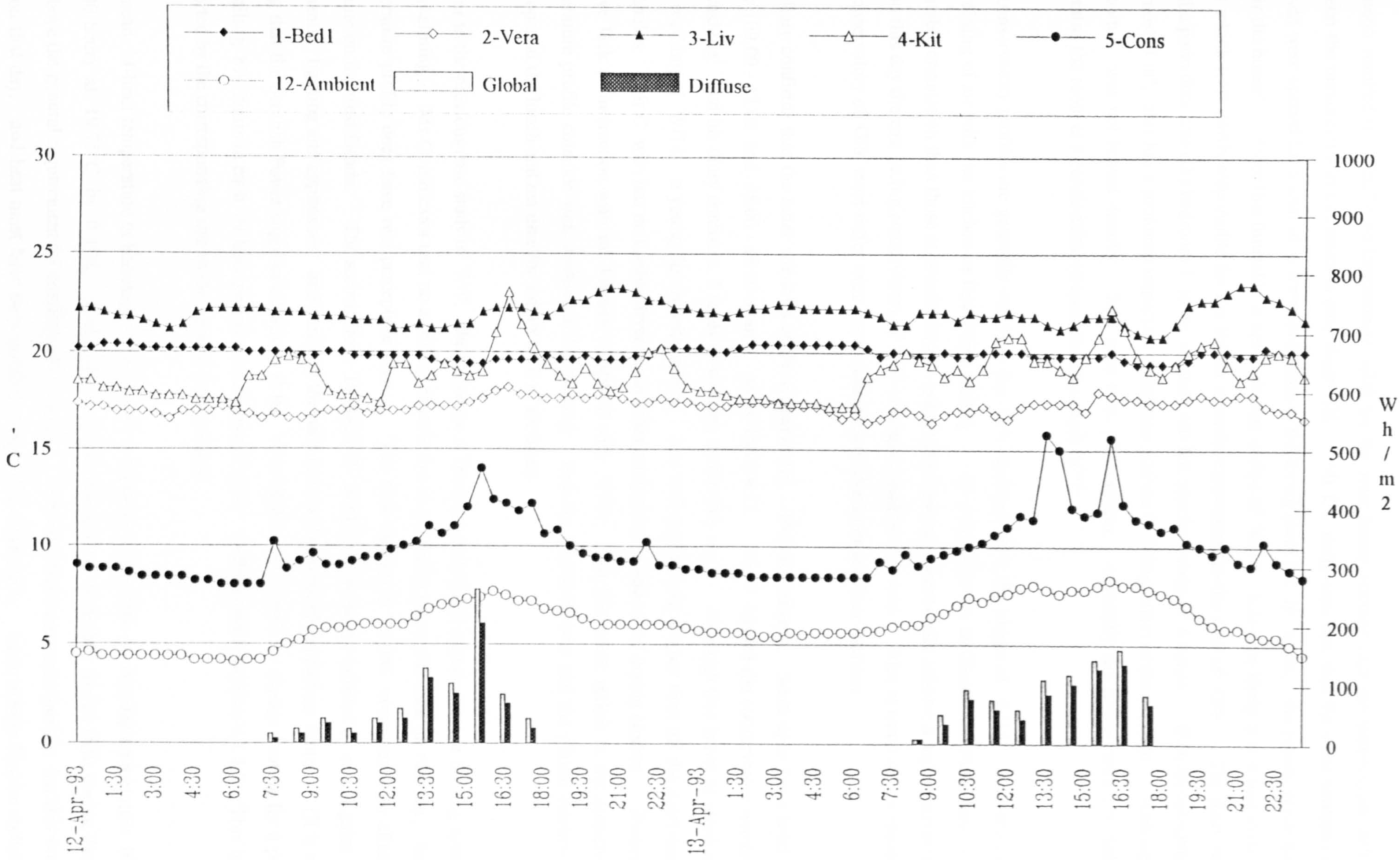


Figure 6.5 - 12 & 13 April 1993 - G/6

afternoon resulted in virtually no temperature uplift for the west facing veranda and the temperature difference between the maximum and minimum is only about 1K. Mr C's diary confirms that the outer windows of the veranda were opened for a total of 6 hours and those of the living room for 10 hours, the reason given for both "to air the house". Since this timetable is not unsimilar to that of W/14, it is then likely that it was lower open areas which were partly responsible for the higher veranda temperature in the case of G/6. The diary records that the patio door from the bedroom 1 to the veranda was left ajar for a total of 6 hours. With an openable area of almost 3 m^2, this has a profound impact on ventilation and the buffering effect of the veranda. Although the bedroom 1 was not heated directly, heat gain from other spaces, especially the living room and hallway, maintains the room at a comfortable temperature at around 20°C.

The conservatory profiles are generally similar, but G/6 does not have the surges of W/14, indicating either less mixing of air with the kitchen or less utility activity. As conservatories at Glenburnie Place have a more favourable orientation than those at Wardie Road, potentially these sunspaces could achieve a higher temperature. But on this day the east facing conservatory of G/6 is handicapped by dull start. Also at times of low insolation, the conservatory of G/6 must suffer extra transmission losses due to its top floor location.

The diary confirms that the outer windows of the conservatory, like the veranda, were open for a total of 6 hours (09.00 - 12.00 and 15.00 - 18.00 hours), as in Table 6.27. Mr C opened the conservatory windows to dry washing, and his diary confirms 3 loads of washing within this week. Although this is not as much as the daily washing of W/14, a young family with a baby, it is still significantly higher than all the diary-keeping households. Mr C who has no tumble dryer again relies on opening windows for drying clothes. Despite the relative lack of interaction with the kitchen compared with W/14, the two small spikes in the conservatory temperature profile coincide with ventilation for cooking: both the glazed louvres and the glazed kitchen door were open at the lunch and tea time for a daily total of six hours.

Similar to the previous case study of W/9, the influence of the less controllable electric storage heating system is overwhelming. Mr C indicates that no auxiliary electric fire in the living room was used on that day, but the temperature profile does have two perceptible rises. The first starting at 16.00 corresponds to afternoon sunshine on the west facade. The second from 19.00-21.00 is likely to be partly induced by casual gains from occupants, lighting and appliances, and partly by the early evening recharge of the storage heater. (It is worth noting that the Scottish Power supplies electricity at the 'controlled circuit' tariff for storage heating for a period of totalling 8½ hours in each 24 hour period commencing at noon, as described in Section 4.1.4.) This is also supported by the corresponding rise of the hallway temperatures.

The mean 24-hour temperature of bedroom 1 at 19.9°C is actually higher than the daytime temperature (07.00 - 23.00 hour) at 19.75°C by 0.15K, so that the overnight temperature is slightly higher than during daytime and above the general requirement for comfortable sleeping. This room has a convector heater, but this was not used on that day, and heat must have been gained, mainly by conduction, from storage heaters recharging overnight in the other spaces This relatively high overnight temperature was repeated in all the other habitable rooms.

Mr C's habit of leaving most internal doors, including the kitchen-conservatory door and the bedroom 1 patio door, open during the day is also influenced by the pet dog. Findings in Section 5.3.7 have identified the connection between pet ownership and a high ventilation demand, particularly evident in electric-heated houses. Mr C does admit that Rocky is allowed to wander freely inside the house and in the two sunspaces, in the latter case probably from early spring until late autumn, when the veranda is used as a kennel and the conservatory for feeding.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR^2w
12 Apr.'93	6	6	6	6	6	6	9	6
Opening period	(9-12 & 15-18)	(9-12 & 15-18)	(9-12 & 15-18)	(9-12 & 15-18)	(9-12 & 15-18)	(9-12 & 15-18)	(9-19)	(9-12 & 15-18)

Table 6.27 Daily Summary Of Opening Windows/Doors From Diary (Hours of opening in brackets).

Legend:

Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^2w	Bedroom 2 window

Having identified that pet ownership influences the pattern of opening internal doors, bedroom 1 patio door and kitchen glazed door from spring to autumn, it is fruitful to examine whether this has continued in the winter months when the weather is likely to be too cold or dull to have any windows or doors opened on to the two sunspaces for any length of time.

6.3.5 DAILY PROFILE - 18 JANUARY 1994

Dull and cold day with light drizzle in the late afternoon

The weather on 18 January 1994 is a typical cold, dull and wet winter day with minimal global radiation measured. Potentially, the two sunspaces can contribute ventilation preheat in such weather more by heat recovery mode than by solar gain. The mean daily ambient temperature is 5°C and the daytime (07.00 - 23.00 hour) temperature is slightly warmer at only 5.5°C. This is quite similar to the 12th April. Therefore it appears to be the wintry dullness - 'dreich' is a Scottish term in describing such weather - that deters the occupants from opening any of the outer windows, as confirmed by the weekly diary (Table 6.28). This perceptional difference of weather and the consequences with respect to the occupants' intervention may be important. Mr and Mrs C seem to react to what they see from within, rather than what they might feel outside. Even then a bright cold April day might 'feel' warmer than a dull cold January day without any other significant difference - i.e. temperature or wind velocity. The extra solar radiation is of course a tangible physiological difference, but the psychological sense of well being could well be influential. It also accords with the tendency to ventilate in autumn and spring at a level higher than warranted by outside temperature, the sunshine again working at two levels - that of an energy provider and an icon of good cheer. The two sunspaces work very well as buffer zones, with the respective temperatures in the living room and bedroom 1, as in Figure 6.6 (overleaf), at least 11K and 9K above that of the veranda, which is in turn about 5K above ambient. The conservatory also enjoys a similar degree of temperature uplift of about 9 - 14°C during the daytime with two minimal spikes at 10.00 and 18.00 hour. Mr C stated in the diary that no washing was done in this particular week.

(in hours)	Cw	C/Kd	C/Kl	B/Vp	L/Vd	Vw	Lw	BR^2w
18 Jan-94	0	6	6	0	0	0	0	0
Opening period		(9-12 & 15-18)	(9-12 & 15-18)					

Table 6.28 Daily Summary Of Opening Windows/Doors From Diary (Hours of opening in brackets).

Legend:

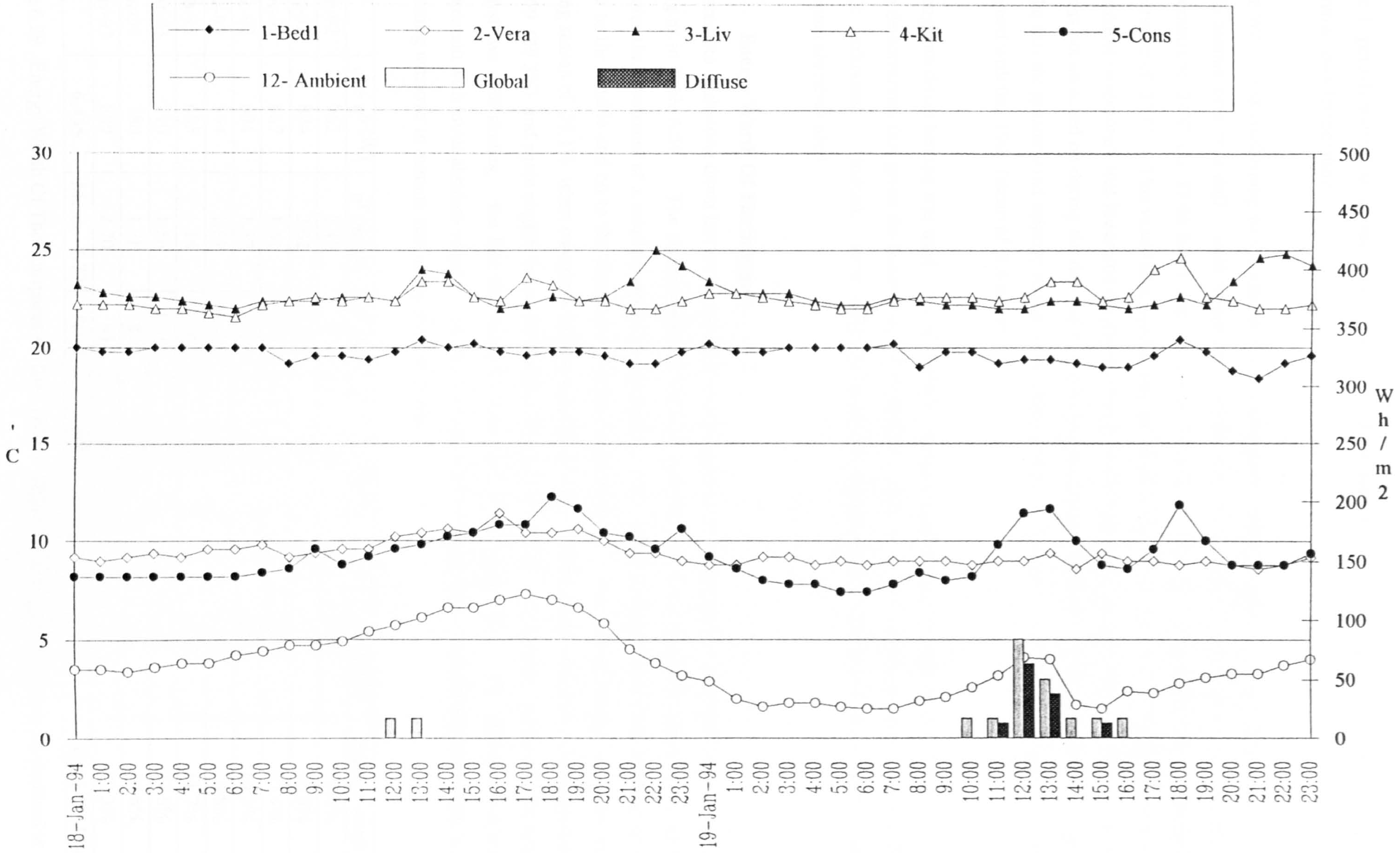
Cw	Outer Conservatory window
C/Kd	Conservatory / Kitchen glazed door
C/Kl	Conservatory / Kitchen louvres
B/Vp	Bedroom / Veranda patio door
L/Vd	Living room / Veranda glazed door
Vw	Outer Veranda window
Lw	Living room window
BR^2w	Bedroom 2 window

Having propounded a notion of 'feel-good' or 'feel-bad' perceptions of outside conditions influencing decisions with respect to opening window, this is likely to operate within a broader awareness of season. The 19th January is somewhat colder than the 18th and significantly brighter, but does not result in more opening of windows. It does however result in a rather greater 'lift' in temperature within glazed spaces. Also in the case of the conservatory, the glazed roof admits enough solar radiation from 11-14.00 to give a respectable surge; while a second surge from 18-20.00 corresponds to a cooking gain from the kitchen.

All this suggests that on a low solar radiation day with no occupant intervention and operating in buffering/heat recovery mode, the two sunspaces perform similarly in spite of their different orientation and the extra transmission loss from the conservatory. The west facing veranda shows no impact of solar gains although there is a gentle rise of temperature from 9°C to almost 11°C during the day, corresponding to the rising ambient temperature. The respective temperature differences of 13K and 10K between the veranda, the living room and bedroom 1 are slightly better than the subset of Glenburnie/electric. The n^e for January 1994 is 0.69 ac/hr. This is significantly lower than the subset of Glenburnie/electric at 1 ac/hr and the benchmark value at 1.02 ac/hr for winter in the previous year.

Three out of four storage heaters in the house of G/6 were in use except the one in the kitchen, which was out of order and not used. Although the kitchen was not heated, the temperature profile is very similar to the living room and the hallway (hallway temperature not illustrated) except occasional spikes caused by casual gains whilst cooking. Pet ownership again explains why most internal doors consistently remain open resulting in closely aligned temperature profiles in the whole house. The winter weather, although not noticeably colder, led to the use of the auxiliary electric fire for a total of 4 hours in low setting as indicated in the diary, most probably

Figure 6.6 - 18 & 19 January 1994 - G/6



in the 2 periods starting at around 12.00 and 20.00 hour when there were two gentle temperature upsurges in the living room temperature.

As at W/9, and conforming to the idea of weather perception outlined above, a psychological need to see a visible radiant heat in a dull, cold winter day explains why Mr C used the electric fire to boost the room temperature to 24°C (at 13.00 hour) and 25°C (at 22.00 hour) when the room was already at a comfortable temperature of 23°C. This would also explain why on the following sunnier day on 19 January, even though the ambient temperature was lower and the daytime living room temperature lay between 22 - 23°C, the electric fire was not switched on during the day and was only briefly used just after 21.00 hour. Another explanation may be that the greater wind velocity on the 18th (daily mean of 3.4 m/sec) contributed to a need for extra heat compared with the 19th (mean of 1.4 m/sec).

Although no direct heating was used, the bedroom 1 maintains a steady temperature at around 20°C. This again demonstrates that given the house is so well insulated, there is no need to have the convectors installed in the 2 bedrooms. Indeed, most occupants in electric-heated houses confirm that the convectors in both bedrooms are never used.

6.3.6 Energy Worth Of The Sunspace

The scenario of shutting down late in autumn and opening up early in spring results in a seasonal trend of energy saving as in Table 6.29. The energy saving of 24% in autumn, of 14% in winter and of 54% in spring validates the robustness of a small sunspace in the context of the Scottish climate with more opening up of the house to the outside and on to the sunspaces in spring in particular. The overall energy saving for the first heating season of 29.1% when compared with an equivalent REF+ model is also very close to the previous case of W/9 (29.3%) and again slightly below the benchmark value of 31.2%. Of course, as stated with respect to the first two case studies, the fuel bill would be lower still if the same (n^r - n^e) difference occurred in combination with lower absolute values. So the question of determining what is normal and reasonable in terms of opening windows in autumn and spring is again raised.

	$q^1 + q^s$ (W)	n^r (ac/hr)	q^h (W)	Q^h REF+(kWh)		Q^{h_m} G/6 (kWh)	Energy worth
Sep-92	762	2.42	715	515		466	9.4%
Oct-92	824	2.02	1,318	981		563	42.6%
Nov-92	667	1.51	1,159	835		673	19.4%
Dec-92	604	1.33	1,480	1,101		889	19.3%
Jan-93	594	1.51	1,451	1,080		974	9.8%
Feb-93	605	1.14	1,055	709		626	11.7%
Mar-93	710	1.56	1,146	852		617	27.6%
Apr-93	780	1.78	871	627		310	50.6%
May-93	889	2.70	933	694		123	82.3%
	6,435	**Mean 1.77**	**Total**	**7,394**		**5,241**	**Mean 29.1%**

Table 6.29 Energy Worth Of The Sunspaces of G/6. (REF+ Heated and ventilated to the same standard as G/6)

6.3.7 SUMMARY

The household of Mr and Mrs C represents a typical energy user in many aspects, although the n^c and n^r are slightly above the subset of Glenburnie/ electric. The Qh_m of the G/6 (5,241 kWh) is only +8.4% higher than the subset of Glenburnie/ electric (4,835 kWh) and -6.9% lower than the benchmark (5,631 kWh). The two temperature profiles examined in the previous section confirm a high level of opening up of the house on to the sunspaces, especially in the bedroom 1 and living room on to the veranda (more in spring than winter), and relatively less opening of the outer sunspace windows. Despite the volume being somewhat extended in part of the heating season, it is very encouraging to find the subset of Glenburnie/ electric is merely +7.7% above the predicted 'yardstick' (4,486 kWh for the subset) for the east-west oriented houses with an electric storage heating system. Again, this invalidates the logic of a single rate of air change applied throughout the heating season in terms of thermal modelling. This case study also confirms the relative robustness of the sunspace with respect to 'misuse' or inappropriate interventions, incurring a fairly small penalty in energy saving, and with the impact of the extra opening of windows in autumn and spring softened by the preheating effect.

Had Mr and Mrs C exercised better ventilation controls on the doors/windows abutting the sunspaces (by shutting them down earlier in autumn and opening up later in spring), and also better damper and charge controls on the electric storage heaters, the space heating load would no doubt have been lowered. Indeed, a reasonable level of thermal comfort is achieved by a small number of solar households with a relatively low space heating input. These showed that it is possible to achieve a relatively low n^r by less opening up of the house and the two sunspaces. However, this may result in a stuffy environment with poor air quality, an aspect which has relevance in the final case study, that of the household of G/10.

6.4 CASE STUDY 4 - G/10

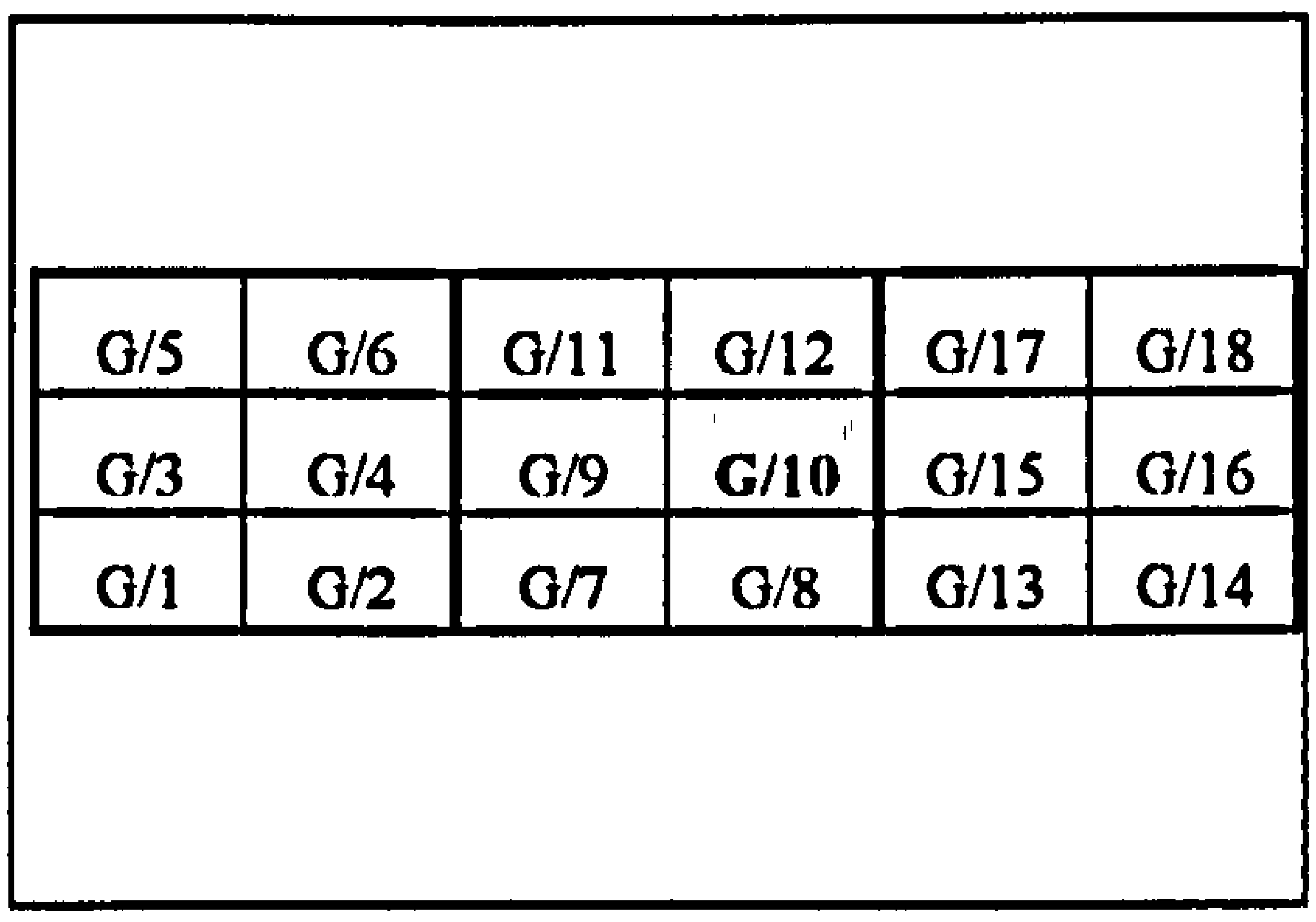
6.4.1 HOUSEHOLD PROFILE

Location first floor, mid-terrace, Glenburnie Place.

Heating system electric storage heating system and convectors in the two bedrooms.

Occupants' profile Mr D aged 35 and lived alone, a heavy smoker, works during the day (09.00 - 17.00 hour), use the storage heaters as background heating and the electric fire and convectors to boost room temperatures when needed.

Author's observation tolerable/stuffy air quality due to low n^r and the heavy smoking habit of the Mr D, but the relatively low house temperature may distract from the poor air quality.



6.4.2 THREE KEY INDICATORS

The household of G/10 has the lowest volumetric space heating load, fuel:warmth ratio and the third lowest cost:warmth ratio (the lowest in electric-heated houses); but it also has a respectable mean living room temperature of 20.16°C and zone 2, 17.75°C. This case study demonstrates that an adequate warmth can be achieved with a relatively low level of space heating input, provided that the ventilation controls are used rather sparingly by the occupant.

When the house is unoccupied during the day, the sunspace performs in passive ventilation pre-heat/heat recovery modes close to design assumptions. The decision on the part of the occupant only to use the electric storage heaters as background heating, and the electric fire in the living room and the convectors in the two bedrooms to boost room temperature if and when needed has maximised the energy saving and performance even though the direct electric tariff is several times more expensive than the storage tariff. This case study also proves the use of the electric fire to top up electric storage background heating is sufficient to provide adequate warmth at least for a single working adult household.

Table 6.30 confirms that the 3 key indicators are significantly below the benchmark and the subset of all-electric. Although G/10 benefits from the lowest transmission loss of 51.88 W/K for a first floor mid-terrace location compared with 79.82 W/K for a ground floor, gable-end one, this difference alone could not have caused such a high variation of 60% in the fuel:warmth ratio between G/10 and the subset of all-electric. The modest demand temperatures and the regime adopted for responsive relative to background heating are clearly influential, but also are other parameters, notably the rate of ventilation.

	Net Qh_m (kWh/m³)	Fuel:warmth (kWh/m³K)	Cost:warmth Ratio (£/K)
G/10	10.88 (-71.1%/ -67.8%)*	0.96 (-66.9%/ 62.4%)*	4.91 (-58%/ -63.9%)*
All electric (14)	33.8	2.55	13.59
Benchmark (34)	**37.75 (±0%)**	**2.9 (±0%)**	**11.68 (±0%)**

Table 6.30 Three key indicators of G/10. (* ±% above benchmark and subset in brackets)

6.4.3 Other Key Indicators - Heating Season And Monthly

The mean veranda temperature is 0.61K below, but at least partly as a consequence of low usage, the conservatory is 1.2K above the all-electric subset. The use of the electric storage heaters as background heating has reduced the disadvantages of the less responsive and controllable storage heating system. The mean n^{c} of G/10 (see Table 6.31) which is just 35% of the benchmark value and 40% of the all-electric subset is inevitably largely responsible for its low space heating load, and as such, equally inevitable raises the issue of air quality compared with the previous three case studies.

	Net Qh_m in kWh/ (±%)/ Qh_SODEM-adj	Z1 + Z2 °C/ Z1 °C/ Z2 °C	Veranda [max/ mean/ min]	Conservatory [max/ mean/ min]	Eff. ac/hr - mean [aut./winter/spring]
G/10	1,623 (-46.5%) 3,031	18.4 / 20.16/ 17.75	14.3	14.56	0.39 [0.4/ 0.4/ 0.36]
All electric (14)	5,041 (± 0 %) 5,047	20.21/ 23.07/ 19.11	19.2/ 14.91/ 13	15.94/ 13.36/ 10.06	0.96 [1.01/ 0.9 / 0.98]
Benchmark (34)	5,630 (+23.5%) 4,558	19.86/ 22.21/ 18.96	19.79/ 15.06/ 11.9	17.18/ 13.08/ 8.81	1.14 [1.18/ 1.02/ 1.2]

Table 6.31 G/10 With Other Data.

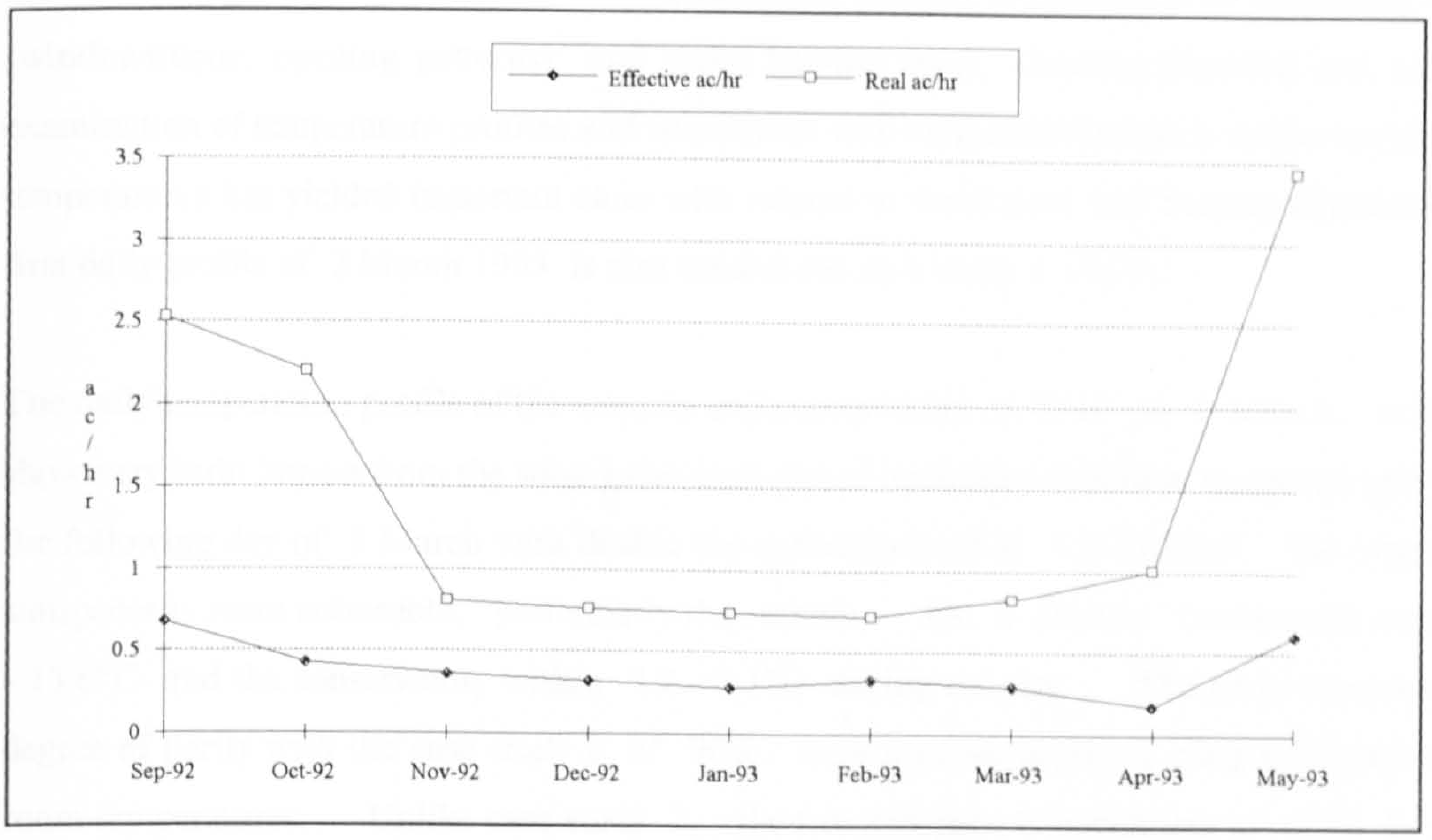
Compared to the subset of Glenburnie/electric, Table 6.32 again demonstrates a consistently lower monthly living room temperature by an average of 2.51K, with a maximum shortfall of 4.04K in November and a minimum of 0.78K in January. For the rest of the house, the temperature difference is about 1K throughout the heating season except November.

The veranda and conservatory temperatures are generally somewhat higher than the Glenburnie/electric subset. It is worth noting that no space heating load is recorded in April and May and virtually none in September. This is the order of performance predicted for a 21°C demand in the living room and a uniform 1.5 rate of air change and a reasonable proportion of the air supply coming in via the sunspaces. Mr D is, however, an exception rather the rule.

	Z1	Z2	Veranda	Conservatory	Ambient	Qh_m	Qh_SODEM-adj
Sep-92	19.41 (21.62)	18.2 (18.3)	16.49 (17.59)	17.59 (17.65)	11.65	7 (192)	0 (85)
Oct-92	18.69 (21.57)	16.41 (17.22)	14.72 (14.42)	14.8 (12.74)	6.56	94 (367)	109 (324)
Nov-92	18.15 (22.19)	15.79 (17.66)	13.4 (12.36)	13.61 (12.45)	5.72	187 (683)	274 (641)
Dec-92	20.3 (22.8)	17.5 (18.18)	11.61 (12.77)	12.05 (10.8)	3.57	429 (785)	722 (889)
Jan-93	22.25 (23.03)	19.0 (18.27)	11.29 (10.98)	12.7 (12.59)	4.76	446 (961)	884 (923)
Feb-93	20.95 (23.64)	18.1 (18.67)	13.81 (13.4)	13.23 (13.57)	6.38	274 (647)	506 (664)
Mar-93	20.07 (23.57)	17.7 (18.18)	14.15 (14.03)	14.3 (13.77)	6.75	186 (627)	408 (586)
Apr-93	20.57 (23.57)	18.26 (19.17)	16.55 (17.36)	16.24 (15.26)	9.02	0 (397)	128 (308)
May-93	20.06 (22.05)	18.81 (19.28)	18.94 (18.51)	18.18 (17.05)	10.74	0 (176)	0 (66)
mean/sum	20.16 (22.67)	17.75 (18.33)	14.55 (14.6)	14.74 (13.99)	7.24	1,623 (4,835)	4,577 (4,486)

Table 6.32 Monthly Data Of G/10. (Electric/ Glenburnie Place Subset values in brackets).

The n^{e} and n^{r} are one of the lowest in the CEC project with a mean of 0.39 and 1.45 ac/hr respectively as shown in Table 6.33. Qh and both n^{e} and n^{r} are re-adjusted from November to January due to irregular meter readings, but the overall values for the period are not affected. The n^{r} is again lower in winter (0.6 ac/hr) than in autumn (1.35) and in spring (1.13). The question to pose is that although such a low winter n^{r} may be acceptable to a single adult working household, will it be suitable or achievable for occupants occupying their houses all day ? In order to appraise the acceptability of such a low n^r, it is also necessary to examine the daily temperature profiles in spring and winter in order to establish whether thermal comfort would be met had the house been occupied all day.



Month	Z1 / Z2	$q^s + q^i$ (W)	n^e / n^r	q^h (W)^1	Q^h (kWh)^1
Sep-92	Z1	139	0.68 / 2.53	10	7
	Z2	439			
Oct-92	Z1	151	0.43 / 2.2	126	94
	Z2	486			
Nov-92	Z1	121	0.36* / 0.81*	259	187
	Z2	385			
Dec-92	Z1	100	0.32* / 0.76*	575	429
	Z2	345			
Jan-93	Z1	94	0.28* / 0.74*	597	446
	Z2	330			
Feb-93	Z1	101	0.33 / 0.72	408	274
	Z2	344			
Mar-93	Z1	135	0.29 / 0.83	250	186
	Z2	401			
Apr-93	Z1	146	0.17 / 1.01	0	0
	Z2	449			
May-93	Z1	176	0.61 / 3.43	0	0
	Z2	513			
		Mean	**0.39 / 1.45**	**2,225**	**1,623**
				Total (W)	**Total (kWh)**

Table 6.33 Effective And Real Rate Of Air Change With Other Data.

(^{1} - q^h and Q^h as measured and * re-adjusted for November - January due to irregular meter reading)

6.4.4 DAILY PROFILE - 2 MARCH 1993

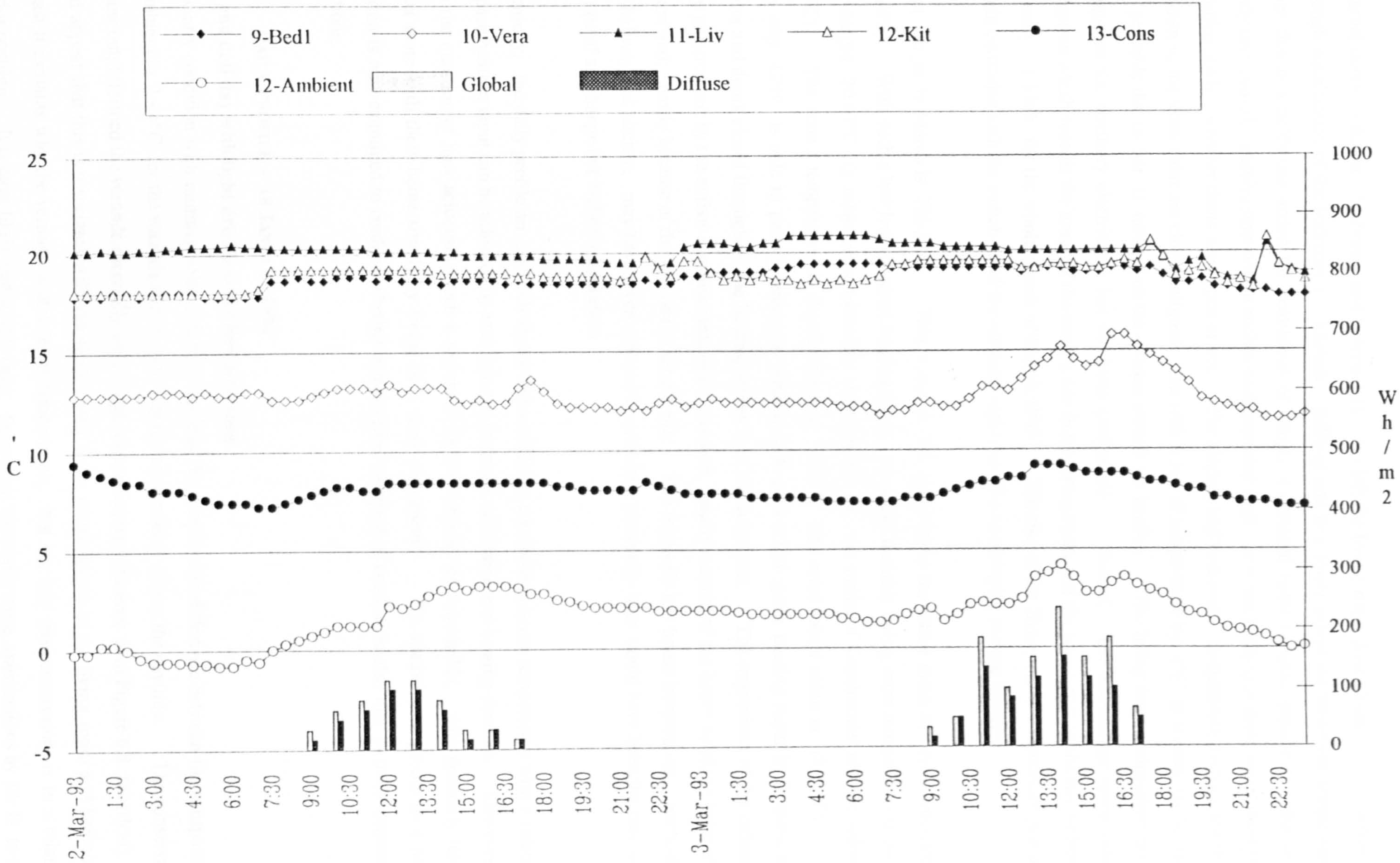
Cold but sunny spring day

G/10 is not one of the diary-keeping households and Mr D did not show much enthusiasm in co-operating with the monitoring work. Therefore daily temperature profiles are unable to be correlated with ventilation controls (windows/doors opening patterns) and space heating input (heating duration and setting). Nonetheless, examination of temperature profiles and correlation with measured data such as the weekly space heating load and temperatures has yielded important clues with respect to ventilation and heating demand of the occupant. The first daily profile of 2 March 1993 is also used in the case study 2 (W/9).

The daily temperature profile of the veranda and conservatory of G/10 on 2 March, as in Figure 6.7 (overleaf), show very little impact from the solar gains with global horizontal radiation measured only at 0.6 kWh/m². On the following day of 3 March with double the radiation level at 1.2 kWh/m², the impact of solar gain on both sunspaces is more noticeable, particularly the veranda. On 2 March, the veranda temperature falls within 12 - 13.6°C and the conservatory within 7.2 - 9.4°C during the day. The daily temperature profile shows some degree of parity with the case study 2 of W/9, both profiles having a clear segregation between sunspace and room temperatures. Unlike case study 2, the two sunspace temperatures of G/10 lie within a narrow range: in the case of the veranda the daily difference is 1.6K (13.6°C - 12°C); and for the conservatory, the difference is even smaller at 1.2K (8.4°C - 7.2°C). This is in sharp contrast to W/9 where the daily difference in the veranda temperature is 4.4K (12.4°C - 8°C) and the conservatory is 4.2K (7.6°C - 3.4°C), the only significant physical difference being orientation. Most importantly, the mean daily veranda and conservatory temperatures of G/10 are relatively high at 12.75°C and 8.12°C respectively and this is almost 2.5°C higher than the W/9 in the case of both sunspaces (mean daily veranda, 10.33°C and conservatory, 5.37°C). The information with respect to ventilation and heating controls on Mr D's returned questionnaire is relatively sketchy, but provides clues. The higher temperatures in the two sunspaces are attributed to less window opening in the outer sunspaces, rather than more heat gain from the house. One of the reasons for less window opening is that Mr D lives alone and works during the day. Mr D usually closes and locks all outer windows and doors on to the sunspaces before leaving for work for security reasons in spite of living in a first floor house. This then indicates that the 4-5K higher temperature in the veranda coupled with the conservatory is due to a combination of the slightly higher temperature in respective 'host' rooms, and the lower rate of heat loss from the recessed veranda. The latter was clearly dominated and therefore clarifies the underlying cause of the same differential in the case of W/9. The small spike in the veranda between 17.30-18.30 is probably caused by heat gain from the living room after Mr D opened the living room glazed door for ventilation for a short period after returning from work.

The house temperature profiles show little sign of premature discharge of heat from most of the storage heaters. The better damper control on the electric storage heater in the living room by Mr D results in a steady comfortable temperature at about 20°C throughout the day, and this theory is also applicable to the use of other storage heaters in the hallway, kitchen and bathroom. It is likely that Mr D switched the damper controls of the storage heaters to the lowest setting of 1 or 2 and set the overnight re-charge control to 2 or 3 (the maximum is 7) before he went to bed. When Mr D woke up in the morning at around 07.00 hour, he opened most of

Figure 6.7 - 2 & 3 March 1993 - G/10



the internal doors (kitchen, bathroom and bedroom 1), but left the living room door closed. The result has been rough equalisation of the bedroom 1, kitchen, hallway and to a lesser extent the bathroom temperatures. Whether this is a deliberate action for ventilation or simply a personal habit remains unknown, but in its relatively unoccupied, passive state within such a well-insulated shell, it is not likely that there would have been large differentials, whether doors were open or not. The kitchen and bedroom 1 temperature profiles which are also shown in the same chart are closely aligned, but with a rise of temperature by 1°C at around 07.30 hour. This is probably due to Mr D turning up the damper control for heating. The living room temperature profile also suggests the auxiliary electric fire has not been used at all. Indeed, the non-storage space heating consumption which records the usage of the electric fire in the living room and the convectors in the two bedrooms was merely 11 kWh for the whole month of March 1993. The rise of the living room temperature just after midnight coincides with the switch-on of the off-peak night tariff for re-charging storage heaters.

The net Qh_m in March is 186 kWh. This is almost 3½ times below the subset mean of Glenburnie/electric (627 kWh). With such a low level of space heating input, the mean monthly living room temperature in March still averages 20.07°C (a relatively comfortable environment cf. the mean of Glenburnie/ electric subset at 23.57°C). The zone 2 temperature is slightly lower at 17.7°C (the same subset mean is 18.18°C). The reason why G/10 is able to provide adequate warmth with such a low space heating input by keeping most windows and doors closed throughout the heating season is of much interest. The impression of the indoor air quality as perceived by the author is of tolerable/stuffy standard, partly because of the heavy smoking habit of the occupant and, partly because of the low rate of air change. The relatively low house temperature, particularly in the hallway and kitchen, may have given a perception of better air quality than would have been the case at the same rate of air change but higher temperature.

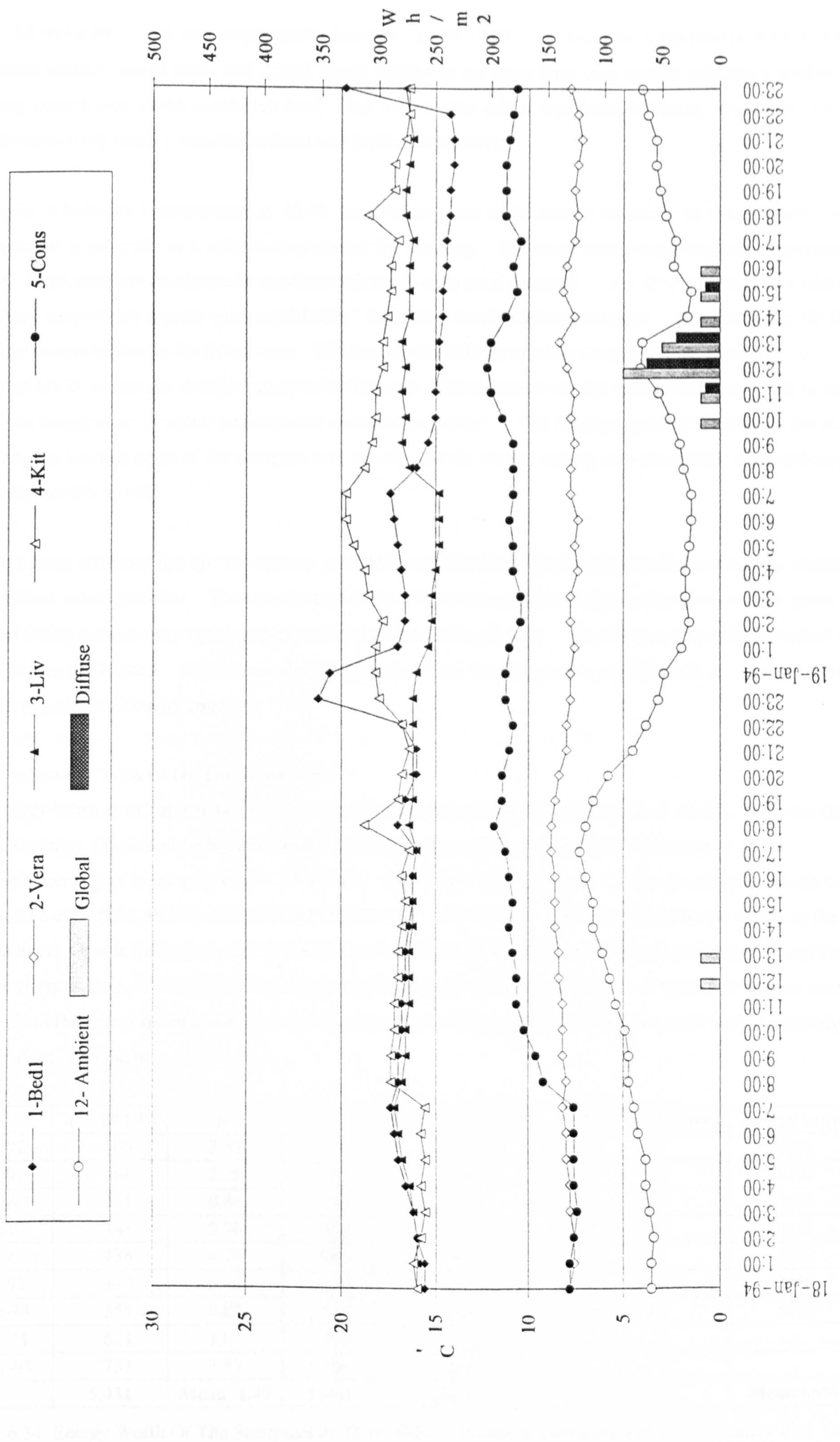
In summary, the daily profile on 2 March shows that a modestly comfortable house temperature with a relatively low space heating input can be achieved by exercising appropriate ventilation and heating controls. However, it raises the question of how achievable such a regime is for the majority of households, who generally tend to interact more with their home simply by living in it more intensively. The temperature profile in a wintry condition is now examined to confirm whether a reasonable standard of comfort is also met in more demanding conditions.

6.4.5 DAILY PROFILE - 18 JANUARY 1994

Cold and dull day with light drizzle in the late afternoon

The wintry condition with minimal solar radiation has kept the temperature difference between the sunspace and the ambient to 2 - 4°C for the veranda and 4 - 6°C for the conservatory during the daytime. The conservatory has now outperformed the veranda thermally with a higher temperature difference as in Figure 6.8 (overleaf). It would appear that this is associated with the significantly lower temperatures in the living room and bedroom 1. At least it explains why the veranda is at a lower temperature, but not why the conservatory is in a relatively superior position. It is most likely that in this case, there must have been some interventions by Mr D to cause this, although wind direction may also be relevant. The daily mean wind speed at 3.4 m/sec from the south-east is recorded in the City of Glasgow. Note for example the tracking of the conservatory relative to the kitchen

Figure 6.8 - 18 & 19 January 1994 - G/10



from 08.00-09.00, and less emphatically between 18.00-19.00. The low temperatures with a smaller difference between heated zones and glazed spaces relative to the other three case studies indicates a smaller heat recovery contribution to the ventilation load, but nevertheless still a significant buffering effect with sunspace temperatures lying steadily between ambient and inside temperatures.

The spike in bedroom 1 temperature at 22.00 hour indicates use of the electric convector by the occupant, while the bedroom is generally at a suitable temperature for sleeping, the mean living room daytime temperature of 16.4°C is not adequate for sedentary comfort if the house were to be occupied. Mr D 's tolerance of a relatively low house temperature appears quite remarkable, but it may simply indicate absence. It is likely that Mr D has used the storage heaters in the living room, kitchen and the hallway at a low charge setting of about 2 - 3. The policy of Mr D to use the storage heaters as background heating and to use the electric fire/convectors to top up the house temperature in winter when needed works in his favour. The rapid response of the electric fire is able to satisfy the thermal needs of the occupant very quickly and the visible radiant heat also satisfy the psychological needs for warmth as well.

The following reference day on 19 January provides a rather better example of sunspaces working in ventilation preheat/heat recovery mode. The stratification of the temperature profiles confirms the effects of solar gains with the east facing conservatory again outperforming the west facing veranda. In this case its profile is further from ambient than the kitchen, which unusually is higher than both the living room and bedroom 1, but still not high enough to provide sedentary comfort.

6.4.6 ENERGY WORTH OF THE SUNSPACES

The energy worth as in Table 6.34 is 65%, significantly higher than the benchmark of 31.2%; but note that in absolute terms, this is not the highest 'worth' of the four case studies, being well below that of W/14. Had the worst scenario B been adopted for n^r values, rather than likely scenario C, the proportional worth would drop to just over 50% and the absolute worth to just over 1,700 kWh. This would then be the lowest of the four case studies, but is unlikely to match reality since scenario B assumes a very small proportion of infiltration occurs via sunspaces. In spite of the re-adjustment from November to January, a consistent pattern emerges with n^r in the winter months slightly lower than autumn and spring even for this household with a relatively low mean n^r of 1.45 ac/hr.

	$q^l + q^s$ (W)	n^r	q^h (W)	Q^h REF+ (kWh)		Q^{h_m} G/10 (kWh)	Energy worth
Sep-92	606	2.53	594	428		7	98%
Oct-92	668	2.20	987	734		94	87%
Nov-92	511	0.81	449	323		187	42%
Dec-92	448	0.76	833	619		429	31%
Jan-93	438	0.74	865	644		446	31%
Feb-93	449	0.72	615	414		274	34%
Mar-93	554	0.83	521	388		186	52%
Apr-93	624	1.01	358	258		0	-
May-93	733	3.43	1,106	823		0	-
	5,031	**Mean 1.45**	**Total**	**4,630**		**1,623**	**Mean 65%**

Table 6.34 Energy Worth Of The Sunspaces of G/10. (REF+ Heated & ventilated to the same standard as G/10).

6.4.7 SUMMARY

This case study proves that the sunspaces have performed very well in a rather non-interventionist mode. The occupants' relatively closed routine allows optimum thermal performance of the sunspace. This accords with the findings of Baker, Guy and Strachan[1] on a test cell in Glasgow - i.e. that a sunspace can provide a significant ventilation preheat contribution especially on a sunny and cold day.

Although the heating regime in this case appears to satisfy Mr D, rooms are at times distinctly cool, and this in turn may mark a relatively stuffy air quality. It is doubtful whether such a regime of heating and ventilation is suitable for other households, for instance OAP or young adult with infant, who are likely to occupy their houses all day and demand a relatively high temperature. Had it been otherwise, then the potential of the sunspaces even at the relatively high latitude of Glasgow would have been significantly greater. Unfortunately, the likelihood is that G/10 constitutes as an exceptional case rather than a norm.

Nonetheless, this case study clearly demonstrates that a 'comfortable' living condition is possible with a relatively low heating input for a well insulated, energy efficient solar house and for a particular household type. There is little doubt had the house been occupied all day, the space heating load would have been higher. In addition, it would have increased the opportunity for the occupants to intervene with respect to the heating and ventilation controls.

6.5 SUMMARY OF THE CHAPTER

The first three case studies demonstrate the psychological and physical needs for fresh air negating optimum energy savings as a result of the provision of the sunspaces. For example, Mrs A, a non-smoker, of W/14 is perhaps more psychologically motivated to airing the house than Mr A as a smoker. This, together with a longstanding airing routine, and needs revolving around a young infant - smelly nappies, large washing loads, etc. - help to explain a very high rate of ventilation around 3.01 ac/hr. Such a value represents the highest end of a sample of 34 houses and so cannot be regarded as typical. However, it does flesh out trends established in the previous chapter with respect to smoking and infants, and is in a disadvantaged location in terms of transmission loss. Therefore it cannot be regarded as that unusual, and the psychological need for ventilation relative to heating is perhaps a subject which deserves even more thorough research. An interesting outcome is that the high ventilation rate is still significantly 'calmed' as an energy waster due to the presence of the sunspaces.

The households of W/9 (Mr and Mrs B) and G/6 (Mr and Mrs C) share similarities with the first case study. Once again the demand for fresh air results in a relatively high level of ventilation both in effective and real rate of air change, but not to the same extent as W/14. The less responsive electric storage heating system does not result in an exceptionally high space heating load on the one hand, but it does cause energy wastage, as demonstrated in the higher overnight temperature, on the other. The presence of both a smoker and non-smoker within the same household of W/9 and two smokers plus a large dog in G/6 again supports the findings

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[1] BAKER P., GUY A., STRACHAN P. PERFORMANCE ASSESSMENT OF A CONSERVATORY IN SOLAR VENTILATION PRE-HEAT MODE. Proceedings of the North Sun '94 - Solar Energy at High Latitudes. September-1992 p.p. 132 - 137.

in Chapter 5: that smokers tend to ventilate more than the non-smokers, and that pets generate a similar propensity to liberally ventilate as households with infants.

The household of G/6 (Mr and Mrs C and Rocky) with a modest n^r of 1.77 ac/hr and W/9 at 1.82 ac/hr represent the middle ground, with the opening up of the house and the sunspaces in the case of the G/6 attributed largely to pet ownership and occupant intervention, whereas the case of W/9 is more driven by personal aspirations than needs. The middle group of eight, just under one quarter of the sample of 34 who co-operated fully with the monitoring programme in the first year, is in the fuel:warmth ratio range of 2.15 - 3.04 kWh/m³K, with a mean of 2.5 kWh/m³K. Only one of these is on the ground floor. In the thirteen houses below this first group, again only one is on the ground floor; while in the highest thirteen, nine are on the ground floor and another two on second floor, gable-end locations. So although this chapter has been emphasising the role of intervention by occupants, the physical parameters are still on the agenda.

G/10 (Mr D) in case study 4 demonstrates that when sunspaces are not used to any great extent, a high relative 'worth' can be achieved. This is in fact an exceptional case, but the low temperatures achieved in the heated zones mean that the 'worth' expressed in kWh is not as great as the highly heated and ventilated case of W/14.. Indeed low fuel bills can also be achieved even when partial opening up of the house and the sunspaces suggest negation of optimum performance. For example, W/12, a second floor, intermediate location house which had the lowest cost:warmth ratio of £4.13/K in the first year of monitoring had significantly lower winter sunspace temperatures compared with G/10 due to greater opening of outer windows; while heated zone temperatures and overall ventilation rates were quite similar to those of G/10 - 18.9°C cf. 18.16°C and n^e = 0.5 ac/hr cf. 0.4 ac/hr respectively for W/12 and G/10. It is also of interest that W/12 is a gas-heated, smoking household without infants or pets, and the author found the air quality tolerable as with G/10. Another house, W/17, has an even lower conservatory temperature then W/12 due to leaving the outer windows open, but ranks 6th lowest in terms of cost:warmth ratio. Again, achieved temperatures in heated zones are modest and ventilation (n^e = 0.67 ac/hr) somewhat more liberal, especially in spring. In this case the household was non-smoking and the author found the air quality fresh.

The four case studies highlight the importance of occupant-related factors and their impact on energy demand for space heating in addition to physical variables. Hence, this chapter demonstrates the importance of embracing such factors in predictive models. Indeed, a deficiency of many manual calculation methods and computer programmes is that energy simulation is based on a 'typical' household with its rate of air change determined primarily by physical characteristics. The household size affects casual gains and water demand, and is allowed to top up air infiltration to a predetermined limit. It would appear from this work, set in the context of other significant field studies (see Section 4.1.5), that such methodology falls within the category of wishful thinking.

CHAPTER 7 CONCLUSIONS

7.1 SUNSPACES AS A PASSIVE SOLAR TECHNIQUE

Monitoring results for the CEC solar-retrofitted project have confirmed that the unheated solar buffer zone, or sunspace, as a passive solar technique is relevant even at this relatively high latitude at 55°52'N. This technique is assessed with reference to an energy-efficient design which emphasises insulation, ventilation and heating and investigates the impact of the two sunspaces on opposite facades of each dwelling. It is worth prefacing conclusions by emphasising again that the technique of small sunspaces is not wholly reliant on solar energy for its success. A completely unglazed, unheated buffer space would also have a mean temperature somewhere between ambient and heated interior, and so would be a viable proposition in terms of ventilation preheat - i.e. in the form of passive heat recovery. The addition of solar energy, trapped due to the greenhouse effect, is a bonus which has been shown to be influential - of the four orientations the south-east veranda performed best and the north-west conservatory worst.

By posing three questions (given in the third chapter on methodology), investigation revealed that firstly, the energy saving of the SOL compares well to both the REF- and the REF+ (where SOL is a solar house, REF-, a 'before' reference house, heated and ventilated to the same standard as SOL, and REF+ is a theoretical 'after' house, again heated and ventilated to the same standard as SOL, but lacking the sunspaces). In the first year, the thermal transformation of the SOL houses has resulted in a theoretical energy saving of 72% or 14,700 kWh when compared to the REF-. However, as none of the occupants would ever have been able to afford to heat and ventilate their REF- to the same standard as the SOL, such comparison remains theoretical. Comparing the SOL with an equivalent REF+ model gives a specific indication of the energy worth of the sunspaces: a substantial energy saving of over 2,500 kWh or 31% in the first year for the mean SOL house. In the second year the performance is marginally better than the first with the fuel:warmth ratio for the middle quartile reducing from 2.5 to 2.4 kWh/m^{3}K (although there is a small sample of 24 households who fully co-operated with the monitoring programme).

Investigation also shows that the amenity value of the two sunspaces is highly rated by nearly all the occupants, answering the second of three questions ***'How useful and usable are the sunspaces to the occupants ?'***. The 'qido' data undoubtedly confirms that both sunspaces were mostly used as intended. The utility-conservatory was well used throughout the year for washing and drying clothes, and a minority of occupants found other seasonal uses for it such as tea drinking and reading. More diversified uses were found for the veranda, ranging from the expected tea drinking and reading to a pet corner, play area for young children and 'winter garden'. However, winter uses were restricted and were commonly qualified by "if sunny". Close examination in Section 4.5 confirms that the sunspaces were usable even in winter if the incoming insolation was high and/or if the temperature was raised by heat gained from the house as a result of opening up extensively.

The third question ***'To what extent are the occupants' interventions affecting energy saving or mitigating optimum performance'*** is more complex to deal with. A user-driven energy load for warmth and ventilation has led to the wide variation of space heating load with the highest household 7.4 times higher than the lowest, and in terms of energy cost by a factor of 6. In broad terms the higher the achieved temperatures and higher the ventilation rates, the higher the space heating load. However, if it is accepted that an energy-efficient reference house without sunspaces, REF+, would be heated and ventilated to the same level to meet the needs/aspirations of the occupants in these two respects, then the sunspaces still work very much in favour of the occupants. In fact for these high users the 'worth' of the sunspaces is quantitatively greater than for medium or low users. The other integral issue is the extent to which the heated volume has been extended into the sunspaces, thereby increasing rather than reducing loads. Again in broad terms the monitoring and subsequent analysis has shown that although a considerable amount of opening up does occur, particularly in autumn and spring, this tendency is often associated with middle or low fuel consumers. There is also a marked tendency to open outer windows at times when ambient temperatures are still low enough to generate heating loads, particularly in spring. The decisions appear to be motivated by a mix of 'custom and practice', subjective perception with respect to the weather and particular household characteristics such as presence of infants or pets. The conclusions with respect to intervention and performance therefore deserve some expansion.

7.2 USER-PERFORMANCE SENSITIVITY

First of all, house temperatures were higher than anticipated especially in the living room and, in some cases, this was higher than the usual level for comfort. A better fuel:warmth ratio would have been achieved had a slightly lower thermostat setting been used in the gas-heated houses and more user-friendly charge and damper controls installed in electric-heated houses. There was a recognisable relationship between high house temperatures and high fuel consumption in the three key indicators; namely, volumetric space heating load, fuel:warmth ratio and, to some extent, cost:warmth ratio. In the latter case, the fuel tariff differentials between electric and gas modify disparities in the final two indicators up or down. Gas-heated houses are on average £110 cheaper for all energy and £46 cheaper for space heating than electric-heated houses during the first heating season.

The influence of affordable warmth

High house temperatures in gas-heated houses confirms that the occupants have a high desire for warmth which is in all probability linked to affordability. High gas consumers generally claim to find their house easy (i.e. affordable) to heat. It is not unusual to find the thermostat set to 23 - 25°C. In electric-heated houses, high house temperatures may also be caused by energy wastage from the less controllable and less responsive electric storage heating systems and this would explain why some households have relatively high temperatures when they are not needed, e.g. at night. This means that for a given thermostat setting, the electric house will average a higher temperature than the gas-heated. So occupants have to learn to adjust controls according to the result required, and although the measured temperatures are higher than needed, at least this eliminates the requirement for a surge of energy to overcome thermal inertia. In general, it is fair to conclude that tenants 'basked' in affordable warmth for the first time, and with a mean heating fuel cost of £150 from September to May (£370 for all fuel), there is moreover a tangible saving compared with their former circumstances.

Thus in contrast to the thermally sub-standard dwellings that the occupants used to live in, the affordable warmth of the SOL house perhaps leads to a rather cavalier attitude towards heating and ventilation controls. Examples of households with a liberal ventilation regime are abundant This results in a space heating load in the first year 23.5% above the yardstick predictions which assume a uniform value of 1.5 ac/hr throughout the heating season. In fact 1.5 ac/hr for n^r is too high in the December to February winter quarter. The value calculated from monitored data is 1.35 ac/hr for the first year and 1.23 for the second year; and in the second year the mean n^r from September to May is estimated as 1.6 ac/hr, not so much greater than the yardstick value.

Seasonal differentials are consistently apparent with all households ventilating more in autumn and spring than in the central winter months. In the coldest winter period most occupants are deterred from opening either the outer windows or the ventilation devices between the house and the sunspaces. With most windows and ventilation devices closed and the two sunspaces mainly operating in the heat recovery/buffering mode, the energy saving is found to be slightly higher than predictions. That said, this was not the case with a minority of households, where occupants stubbornly and consistently operate an extensive open-window routine throughout the year. As stated, temperatures are generally higher than predicted, and a particular psychological response to a dull and cold winter day seems to require a visible radiant heat and so results in unnecessary use of supplementary heating. Similarly, the increased incidence of window opening in spring appears to be in response to the end of a long, cold and dull winter. This is complicated by the fact that what is perceived on a bright spring day, also provides energy, but seldom enough to compensate wholly for the amount of ventilation.

Most sunspaces are well used throughout the year and no evidence of unintended direct heating was found, but in some cases the heated volume was extended to the unheated sunspaces for periods when the ventilation partitions were opened. Where opening up of the sunspaces signifies a change from an indirect to a 'direct-gain' mode, interference with energy saving is relative to the degree of incoming insolation. Some low space heating users, particularly those at Wardie Road with south-east facing verandas, did open up quite often in autumn and spring without negating their overall performance. Also even in cases with a higher than normal level of opening up in autumn and spring, the provision of the sunspaces has reduced the thermal burden of such a regime - that is the technique of ventilation preheat is not dependent on low rates of ventilation.

The reasons behind airing routines are many and complex. There is evidence that some occupants respond to their ventilation and heating controls in an individualistic way. But this is paralleled by a fairly consistent pattern of influential social and occupancy characteristics. For instance, the 'smoking' households ventilate more than the 'non-smoking' households and families with infants and/or pets also incur higher than normal rates of ventilation. However, such a small statistical sample does not allow conclusive analysis and further field studies of a large statistical sample are much needed.

Affordable warmth and physical variables

The way in which physical variables affect heating demands is easier to determine. Gas-heated houses tend to ventilate more than their electric-heated counterparts, probably because gas requires permanent ventilation. Orientation is found to be less critical especially when sunspaces are provided on opposite facades and gains and losses are cancelling each other out. Nevertheless, the south-east verandas of Wardie Road have an identifiable impact on performance. The mean temperatures, higher than those of the west facing veranda in Glenburnie

Place, give an advantage relative to both living room and main bedroom; while the relatively poorer performance of the north-west facing conservatory compared with east facing only impacts on the kitchen and bathroom. Ground floor and second floor gable-end locations also incur comparatively consistent higher heating loads and rates of ventilation than the first floor and mid-terrace partly due to air leakage.

Summary of the last question posed

Despite both physical and occupant-related factors negating optimum energy saving in some households, the sunspace as a passive solar technique proves itself to be fairly robust. Not only is this technique well suited to residents whose almost exotic need for fresh air leads to active and extensive opening of windows regardless of the weather and seasons, but also to less extreme examples, who may occupy the middle ground in terms of performance, whose constant and consistent need for fresh air results in most outer windows remaining ajar throughout the year. In other cases the presence of pets or infants contributes to the partial extension of heated volume by opening the ventilation devices between the sunspaces and the house. In terms of penalties on the energy worth of the sunspaces, these effects have reduced saving by relatively small margins below the mean value around 30% or 2,500 kWh. Therefore, referring to the mean as a norm, this system can be seen to withstand fairly vigorous occupant intervention.

7.3 OTHER LESSONS LEARNT

Universal rate of air change

Simulation models and other predictive methodology should be adjusted to accommodate a varying ventilation regime over a heating season, and in general tend not to allow adequately for normal human responses to perceived weather conditions. Such interventions also suggest that heat recovery systems may be compromised and, again, models should make due allowance for this 'phenomenon'.

Size and location of the sunspaces

The dimensional limitations of both sunspaces is thought to have inhibited direct heating in these spaces, although in some households heat gained from the house is not uncommon. The veranda which has a floor area of 3.03 m², and although it is frequently used as a sitting and reading area, it is too small to function as an independent room. Also as it opens directly on to the bedroom 1 instead of the living room, there is reduced risk of it being used and additionally heated as part of the main living space. The specific utility function of the conservatory, which measures 4.44 m², also renders it unlikely to be additionally heated, and merging of conservatory temperature with that of the kitchen due to the door being open tends to be intermittent, often coinciding with cooking/meal periods.

Heating system

The contrast of a rapid, responsive and controllable heating system such as the gas-fired central heating compared with electric storage heating is of interest. Both appear compatible with the sunspace technique, but given that the retrofitted houses are insulated to such high level, the necessity for a central heating system is questionable. Logging of house temperatures confirms that the provision of two fixed heating appliances, one in the living room and one in the hallway, are sufficient to provide adequate warmth. This is supported by the logged bedroom 1 temperatures of electric-heated houses where they are capable of maintaining a comfortable condition with respect to its use without any form of direct heating. Also the simpler the heating controls, the better the chance they will be effectively used by occupants. For example, some elderly occupants found the digital programmer of the gas central heating system too difficult to use, and in such cases a simple 24-hour control dial may be a better alternative.

Ventilation devices

Large and visible ventilation control devices such as the patio door, glazed doors in both the living room and kitchen, glazed louvres as well as all outer windows are well used by most occupants. However, small devices such as the adjustable doorhead slot ventilators are seldom adjusted by most occupants on a daily cycle and some are not even being adjusted seasonally. It would appear that in order to encourage occupants to use a control device, it is essential for it to be visible and simple to operate.

Monitoring periods

The occupants tend to require a relatively long period to adapt from living in a thermally sub-standard dwelling to an energy efficient one. Some households were able to reduce their space heating load by exercising better heating controls in the second heating season. Accordingly, it can be argued that the monitoring programme will be better carried out 12 months after occupants take up residency. Frequently, contractual obligations imposed by the funding agency make this impossible.

Users liaison

The sunspace as a passive solar technique requires appropriate adjustment and control of the heating and ventilation systems to achieve optimum energy saving and thermal comfort. It is essential occupants understand the basic principles of the design and its control operations. Therefore, the publication and distribution of explanatory literature, preparing the occupants to co-operate with the monitoring programme, and a local agent who meets occupants regularly are all vital to ensuring that the system works to best advantage. There is therefore a lesson to be learnt for housing authorities - good doorstep liaison and advice on a regular basis should benefit all concerned. The system used in this instance has been demonstrated to be fairly robust, but capable of being fine-tuned. The monitoring programme at Easthall suggests that the more involved the occupants feel in this process, the more likely there is to be a successful outcome for all concerned.

Appendix: 1.1 St. Marys School, Wallsacy

This example demonstrates that had the dual-skin glazing system incorporated a satisfactory absorber, e.g. heat absorbing louvres, then in addition to providing direct solar gain to the interior, it could also have preheated air for ventilation as shown in example 1 (as in Figure A.1.a) and 2 (as in Figure A.1.b).

$$q^h + q^s + q^i = (\Sigma A.U^{1\text{-}4} + 0.33n^eV)(Ti - To) \qquad (W) \qquad (1)$$

(intermediate situation assumed, so no loss through flank walls)

where q^h is the average 24 hour net space heating load (W);

q^s is the average 24 hour useful solar gain to heated zones (W);

q^i is the average 24 hour useful incidental gain to heated zones (W);

Σ **A.U** is the sum of respective areas of components multiplied by U-values between heated zones and outside (i.e. including buffer spaces) (W/K);

n^e is the effective rate of air change between the inside and outside - i.e. taking into account the 'solar ventilation preheat' (hereafter termed 'SVP') effect of the buffer spaces, so that it will be lower than the real rate of air change as long as there is a positive SVP effect (ac/hr);

V is the volume of the heated zones (m³);

Ti is the mean daily internal air temperature of the heated zones (°C);

and **To** is the mean daily outside air temperature (°C).

If heat loss is now considered relative to two boundary conditions - the outside and a buffer zone between two skins of glass, the heat balance can be re-expressed as equation (2).

$$q^h + q^s + q^i = (\Sigma A.U^{1\text{-}3} + 0.33n^{r1}V)(Ti - To) + (\Sigma A.U^{4A} + 0.33n^{r2}V)(Ti - Ts) \qquad (W) \qquad (2)$$

(where n^{r1} and n^{r2} are real rates of air change with To and Ts respectively.)

If a relatively high proportion of air change is through surface 4 and there is a significant temperature rise between To and Ts, then the real rate of air change $(n^{r1} + n^{r2})$ will be significantly greater than n^e in equation 1, especially if most of the air change occurs through surface 4. For example:

$q^h = 0$, $q^s = 1{,}000$ (Sept.- May), $q^i = 3{,}500$, Σ **A.U** = 37 (opaque) + 123 (glazed),

V = 240 m³, **Ti** = 22°C, **To** = 6.5°C.

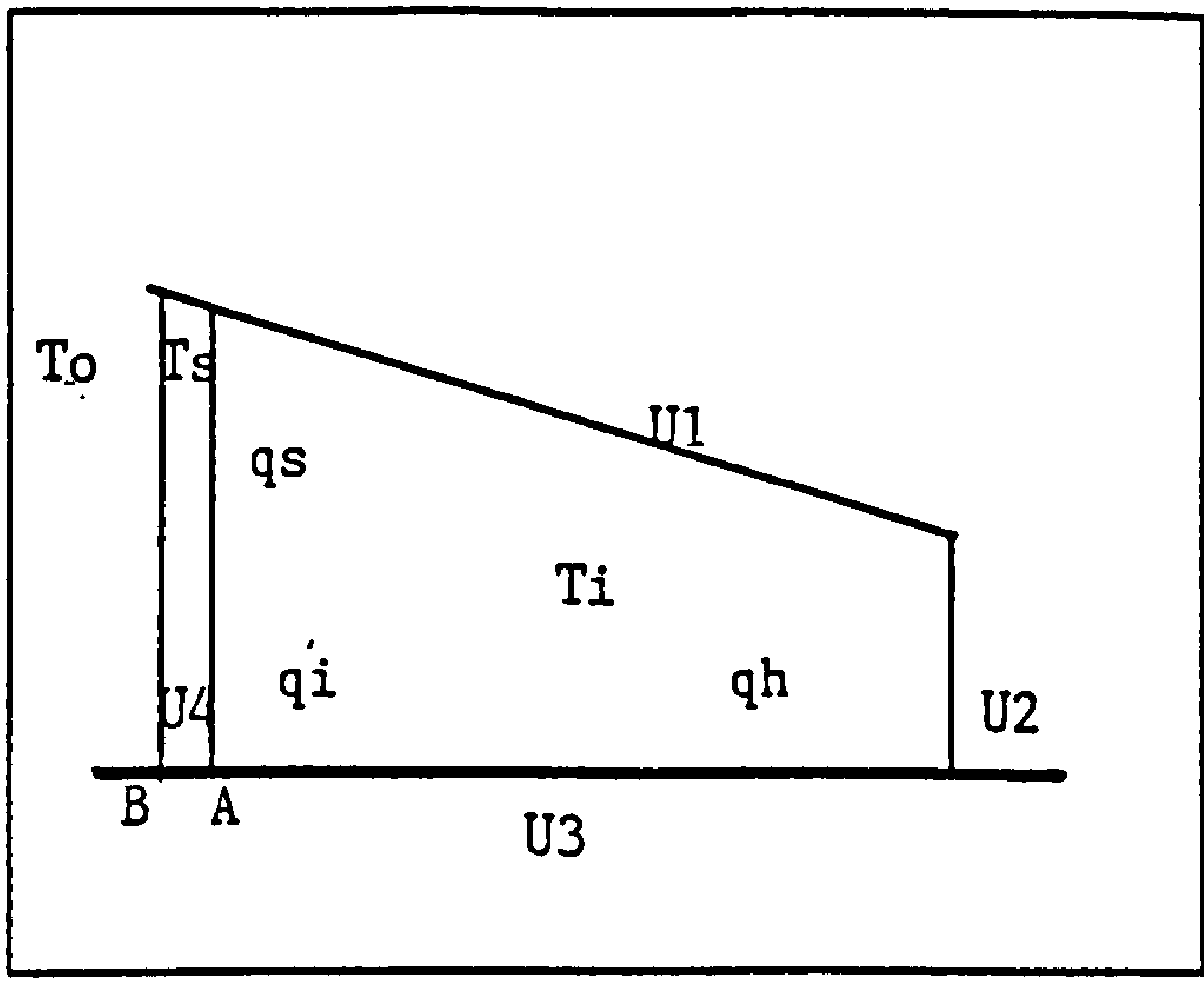


Figure A.1.a Design Incorporating a Buffer Space.

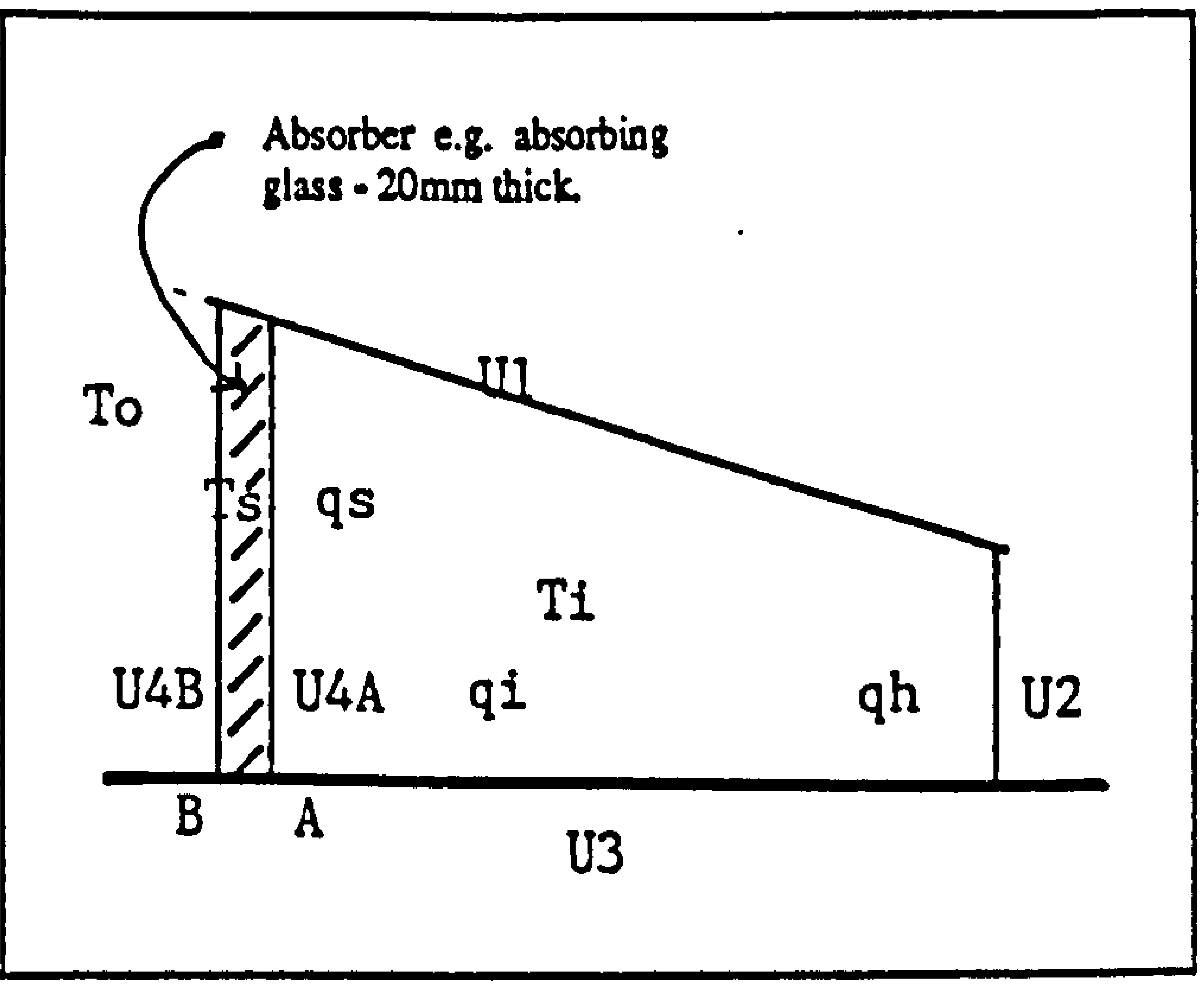


Figure A.1.b Design Incorporating an Efficient Absorber.

Example 1 (use equation 1)

$0 + 1000 + 3500 = (160 + .33\ n^{e}\ 240)\ (15.5)$

$4500 = 2480 + 1227.6\ n^{e}$

so $n^{e} = 1.65$ ac/hr (note values < 1.65 would raise internal temperature).

Example 2 (use equation 2)

If $Ts = 16.5°C$, $\Sigma A.U.^{4A.} = 195$ W/K (single glazing)

$0 + 1000 + 3500 = (37 + .33\ n^{r1}\ 240)\ (15.5) + (195 + .33\ n^{r2}\ 240)\ (5.5)$

$4500 = (573.5 + 1227.6\ n^{r1}) + (1072.5 + 435.6\ n^{r2})$

so $1227.6\ n^{r1} + 435.6\ n^{r2} = 2854$

if $n^{r1} = 0.5$, then $n^{r2} = 5.14$

so $n^{r1} + n^{r2} = \underline{5.64\ \text{ac/hr}}$

If $n^{r1} = 1.0$ then $n^{r2} = 3.73$ so $n^{r1} + n^{r2} = \underline{4.73\ \text{ac/hr}}$

If $n^{r1} = 1.65$ (previous n^{e} in equation 1) $n^{r2} = 1.9$ so $n^{r1} + n^{r2} = \underline{3.55\ \text{ac/hr}}$

Therefore in the above example, with a favourable solar lift in temperature in the air gap between the two skins, the real rate is always significantly higher than effective rate. So this scenario ensures better air quality than the equivalent model with double glazing but no ventilation preheat.

LOSS TO BOUNDING SURFACES

GROUND FLOOR- GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)	18.08	0.37	6.69
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-veranda (1.4)	4.42	1.464	6.47
		Sum	26.59

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	35.51	0.37	13.14
Floor without carpet & underlay (2.2)	12.6	0.42	5.29
BR1-veranda (2.3)	9.53	1.887	17.98
BR1-fuel st. (2.4)	2.19	0.733	1.61
BR1/hall-stair (2.5)	11.14	0.536	5.97
BR2-store (2.6)	6.63	0.733	4.86
Door-stair (2.7)	1.78	2.46	4.38
K/Ba-conservatory (2.8)	10.27	1.944	19.96
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.245	2.20
Kitchen gable wall (2.11)	10.64	0.245	2.61
		Sum	82.31
		Total	*108.90*

GROUND FLOOR- MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)	18.08	0.37	6.69
Opaque wall (1.2)- 20.08 less 11.15 gable wal	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-veranda (1.4)	4.42	1.464	6.47
		Sum	23.87

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	35.51	0.37	13.14
Floor without carpet & underlay (2.2)	12.6	0.42	5.29
BR1-veranda (2.3)	9.53	1.887	17.98
BR1-fuel st. (2.4)	2.19	0.733	1.61
BR1/hall-stair (2.5)	11.14	0.536	5.97
BR2-store (2.6)	6.63	0.733	4.86
Door-stair (2.7)	1.78	2.46	4.38
K/Ba-conservatory (2.8)	10.27	1.944	19.96
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.245	2.20
Kitchen gable wall (2.11)- omit gable end	0	0.245	0.00
		Sum	79.70
		Total	*103.57*

FIRST FLOOR- GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-veranda (1.4)	4.42	1.464	6.47
		Sum	19.90

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.3	0.00
Floor without carpet & underlay (2.2)- omit	0	0.4	0.00
BR1-veranda (2.3)	9.53	1.887	17.98
BR1-fuel st. (2.4)	2.19	0.733	1.61
BR1/hall-stair (2.5)	11.14	0.536	5.97
BR2-store (2.6)	6.63	0.733	4.86
Door-stair (2.7)	1.78	2.46	4.38
K/Ba-conservatory (2.8)	10.27	1.944	19.96
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.245	2.20
Kitchen gable wall (2.11)	10.64	0.245	2.61
		Sum	63.88
		Total	*83.78*

FIRST FLOOR- MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)- 20.08 less 11.15 gable wal	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-veranda (1.4)	4.42	1.464	6.47
	16.12	Sum	17.18

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-veranda (2.3)	9.53	1.887	17.98
BR1-fuel st. (2.4)	2.19	0.733	1.61
BR1/hall-stair (2.5)	11.14	0.536	5.97
BR2-store (2.6)	6.63	0.733	4.86
Door-stair (2.7)	1.78	2.46	4.38
K/Ba-conservatory (2.8)	10.27	1.944	19.96
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.245	2.20
Kitchen gable wall (2.11)- omit gable end	0	0.245	0.00
		Sum	61.27
		Total	*78.45*

SECOND FLOOR- GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-veranda (1.4)	4.42	1.464	6.47
Add roof loss (1.5)	18.08	0.153	2.77
		Sum	22.67

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	0	0.37	0.00
Floor without carpet & underlay (2.2)	0	0.42	0.00
BR1-veranda (2.3)	9.53	1.887	17.98
BR1-fuel st. (2.4)	2.19	0.733	1.61
BR1/hall-stair (2.5)	11.14	0.536	5.97
BR2-store (2.6)	6.63	0.733	4.86
Door-stair (2.7)	1.78	2.46	4.38
K/Ba-conservatory (2.8)	10.27	1.944	19.96
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.245	2.20
Kitchen gable wall (2.11)	10.64	0.245	2.61
Roof loss (2.12)- add	35.51	0.153	5.43
		Sum	69.31
		Total	*91.98*

SECOND FLOOR- MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)- 20.08 less 11.15 gable wal	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-veranda (1.4)	4.42	1.464	6.47
Add roof loss (1.5)	18.08	0.153	2.77
		Sum	19.95

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-veranda (2.3)	9.53	1.887	17.98
BR1-fuel st. (2.4)	2.19	0.733	1.61
BR1/hall-stair (2.5)	11.14	0.536	5.97
BR2-store (2.6)	6.63	0.733	4.86
Door-stair (2.7)	1.78	2.46	4.38
K/Ba-conservatory (2.8)	10.27	1.944	19.96
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.245	2.20
Kitchen gable wall (2.11)- omit gable end	0	0.245	0.00
Roof loss (2.12)- add	35.51	0.153	5.43
		Sum	66.71
		Total	*86.65*

Appendix 3.1 Summary of Transmission Losses - solar model to bounding surfaces of heated volume

LOSS TO OUTSIDE VIA SUNSPACES

GROUND FLOOR GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)	18.08	0.37	6.69
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-veranda-outside (1.4*)	4.42	0.926	4.09
		Sum	24.21

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	35.51	0.37	13.14
Floor without carpet & underlay (2.2)	12.6	0.42	5.29
BR1-veranda-outside (2.3*) inc. ground loss	9.53	1.046	9.97
BR1-fuel st.-outside (2.4*)	2.19	0.375	0.82
BR1/hall-stair-outside (2.5*)	11.14	0.371	4.13
BR2-store-outside (2.5*)	6.63	0.417	2.76
Door-stair-store-outside (2.7*)	1.78	0.807	1.44
K/Ba-conservatory-outside (2.8*)	10.27	0.873	8.97
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)	10.64	0.2436	2.59
		Sum	55.61
		Total	*79.82*

FIRST FLOOR GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-veranda-outside (1.4*)	4.42	1.0225	4.52
		Sum	17.95

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-veranda-outside (2.3*)	9.53	1.212	11.55
BR1-fuel st.-outside (2.4*)	2.19	0.375	0.82
BR1/hall-stair-outside (2.5*)	11.14	0.371	4.13
BR2-store-outside (2.5*)	6.63	0.417	2.76
Door-stair-store-outside (2.7*)	1.78	0.807	1.44
K/Ba-conservatory-outside (2.8*)	10.27	0.92	9.45
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)	10.64	0.2436	2.59
		Sum	39.24
		Total	*57.20*

SECOND FLOOR GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-veranda-outside (1.4*)	4.42	0.998	4.41
Roof loss (1.5*)- add	18.08	0.153	2.77
		Sum	20.61

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-veranda-outside (2.3*) inc. roof loss	9.53	1.223	11.66
BR1-fuel st.-outside (2.4*)	2.19	0.375	0.82
BR1/hall-stair-outside (2.5*)	11.14	0.371	4.13
BR2-store-outside (2.6*)	6.63	0.417	2.76
Door-stair-store-outside (2.7*)	1.78	0.807	1.44
K/Ba-conservatory-outside (2.8*)	10.27	0.98	10.06
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)	10.64	0.2436	2.59
Roof loss (2.12*)- add	35.51	0.153	5.43
		Sum	45.40
		Total	*66.01*

LOSS TO OUTSIDE VIA SUNSPACES

GROUND FLOOR MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)	18.08	0.37	6.69
Opaque wall (1.2)-20.08 less 11.15 gable wall	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-veranda-outside (1.4*)	4.42	0.926	4.09
		Sum	21.49

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	35.51	0.37	13.14
Floor without carpet & underlay (2.2)	12.6	0.42	5.29
BR1-veranda-outside (2.3*) inc. ground loss	9.53	1.046	9.97
BR1-fuel st.-outside (2.4*)	2.19	0.375	0.82
BR1/hall-stair-outside (2.5*)	11.14	0.371	4.13
BR2-store-outside (2.6*)	6.63	0.417	2.76
Door-stair-store-outside (2.7*)	1.78	0.807	1.44
K/Ba-conservatory-outside (2.8*)	10.27	0.873	8.97
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)- omit gable end	0	0.2436	0.00
		Sum	53.02
		Total	*74.51*

FIRST FLOOR MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)-20.08 less 11.15 gable wall	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-veranda-outside (1.4*)	4.42	1.0225	4.52
		Sum	15.23

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-veranda-outside (2.3*)	9.53	1.212	11.55
BR1-fuel st.-outside (2.4*)	2.19	0.375	0.82
BR1/hall-stair-outside (2.5*)	11.14	0.371	4.13
BR2-store-outside (2.6*)	6.63	0.417	2.76
Door-stair-store-outside (2.7*)	1.78	0.807	1.44
K/Ba-conservatory-outside (2.8*)	10.27	0.92	9.45
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)- omit gable end	0	0.2436	0.00
		Sum	36.65
		Total	*51.88*

SECOND FLOOR MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)-20.08 less 11.15 gable wall	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-veranda-outside (1.4*)	4.42	0.998	4.41
Roof loss (1.5*)- add	18.08	0.153	2.77
		Sum	17.89

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-veranda-outside (2.3*) inc. roof loss	9.53	1.223	11.66
BR1-fuel st.-outside (2.4*)	2.19	0.375	0.82
BR1/hall-stair-outside (2.5*)	11.14	0.371	4.13
BR2-store-outside (2.6*)	6.63	0.417	2.76
Door-stair-store-outside (2.7*)	1.78	0.807	1.44
K/Ba-conservatory-outside (2.8*)	10.27	0.98	10.06
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)- omit gable end	0	0.2436	0.00
Roof loss (2.12*)- add	35.51	0.153	5.43
		Sum	42.81
		Total	*60.69*

Appendix 3.1 Summary of Transmission Losses - solar model to outside via buffers

LOSS TO OUTSIDE (NO SUNSPACES)

GROUND FLOOR- GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)	18.08	0.37	6.69
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-open veranda & outside (1.4) - *	4.42	1.213	5.36
		Sum	25.48

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	35.51	0.37	13.14
Floor without carpet & underlay (2.2)	12.6	0.42	5.29
BR1-open veranda & outside (2.3) - *	9.53	0.6595	6.29
BR1-fuel st. & outside (2.4) - *	2.19	0.2436	0.53
BR1/hall-stair & outside (2.5) - *	11.14	0.536	5.97
BR2-store & outside (2.6) - *	6.63	0.417	2.76
Door-stair & outside (2.7) - *	1.78	0.807	1.44
K/Ba-outside (2.8) - *	10.27	0.983	10.10
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)	10.64	0.2436	2.59
		Sum	54.61
		Total	*80.09*

FIRST FLOOR- GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-open veranda & outside (1.4) - *	4.42	1.213	5.36
		Sum	18.79

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-open veranda & outside (2.3) - *	9.53	0.6595	6.29
BR1-fuel st. & outside (2.4) - *	2.19	0.2436	0.53
BR1/hall-stair & outside (2.5) - *	11.14	0.536	5.97
BR2-store & outside (2.6) - *	6.63	0.417	2.76
Door-stair & outside (2.7) - *	1.78	0.807	1.44
K/Ba-outside (2.8) - *	10.27	0.983	10.10
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)	10.64	0.2436	2.59
		Sum	36.18
		Total	*54.97*

SECOND FLOOR- GABLE END

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)	20.08	0.2436	4.89
Windows (1.3)	2.8	3.05	8.54
Living room-open veranda & outside (1.4) - *	4.42	1.213	5.36
Add roof loss (1.5)	18.08	0.153	2.77
		Sum	21.56

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-open veranda & outside (2.3) - *	9.53	0.6595	6.29
BR1-fuel st. & outside (2.4) - *	2.19	0.2436	0.53
BR1/hall-stair & outside (2.5) - *	11.14	0.536	5.97
BR2-store & outside (2.6) - *	6.63	0.417	2.76
Door-stair & outside (2.7) - *	1.78	0.807	1.44
K/Ba-outside (2.8) - *	10.27	0.983	10.10
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)	10.64	0.2436	2.59
Add roof loss (2.12) less veranda	35.51	0.153	5.43
		Sum	41.61
		Total	*63.17*

GROUND FLOOR- MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)	18.08	0.37	6.69
Opaque wall (1.2)- 20.08 less 11.15 gable wall	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-open veranda & outside (1.4) - *	4.42	1.213	5.36
		Sum	22.76

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)	35.51	0.37	13.14
Floor without carpet & underlay (2.2)	12.6	0.42	5.29
BR1-open veranda & outside (2.3) - *	9.53	0.6595	6.29
BR1-fuel st. & outside (2.4) - *	2.19	0.2436	0.53
BR1/hall-stair & outside (2.5) - *	11.14	0.536	5.97
BR2-store & outside (2.6) - *	6.63	0.417	2.76
Door-stair & outside (2.7) - *	1.78	0.807	1.44
K/Ba-outside (2.8) - *	10.27	0.983	10.10
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)- omit gable end	0	0.2436	0.00
		Sum	52.01
		Total	*74.77*

FIRST FLOOR- MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)- 20.08 less 11.15 gable wall	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-open veranda & outside (1.4) - *	4.42	1.213	5.36
		Sum	16.07

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-open veranda & outside (2.3) - *	9.53	0.6595	6.29
BR1-fuel st. & outside (2.4) - *	2.19	0.2436	0.53
BR1/hall-stair & outside (2.5) - *	11.14	0.536	5.97
BR2-store & outside (2.6) - *	6.63	0.417	2.76
Door-stair & outside (2.7) - *	1.78	0.807	1.44
K/Ba-outside (2.8) - *	10.27	0.983	10.10
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)- omit gable end	0	0.2436	0.00
		Sum	33.58
		Total	*49.65*

SECOND FLOOR- MID-TERRACE

ZONE 1- LIVING ROOM	m2	U-values	H1 (W/K)
Floor with carpet & underlay (1.1)- omit	0	0.37	0.00
Opaque wall (1.2)- 20.08 less 11.15 gable wall	8.9	0.2436	2.17
Windows (1.3)	2.8	3.05	8.54
Living room-open veranda & outside (1.4) - *	4.42	1.213	5.36
Add roof loss (1.5)	18.08	0.153	2.77
		Sum	18.84

ZONE 2- REST OF THE HOUSE	m2	U-values	H2 (W/K)
Floor with carpet & underlay (2.1)- omit	0	0.37	0.00
Floor without carpet & underlay (2.2)- omit	0	0.42	0.00
BR1-open veranda & outside (2.3) - *	9.53	0.6595	6.29
BR1-fuel st. & outside (2.4) - *	2.19	0.2436	0.53
BR1/hall-stair & outside (2.5) - *	11.14	0.536	5.97
BR2-store & outside (2.6) - *	6.63	0.417	2.76
Door-stair & outside (2.7) - *	1.78	0.807	1.44
K/Ba-outside (2.8) - *	10.27	0.983	10.10
BR2 window (2.9)	1.4125	3.05	4.31
BR2 wall (2.10)	8.99	0.2436	2.19
Kitchen gable wall (2.11)- omit gable end	0	0.2436	0.00
Add roof loss (2.12) less veranda	31.07	0.153	4.75
		Sum	38.34
		Total	*57.17*

Appendix 3.1 Summary of Transmission Losses - REF^{+} model

Appendix 3.2

CEC PASSIVE SOLAR ENERGY DEMONSTRATION PROJECT EASTHALL GLASGOW

QUESTIONNAIRE Spring Edition (cec22-31.doc)

Up till now, you will probably have been too well aware that you had been living in a 'hard-to heat' house. Now, you are coming back to one of Europe's most energy efficient houses- partly due to 'passive solar' design which involves the use of conventional building elements for solar energy collection, heat storage and heat distribution. Both the glazed-in veranda and the new conservatory extension collect and store solar energy while window and door head ventilators allow warmed air to circulate inside the house. Together with high level of insulation in walls, floors, roofs and new double glazed windows, this will mean your house is now very cheap to heat- even in the coldest weather. Also, the solar collectors on the roof are designed to lower your water-heating bills even further.

This questionnaire is intended to assess:

A. your thermal comfort level within the house,

B. your response to the central heating system- gas or electric and ventilation controls,

C. your response to additional unheated amenities seasonally e.g. conservatory extension and glazed veranda, hereafter generally refer to 'sunspaces' and heated spaces,

D. the overall energy saving (reduction in fuel bills) in comparison with dwellings before upgrading.

Note:

All information given in this questionnaire will be solely used by the Mackintosh School of Architecture team and will be treated in strict confidentiality. Under no circumstance will the information be passed on and used by a third party without the written consent of the resident.

Please tick only one box for each question, or set your comments in the space provided.

Section 1: *Thermal comfort*

In order to assess how comfortable your house is, please answer the following questions by ticking in the space provided.

1.1 Do you find the house comfortable to live in ?
☑ ☐ ☐ ☐ ☐
Very comfortable Comfortable Very uncomfortable

1.2 Do you find the house difficult to heat in winter ?
☐ ☐ ☑ ☐ ☐
Very difficult Easy Very easy

1.3 How many room(s) do you heat in winter ? (2 room(s)
Your house has 8 rooms namely:
Heated rooms: [✓ Master Bedroom], [✓ Living Room], Kitchen, Bathroom, Bedroom 2 and [✓ Hallway]
Unheated rooms: Veranda and Conservatory.

1.4 Do you use any additional heating appliances ? yes ☐ / no ☑
If yes, please list type (i.e. Calor gas/ fan heater), room locations
Heater type ______ Location(s) ______

1.5 Do you find the house overheating in summer ? yes ☑ / no ☐
Location(s) ______

1.6 Do you find your house draughty ? yes ☑ / no ☐
If yes, please indicate the locations. Front Door Verandah & conservatory

1.7 Have you noticed any improvements in health amongst members of your household ? yes ☑ / no ☐
If yes, please give details i.e. asthma in young children
Flu / colds

1.8 Please list current uses of your sunspaces
Conservatory - summer Drying clothes,
- winter " "
Veranda - summer pet corner,
- winter " "
(Examples of uses- dining area, tea area, drinking area, pet corner, wendy house, reading area, writing area..............)

Section 2: *Personal details*

In order to help us to classify your answer statistically, may we ask you a few questions about yourself and your family.

2.1 Please supply the following details about yourself:-

Name: ______ Address: ______ (Wardie Road/ [✓ Glenburnie Place])

2.2 Please supply the following details about all occupants.

Occupant	Age range	Sex	Smoking
YOURSELF	Infant: below 10 yrs old Teenage: 10-17 yrs old Adult: over 18 yrs old OAP: old aged pensioner	M/ F ☐ ☐	Smoker/ non-smoker ☐ ☐

1st occupant Infant/ teenage/ adult/ OAP M/ F ( ) ( ) (✓) ( ) (✓)( ) Smoker/ non-smoker (✓) ( )

2nd occupant Infant/ teenage/ adult/ OAP M/ F ( ) ( ) (✓) ( ) ( )(✓) Smoker/ non-smoker (✓) ( )

3rd occupant Infant/ teenage/ adult/ OAP M/ F ( ) ( ) ( ) ( ) ( )( ) Smoker/ non-smoker ( ) ( )

4th occupant Infant/ teenage/ adult/ OAP M/ F ( ) ( ) ( ) ( ) ( )( ) Smoker/ non-smoker ( ) ( )

5th occupant Infant/ teenage/ adult/ OAP M/ F ( ) ( ) ( ) ( ) ( )( ) Smoker/ non-smoker ( ) ( )

2.3 Please list the appropriate occupancy pattern in a typical week. Please indicate the number of occupants in each session.

	Overnight (say midnight- 6 am)	Morning (6 am- 12 noon)	Afternoon (12 noon- 6 pm)	Evening (6 pm- midnight)
Weekday 1	2	2¼ 1½	2	2
Saturday	2	2	2	2
Sunday	2	2	2	2
Weekday 2 (for residents with i.e. alternative day part-time job)	2	1	2	2 1 ✓

Please use 1/2 for occupant staying half of the session.

2.4 Please circle the dates in which you and all occupants were away for more than 2 consecutive days.

SEPTEMBER

M	T	W	T	F	S	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

OCTOBER

M	T	W	T	F	S	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

NOVEMBER

M	T	W	T	F	S	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

DECEMBER'92

M	T	W	T	F	S	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

JANUARY'93

M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

FEBRUARY

M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

2.5 Please tick in the box provided if you have the following appliances:

- Central heating system: (✓) electric / ( ) gas
- Cooker (✓) electric / ( ) gas
- Washing machine (✓) yes / ( ) no
- Dishwasher ( ) yes / ( ) no
- Washer dryer ( ) yes / ( ) no
- Tumble dryer ( ) yes / (✓) no
- Portable heaters e.g. Calor gas/ fan heater ( ) yes / (✓) no

If yes, please give type ________________

Section 3: Any other comments

3.1 Do you find the extract fan noisy when in operation ?

yes ( )/ no (✓)

3.2 If there are any comments that you would like to make. Please list in the space provided:

A detailed questionnaire will be issued in autumn/ winter this year.
Thank you for your support to this project.

Appendix 3.2

In order to assess whether the solar house design lives up with its performance expectation, please give details regarding heating and ventilation controls to the following questions.

Do you leave the following french windows, louvers, hit & miss door head ventilators, sliding patio door, outer sunspace windows open ?

Please circle your answers.

4.1 Veranda Outer Veranda Windows

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	Often	Sometimes	[✓ Hardy ever]

4.1.1 *Living room to Veranda* French window

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	[✓ Sometimes]	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	Often	Sometimes	[✓ Hardy ever]

Hit & Miss Doorhead Ventilator

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever

4.1.2 *Master Bedroom to Veranda* Sliding Patio Door

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	Often	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	[✓ Often]	Sometimes	Hardy ever

Hit & Miss Doorhead Ventilator

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	[✓ Often]	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	[✓ Often]	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever

4.2 Conservatory Outer conservatory windows

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	Sometimes	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	Hardy ever	Often	[✓ Sometimes]	Hardy ever

4.2.1 *Kitchen to Conservatory* French Window

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	[✓ Sometimes]	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	Often	[✓ Sometimes]	Hardy ever

Louvers

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	[✓ Sometimes]	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	[✓ Often]	Sometimes	Hardy ever

4.3 Living Room Living Room double windows

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	[✓ Sometimes]	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	[✓ Often]	Sometimes	Hardy ever

4.4 Small Bedroom 2 Bedroom Single Window

	Autumn (Sept.- Nov.)			Winter (Dec.- Feb.)			Spring (Mar. onwards)		
Day	Often	Sometimes	Hardy ever	Often	[✓ Sometimes]	Hardy ever	[✓ Often]	Sometimes	Hardy ever
Night	Often	Sometimes	Hardy ever	Often	Sometimes	[✓ Hardy ever]	[✓ Often]	Sometimes	Hardy ever

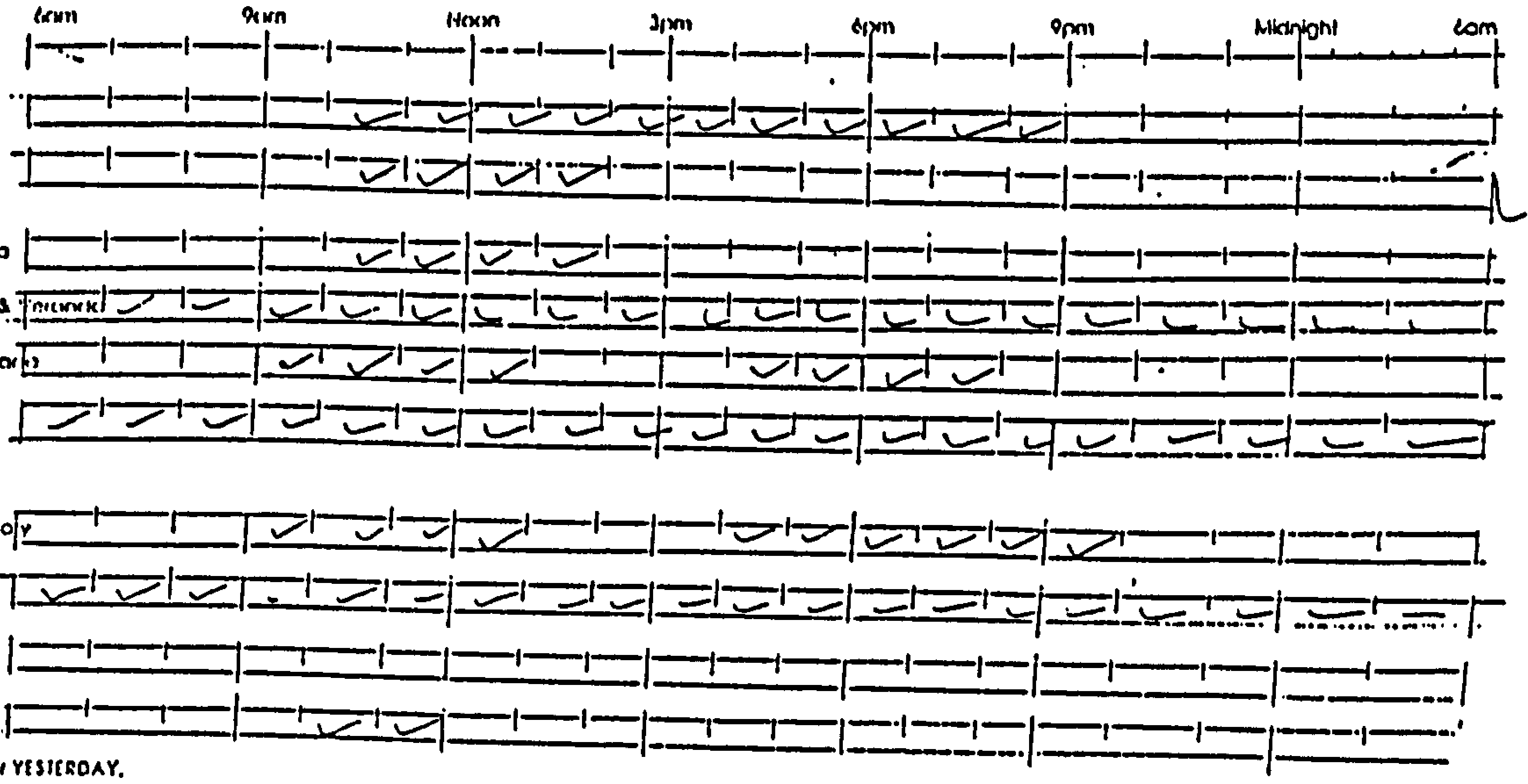
Appendix 3.3

Gas
2 Adult + 1 infant

CEC PASSIVE SOLAR ENERGY DEMOSTRATION PROJECT, EASTHALL
Weekly log sheet

Date of record: 13/4/95 Tuesday
House number: 45 02 (Wardie Road/ Glenhuntle Place)

Q1. Please tick the period of time in which you had the door/ventilators open YESTERDAY.



1.1 Outer sunspace windows
1.1.a Conservatory
1.1.b Veranda

1.2 Veranda
1.2.a Patio door between Master Bed'm & Veranda
1.2.b Door head ventilator betweenMaster Bed'm & Veranda
1.2.c French window between Living Room & Veranda
1.2.d French window head ventilator between Living Room & Veranda

1.3 Conservatory
1.3.a French window between kitchen & Conservatory
1.3.b Louvers between kitchen & Conservatory

1.4 Other outer windows
1.4.a Bedroom 2
1.4.b Living Room

Q2. Please list the appropriate occupancy pattern for YESTERDAY.

	Overnight (say midnight- 6 am)	Morning (6 am- 12 noon)	Afternoon (12 noon- 6 pm)	Evening (6 pm- midnight)
Yesterday	3	2½	2½	3

Please use 1/2 for occupant staying half of the session.

Q3. Please answer the following questions and give details.

3.1 Did you open any outer sunspace windows YESTERDAY ? ✓ Yes / ___ No

If yes, please give details.......... (please refer to Question 1.1 a & b)

Location	Approx. duration (hours)	Reasons (i.e. to air the house/ too hot/ too stuffy/ too humid / clothes on pulley. ......)
Veranda	~~3~~ 4	To air the house........
Conservatory	~~8~~ 4	Clothes on pulley.. ..

3.2 Did you use the electric/ gas fire in your Living Room YESTERDAY ? ✓ Yes / ___ No

If yes, please suggest reasons ....(i.e. too cold/ overcast sky/ snowing outside/ thermometer reading too low/ don't know)

Reason(s) quite cold Approx. duration 6 hours Setting: ~~Low / medium / High~~* Please delete

3.3 Did you use any additional heating applicances YESTERDAY ? ___ Yes / ✓ No

If yes, please give types (i.e. fan heater/ Calor Gas/ convector...)

Heater type	Location	Approx. duration (hours)

3.4 Please list your heating control settings

Gas c/h House
Thermostatic control setting 23 °C
~~All day heating~~ / Twice a day heating * Please delete
If twice a day heating, please list periods- 1st 7am 9am & 2nd 4pm 6pm

Radiator valve setting		
Master Bedroom-	OFF / I / II / [✓ III] / FULL	* Please circle
Living Room-	OFF / I / II / [✓ III] / FULL	
Kitchen-	OFF / I / [✓ II] / III / FULL	
Bathroom-	OFF / I / [✓ II] / III / FULL	
Bedroom 2-	OFF / I / II / [✓ III] / FULL	
Hallway-	OFF / I / [✓ II] / III / FULL	

~~Electric c/h House~~
~~Storage heater. Overnight control charge~~

~~Living Room-~~	~~1 2 3 4 5 6 7 8 9~~	~~Please circle~~
~~Kitchen-~~	~~1 2 3 4 5 6 7 8 9*~~	
~~Hallway-~~	~~1 2 3 4 5 6 7 8 9*~~	
~~Bathroom-~~	~~1 2 3 4 5 6 7 8 9*~~	

~~Panel heaters:~~	~~Heater setting~~	~~Approx. duration (hrs)~~
~~Master Bedroom-~~	~~1 2 3 4 5 6 7 8 9*~~	
~~Bedroom 2-~~	~~1 2 3 4 5 6 7 8 9*~~	

3.5 Did you use your washing machine/ washer dryer and tumble dryer this week ? ✓ Yes / ___ No

If yes, give details- 1 load of washing
_____ load of tumble drying

4. How did you feel YESTERDAY ?

Please feel free to write your feeling i.e. thermal comfort etc......

okay Comfortable but we have to put the fire back on in the mornings & evenings now, as its quite Cold now.

Thank you for your support

Appendix 3.3

CEC PASSIVE SOLAR ENERGY DEMOSTRATION PROJECT, EASTHALL
Weekly log sheet

Date of record: 19th Jun 94 wed)
House number: 07 45 (Wardie Road/ ~~Glenburnie Place~~)

Q1. Please tick the period of time in which you had the door/ventilators open YESTERDAY.

6am — 9am — Noon — 3pm — 6pm — 9pm — Midnight — 6am

1.1 Outer sunspace windows
1.1.a Conservatory ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
1.1.b Veranda ✓ ✓ ✓

1.2 Veranda
1.2 a Patio door between Master Bed'm & Veranda ✓ ✓ ✓
1.2.b Door head ventilator betweenMaster Bed'm & Veranda
1.2.c French window between Living Room & Veranda
1.2.d French window head ventilator between Living Room & Veranda

1.3 Conservatory
1.3.a French window between kitchen & Conservatory
1.3.b Louvers between kitchen & Conservatory

1.4 Other outer windows
1.4.a Bedroom 2
1.4.b Living Room

Q2. Please list the appropriate occupancy pattern for YESTERDAY.

	Overnight (say midnight- 6 am)	Morning (6 a.m- 12 noon)	Afternoon (12 noon- 6 pm)	Evening (6 pm- midnight)
Yesterday	5	3	2½	3

Please use 1/2 for occupant staying half of the session.

Q3. Please answer the following questions and give details.
3.1 Did you open any outer sunspace windows YESTERDAY ? [✓ Yes] / ___ No
If yes, please give details........... (please refer to Question 1.1 a & b)

Location	Approx. duration (hours)	Reasons (i.e. to air the house/ too hot/ too stuffy/ too humid / clothes on pulley........)
Veranda	5hours	to air the house
Conservatory	11 hours	" " " "

3.2 Did you use the electric/ gas fire in your Living Room YESTERDAY ? [✓ Yes] / ___ No
If yes, please suggest reasons ....(i.e. too cold/ overcast sky/ snowing outside/ thermometer reading too low/ don't know)
Reason(s) Cold outside Approx. duration 7 hours Setting: Low / medium / High * Please delete

3.3 Did you use any additional heating applicances YESTERDAY ? ___ Yes / [✓ No]
If yes, please give types (i.e. fan heater/ Calor Gas/ convector...)

Heater type	Location	Approx. duration (hours)

3.4 Please list your heating control settings
Gas c/h House
Thermostatic control setting 23 °C
All day heating / twice a day heating * Please delete
If twice a day heating, please list periods- 1st 8am 10am 2nd 4pm 6pm
Radiator valve setting Master Bedroom- OFF / I / II / [✓ III] / FULL * Please circle
Living Room- OFF / I / II / [✓ III] / FULL
Kitchen- OFF / I / [✓ II] / III / FULL
Bathroom- OFF / I / [✓ II] / III / FULL
Bedroom 2- OFF / I / II / [✓ III] FULL
Hallway- OFF / I / [✓ II] / III / FULL

Electric c/h House
Storage heater: Overnight control charge
Living Room- 1 2 3 4 5 6 7 8 9 Please circle
Kitchen- 1 2 3 4 5 6 7 8 9 *
Hallway- 1 2 3 4 5 6 7 8 9 *
Bathroom- 1 2 3 4 5 6 7 8 9 *

Panel heaters: Heater setting Approx. duration (hrs)
Master Bedroom- 1 2 3 4 5 6 7 8 9 *
Bedroom 2- 1 2 3 4 5 6 7 8 9 *

3.5 Did you use your washing machine/ washer dryer and tumble dryer this week ? [✓ Yes] / ___ No
If yes, give details- 1 load of washing
___ load of tumble drying

4. How did you feel YESTERDAY ?
Please feel free to write your feeling i.e. thermal comfort etc. ....
once the house had been heated in the morning and in the evening the house was very comfortable

Thank you for your support

Appendix 3.3

CEC PASSIVE SOLAR ENERGY DEMOSTRATION PROJECT, EASTHALL
Weekly log sheet

Date of record 6th Oct (Wed)   House number: 45 (Wardie Road/ Glenburnie Place)

Q1. Please tick the period of time in which you had the door/ventilators open YESTERDAY.

6am 9am Noon 3pm 6pm 9pm Midnight 6am

1.1 Outer sunspace windows
1.1.a Conservatory ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
1.1.b Veranda ✓ ✓ ✓ ✓ ✓ ✓

1.2 Veranda
1.2.a Patio door between Master Bed'm & Veranda
1.2.b Door head ventilator between Master Bed'm & Veranda
1.2.c French window between Living Room & Veranda
1.2.d French window head ventilator between Living Room & Veranda

1.3 Conservatory
1.3.a French window between kitchen & Conservatory
1.3.b Louvers between kitchen & Conservatory

1.4 Other outer windows
1.4.a Bedroom 2
1.4.b Living Room

Q2. Please list the appropriate occupancy pattern for YESTERDAY.

	Overnight (say midnight - 6 am)	Morning (6 am - 12 noon)	Afternoon (12 noon - 6 pm)	Evening (6 pm - midnight)
Yesterday	3	2½	2½	3

Please use 1/2 for occupant staying half of the session.

Q3. Please answer the following questions and give details.

3.1 Did you open any outer sunspace windows YESTERDAY ? ____ Yes / ____ No
If yes, please give details........... (please refer to Question 1.1 a & b.)

Location	Approx. duration (hours)	Reasons (i.e. to air the house/ too hot/ too stuffy/ too humid / clothes on pulley........)
Veranda	6 hours	to air the house
Conservatory	8 hours	" " "

3.2 Did you use the electric/ gas fire in your Living Room YESTERDAY ? ✓ Yes / ____ No
If yes, please suggest reasons ....(i.e. too cold/ overcast sky/ snowing outside/ thermometer reading too low/ don't know)

Reason(s) quite cold   Approx. duration 6 hours   Setting: Low / medium / High*   Please delete

3.3 Did you use any additional heating appliances YESTERDAY ? ____ Yes / ✓ No
If yes, please give types (i.e. fan heater/ Calor Gas/ convector...)

Heater type	Location	Approx. duration (hours)

3.4 Please list your heating control settings

Gas c/h House
Thermostatic control setting 23 °C
All day heating / twice a day heating * Please delete
If twice a day heating, please list periods- 1st 6am-9am & 2nd 4pm-7pm

Radiator valve setting		* Please circle
Master Bedroom-	OFF / I / II / [✓ III] / FULL	
Living Room-	OFF / I / II / [✓ III] / FULL	
Kitchen-	OFF / I / II / [✓ III] / FULL	
Bathroom-	OFF / I / II / [✓ III] / FULL	
Bedroom 2-	OFF / I / II / [✓ III] / FULL	
Hallway-	OFF / I / II / [✓ III] / FULL	

✓

Electric c/h House
Storage heater: Overnight control charge

Living Room	1 2 3 4 5 6 7 8 9	Please circle
Kitchen-	1 2 3 4 5 6 7 8 9 *	
Hallway-	1 2 3 4 5 6 7 8 9 *	
Bathroom-	1 2 3 4 5 6 7 8 9 *	

Panel heaters:	Heater setting	Approx. duration (hrs)
Master Bedroom-	1 2 3 4 5 6 7 8 9 *	
Bedroom 2-	1 2 3 4 5 6 7 8 9 *	

3.5 Did you use your washing machine/ washer dryer and tumble dryer this week ? ✓ Yes / ____ No
If yes, give details- 7 load of washing
____ load of tumble drying

4. How did you feel YESTERDAY ?
Please feel free to write your feeling i.e. thermal comfort etc......

It is usually quite cold in the house first thing in the morning, so the central heating gets put on for an hour or so. After that everything is okay (n warm). We put the fire on usually if it gets cold later. All in all its usually lovely and warm.

Thank you for your support

Appendix 4.1.a

ENERGY CONSUMPTION FOR SPACE HEATING

September 1992 - May 1993

1 kWh/m^{3}K

2 £/K

[ ] Rank

3 kWh/m^3

4 £

Wardie Road

1	3.34 [23]		2.33 [13]	4.17 [29]		1.28 [2]	1.65 [7]		2.15 [14]	1
2	10.81 [15]		7.53 [10]	13.50 [22]		4.13 [1]	6.15 [6]		8.49 [13]	2
3	48.29 [26]		32.96 [16]	52.21 [27]		15.09 [4]	17.19 [7]		34.41 [17]	3
4	156.18 [19]		106.60 [13]	168.85 [20]		48.79 [2]	64.10 [5]		106.32 [12]	4
1	2.10 [11]		1.35 [3]	2.56 [16]		3.88 [27]	1.45 [6]		2.02 [9]	1
2	6.78 [7]		6.86 [8]	11.00 [16]		12.57 [19]	5.58 [4]		11.06 [17]	2
3	28.44 [11]		18.86 [6]	31.31 [14]		33.53 [28]	14.58 [3]		26.57 [10]	3
4	91.95 [9]		96.00 [10]	134.41 [15]		173.16 [21]	55.98 [4]		145.37 [16]	4
1			2.78 [20]	2.68 [18]		4.55 [30]	3.66 [26]		5.24 [33]	1
2			16.40 [28]	17.04 [31]		14.73 [24]	16.74 [29]		16.95 [30]	2
3			41.21 [21]	34.44 [18]		57.74 [29]	61.53 [30]		63.56 [31]	3
4			243.20 [30]	218.92 [27]		186.77 [23]	280.99 [34]		205.62 [26]	4
		No.41			**No. 43**			**No. 45**		

ENERGY CONSUMPTION FOR SPACE HEATING

September 1992 - May 1993

Glenburnie Place

1	4.79 [31]		2.66 [17]	1.42 [4]		2.76 [19]			3.53 [24]	1
2	15.51 [26]		11.69 [18]	4.60 [2]		8.92 [14]			20.58 [33]	2
3	72.64 [33]		35.14 [19]	14.36 [2]		36.67 [20]			45.78 [23]	3
4	234.98 [29]		154.64 [18]	46.66 [1]		118.59 [14]			267.15 [33]	4
1	3.09 [22]		1.81 [8]	2.54 [15]		0.96 [1]	2.25 [12]		1.42 [4]	1
2	14.61 [23]		5.86 [5]	8.21 [12]		4.91 [3]	12.83 [21]		7.25 [9]	2
3	43.05 [22]		20.77 [8]	31.11 [12]		10.88 [1]	31.44 [14]		15.39 [5]	3
4	203.77 [25]		62.21 [6]	100.60 [11]		55.39 [3]	178.94 [22]		78.75 [8]	4
1	3.04 [21]		2.05 [10]	5.02 [32]		3.96 [28]	6.17 [34]		3.68 [25]	1
2	23.97 [34]		7.56 [11]	16.25 [27]		12.79 [20]	19.97 [32]		15.33 [25]	2
3	31.25 [13]		21.08 [9]	71.93 [33]		46.16 [24]	80.62 [34]		46.39 [25]	3
4	246.16 [31]		77.82 [7]	232.65 [28]		149.30 [17]	260.79 [32]		193.01 [24]	4
		No.5			**No. 7**			**No. 9**		

░ 8 all-round best in terms of energy consumption. (37.5% electric).

▓ 8 all-round worst in terms of energy consumption. (50% electric).

lowest cost - gas

lowest energy consumption - electric

highest cost - electric

highest energy consumption - gas

Appendix 4.1.b

ENERGY CONSUMPTION FOR SPACE HEATING

September 1993 - May 1994

1 kWh/m^{3}K 2 £/K

[ ] Rank 3 kWh/m^3 4 £

Wardie Road

1	4.14 [20]	2.14 [10]			1.41 [5]		1
2	12.47 [16]	6.54 [8]			4.9 [2]		2
3	65.16 [21]	30.82 [11]			15.41 [4]		3
4	198.84 17	94.07 [8]			53.55 [2]		4
1	1.82 [8]	1.40 [4]	2.65 [14]		1.45 [6]	2.06 [9]	1
2	5.55 [6]	5.89 [7]	11.02 [14]		5.26 [4]		2
3	25.59 [8]	20.73 [7]	36.11 [14]		16.02 [5]	27.75 [9]	3
4	78.08 [6]	86.94 [7]	150.27 [15]		58 [3]		4
1		2.87 [15]	1.23 [3]	2.41 [13]		4.91 [22]	1
2		17.65 [21]	11.62 [15]	7.34 [9]		14.98 [18]	2
3		44.87 [17]	13.93 [3]	31.50 [12]		60.73 [20]	3
4		275.48 [21]	132.13 [11]	96.12 [9]		185.31 [16]	4
	No.41		No. 43		No. 45		

ENERGY CONSUMPTION FOR SPACE HEATING

September 1993 - May 1994

Glenburnie Place

1	4.63 [21]	2.23 [12]		2.87 [15]		3.98 [19]	1
2	14.12 [17]	9.99 [12]		8.76 [10]		23.5 [23]	2
3	72.93 [22]	33.15 [13]		40.08 [15]		55.12 [18]	3
4	222.53 [12]	148.54 [14]		122.26 [10]		325.64 [23]	4
1	2.14 [10]	1.62 [7]	3.18 [17]	1.08 [2]		0.62 [1]	1
2	10.55 [13]	4.93 [3]	9.71 [11]	5.18 [5]		4.22 [1]	2
3	28.28 [10]	20.22 [6]	44.03 [16]	12.64 [2]		6.68 [1]	3
4	139.35 [13]	61.67 [5]	134.28 [12]	60.56 [4]		45.08 [1]	4
1			5.43 [23]		6.68 [24]	3.92 [18]	1
2			16.57 [20]		20.39 [22]	16.32 [19]	2
3			85.83 [23]		94.94 [24]	55.47 [19]	3
4			261.88 [20]		289.72 [22]	230.83 [19]	4
	No.5		No. 7		No. 9		

☐ 7 all-round best in terms of energy consumption.
(43% electric).

▨ 6 all-round worst in terms of energy consumption.
(33.3% electric).

lowest cost - gas	highest cost - electric
lowest energy consumption - electric	highest energy consumption - gas

Appendix 4.2

Summary of Monthly and Seasonal Air Temperatures

	SOLAR HOUSES						REFERENCE HOUSES					
	1992-1993			1993-1994			1992-1993			1993-1994		
Month	Zone 1	Zone 2	All	Zone 1	Zone 2	All	Zone 1	Zone 2	All	Zone 1	Zone 2	All
Sept.	21.66	19.64	20.2	22.41	20.51	21.03	18.89	17.31	17.74			
Oct.	21.63	18.41	19.29	22.21	19.39	20.16	18.12	13.91	15.06			
Nov.	22.14	18.59	19.56	21.85	18.58	19.47	19.8	12.22	14.29			
Autumn	21.81	18.88	19.68	22.16	19.49	20.22	18.93	14.47	15.69			
Average	V:15.3	C:13.19	To:8.08	V:16.78	C:13.96	To:8.25						
Dec.	22.25	18.62	19.61	22.36	18.65	19.66	19.58	11.27	13.54	Note : Temperature data not available for reference houses for 1993-1994.		
Jan.	22.48	18.77	19.78	22.13	18.34	19.38	18.68	12.65	14.29			
Feb.	22.85	19.2	20.19	21.96	18.14	19.18	19.3	14.03	15.47			
Winter	22.52	18.85	19.85	22.16	18.38	19.41	19.18	12.6	14.4			
Average	V:13.15	C:11.04	To:4.83	V:12.21	C:9.64	To:3.25						
Mar.	22.56	18.89	19.89	22.09	18.3	19.33	19.19	13.91	15.35			
Apr.	22.53	19.5	20.33	22.22	19.31	20.1	19.86	16.32	17.29			
May.	22.24	20.03	20.63	22.51	20.34	20.93	19.7	17.2	17.88			
Spring	22.44	19.47	20.28	22.28	19.31	20.12	19.58	15.8	16.84			
Average	V:16.41	C:14.75	To:8.46	V:16.25	C:14.78	To:8.16						
Season	22.26	19.07	19.94	22.2	19.06	19.92	19.23	14.3	16			
	V:14.96	C:13.01	To:7.14	V:15.09	C:12.81	To:6.57						

Appendix 4.3.a

Air temperatures (°C), and effective rates of air change (ac/h)

g	gas	I	home with infants.
e	electricity	O	home with old age pensioners only
p	pet	A	home with adults - no infants.
◑	home with smokers	☐	home with non-smokers
Z1	living room	all	all of house
Z2	rest of house	n^e	effective rate of air change

(i)-(v) comfort on a scale where (i) is "very comfortable", (iii) is "comfortable" and (v) is "very uncomfortable".

a-c air quality scale (perception by MA) where a=fresh, b=tolerable, c=stuffy. (From 1992-93 questionnaire).

Wardie Road : September - November 1992

Z1	23.75	g		22.45	g	22.82	g		20.66	g	19.95	g		21.39	g
Z2	20.84	I		20.77	O p	18.4	O p		17.91	A	16.73	O		19.42	I
all	21.64	◑		21.23	◑	19.61	◑		18.66	◑	17.61	☐		19.96	☐
n^e	[1.04]	b		[0.81]	(i) b	[1.63]	a		[0.59]	b	[0.61]	a		[0.78]	b
Z1	22.2	g		23.75	e	21.29	e		22.62	g	19.48	g		21.96	e
Z2	19.63	I		20.42	O	17.08	O		19.93	I	16.29	O		19.14	O
all	20.33	☐		21.33	◑	18.23	◑		20.67	◑	17.16	☐		19.91	◑
n^e	[0.89]	(iii) b		[0.41]	(i) c	[1.33]	(iii) a		[1.36]	a	[0.46]	(i) b		[0.86]	(i) b
Z1	23.33			23.44	e	22.51	e		22.39	g	25.53	e		21.12	g
Z2	18.78	☐		21.11	A	18.38	O p		19.36	O	23.26	I p		18.29	I
all	20.02			21.75	◑	19.51	◑		20.19	◑	23.88	◑		19.07	◑
n^e		(iii) b		[0.64]	(iii) c	[0.89]	(iii) c		[2.55]	(i) a	[1.08]	(i) c		[1.85]	(i) a

No. 41 **No. 43** **No. 45**

Wardie Road : December - February 1992-93

Z1	23.78	g		22.36	g	22.76	g		20.96	g	20.9	g		20.94	g
Z2	20.54	I		20.76	O p	8.06	O p		17.71	A	15.46	O		18.48	I
all	21.42	◑		21.19	◑	9.35	◑		18.6	◑	16.94	☐		19.15	☐
ne	[1.21]	b		[0.73]	(i) b	[1.38]	a		[0.33]	b	[0.41]	a		[0.72]	b
Z1	24.91	g		22.93	e	22.8	e		23.34	g	19.58	g		23.03	e
Z2	19.01	I		19.22	O	18.16	O		20.01	I	15.41	O		19.85	O
all	20.62	☐		20.23	◑	19.43	◑		20.93	◑	16.55	☐		20.72	◑
ne	[0.73]	(iii) b		[0.32]	(i) c	[1.01]	(iii) a		[1.73]	a	[0.38]	(i) b		[0.86]	(i) b
Z1	25.28			24.88	e	23.58	e		21.32	g	26.65	e		21.72	g
Z2	21.69	☐		21.22	A	18.48	O p		18.58	O	23.35	I p		17.77	I
all	22.67			22.22	◑	19.87	◑		19.33	◑	24.25	◑		18.85	◑
ne		(iii) b		[0.63]	(iii) c	[0.75]	(iii) c		[1.35]	(i) a	[1.05]	(i) c		[1.85]	(i) a

No. 41 **No. 43** **No. 45**

Wardie Road : March - May 1993

Z1	23.64	g		22.43	g	22.89	g		21.05	g	20.57	g		21.09	g
Z2	20.96	I		21.13	O p	18.82	O p		18.96	A	17.08	O		19.43	I
all	21.69	◑		21.48	◑	19.93	◑		19.53	◑	18.04	☐		19.88	☐
n^e	[1.46]	b		[0.79]	(i) b	[1.78]	a		[0.59]	b	[0.99]	a		[1.18]	b
Z1	24.47	g		24.43	e	22.87	e		23.16	g	19.35	g		22.27	e
Z2	19.84	I		20.78	O	19.39	O		20.38	I	17.15	O		19.35	O
all	21.1	☐		21.78	◑	20.34	◑		21.14	◑	17.75	☐		20.15	◑
n^e	[1.11]	(iii) b		[0.39]	(i) c	[1.45]	(iii) a		[2.39]	a	[0.41]	(i) b		[0.89]	(i) b
Z1	24.66			24.69	e	23.32	e		21.13	g	25.56	e		22.12	g
Z2	21.92	☐		20.87	A	19.51	O p		19.49	O	22.88	I p		19.24	I
all	22.67			21.92	◑	20.55	◑		19.94	◑	23.61	◑		20.03	◑
n^e		(iii) b		[1.05]	(iii) c	[0.88]	(iii) c		[0.91]	(i) a	[1.04]	(i) c		[2.3]	(i) a

No. 41 **No. 43** **No. 45**

☐	8 best in terms of energy consumption	▨	8 worst in terms of energy consumption

Appendix 4.3.b

Air temperatures (°C), and effective rates of air change (ac/h)

g	gas	I	home with infants.
e	electricity	O	home with old age pensioners only
p	pet	A	home with adults - no infants.
○	home with smokers	□	home with non-smokers
Z1	living room	all	all of house
Z2	rest of house	n^e	effective rate of air change

(i)-(v) comfort on a scale where (i) is "very comfortable", (iii) is "comfortable" and (v) is "very uncomfortable".

a-c air quality scale (perception by MA) where a=fresh, b=tolerable, c=stuffy. (From 1992-93 questionnaire).

Glenburnie Place : September - November 1992

Z1	22.49	g	21.91	e	18.96	g	21.54	g	19.34		22.78	e
Z2	22.6	A p	19.23	O p	17.39	A	20.51	A	17.13		18.29	O p
all	22.57	○	19.96	○	17.82	□	20.79	□	17.73		19.52	○
ne	[1.86]	(i) b	[1.41]	(i) b	[0.94]	a	[1.39]	(ii) a	2.1	(iii) a	[1.31]	a
Z1	25.06	e	23.15	g	21.09	g	18.75	e	23.03	e	20.42	e
Z2	19.25	O	18.81	I	17.49	O	17.69	A	19.5	A	16.98	O
all	20.83	○	20	□	18.47	○	17.98	○	20.46	○	17.92	○
ne	[1.34]	c	[1.29]	(i) a	[1.11]	(i) a	[0.4]	(iii) b	[1.23]	(ii) b	[0.82]	(iii) b
Z1	19.15	e	19.73	g	21.91	g	19.4	g	21.71	g	23.05	e
Z2	14.37	I p	15.59	O	19.84	O	18.44	A p	20.29	I	17.94	O p
all	15.84	○	16.72	□	20.41	○	18.7	○	20.68	○	19.34	○
ne	[1.42]	(iii) b	[0.54]	(i) c	[1.84]	(i) c	[1.96]	(v) a	[2.51]	(i) a	[0.99]	(iii) b

No. 5 No. 7 No. 9

Glenburnie Place : December - February 1992-93

Z1	22.74	g	23.48	e	17.83	g	20.72	g	21.7		24.38	e
Z2	22.49	A p	19.53	O p	16.1	A	20.15	A	19		19.4	O p
all	22.56	○	20.61	○	16.57	□	20.3	□	19.74		20.76	○
ne	[1.96]	(i) b	[1.01]	(i) b	[0.22]	a	[1.25]	(ii) a		(iii) a	[1.49]	a
Z1	26.29	e	23.67	g	21.89	g	21.24	e	24.28	e	21.66	e
Z2	20.42	O	15.58	I	18.5	O	18.2	A	21.09	A	15.69	O
all	22.03	○	17.79	□	19.43	○	19.03	○	21.96	○	17.32	○
ne	[1.17]	c	[1.08]	(i) a	[1]	(i) a	[0.4]	(iii) b	[1.14]	(ii) b	[0.6]	(iii) b
Z1	20.4	e	21.02	g	22.81	g	19.89	g	21.25	g	23.46	e
Z2	14.36	I p	16.26	O	21.81	O	18.36	A p	19.68	I	18.45	O p
all	16.01	○	17.56	□	22.08	○	18.78	○	20.11	○	19.82	○
ne	[1.08]	(iii) b	[0.62]	(i) c	[1.58]	(i) c	[1.39]	(v) a	[2.37]	(i) a	[1.07]	(iii) b

No. 5 No. 7 No. 9

Glenburnie Place : March - May 1993

Z1	22.5	g	22.44	e	18.16	g	20.85	g	22.89		23.28	e
Z2	21.43	A p	19.69	O p	16.98	A	19.94	A	20.76		18.8	O p
all	21.73	○	20.44	○	17.3	□	20.19	□	21.34		20.02	○
ne	[1.99]	(i) b	[0.95]	(i) b	[0.76]	a	[1.23]	(ii) a		(iii) a	[1.4]	a
Z1	25.12	e	23.61	g	21.92	g	20.57	e	22.97	e	22.29	e
Z2	19.3	O	17.79	I	19.61	O	18.25	A	19.96	A	17.34	O
all	20.89	○	19.38	□	20.24	○	18.88	○	20.78	○	18.69	○
ne	[1.11]	c	[1.42]	(i) a	[1.13]	(i) a	[0.36]	(iii) b	[1]	(ii) b	[0.75]	(iii) b
Z1	24.02	e	20.82	g	22.75	g	19.53	g	21.13	g	23.77	e
Z2	18.89	I p	17.03	O	21.53	O	18.69	A p	19.31	I	18.75	O p
all	20.29	○	18.07	□	21.86	○	18.92	○	19.81	○	20.12	○
ne	[1.23]	(iii) b	[0.72]	(i) c	[1.73]	(i) c	[1.52]	(v) a	[2.7]	(i) a	[1.26]	(iii) b

No. 5 No. 7 No. 9

□ 8 best in terms of energy consumption

▨ 8 worst in terms of energy consumption

Appendix 4.3.c

Air temperatures (°C) and effective rates of air change (ac/h)

g	gas	I	home with infants.
e	electricity	O	home with old age pensioners only
p	pet	A	home with adults - no infants.
◐	home with smokers	❑	home with non-smokers
Z1	living room	all	all of house
Z2	rest of house	ne	effective rate of air change

(i)-(v) comfort on a scale where (i) is "very comfortable", (iii) is "comfortable" and (v) is "very uncomfortable".
a-c air quality scale (perception by MA) where a=fresh, b=tolerable, c=stuffy. (From 1992-93 questionnaire).

Wardie Road : September - November 1993

Z1	24.23	g	21.65	g	22.36	g	21.59	g	19.82	g	22.12	g
Z2	21.23	I	20.71	O p	19.2	O p	19.28	A	17.22	O	21.07	I
all	22.05	◐	20.97	◐	20.06	◐	19.91	◐	17.93	❑	21.35	◐
ne	[1.38]	b	[0.57]	(i) b		a		b	[0.42]	a		b
Z1	23.53	g	23.33	e	22.18	e	23.84	g	19.9	g	22.29	e
Z2	19.55	I	20.47	O	18.73	O	20.2	I	17.47	O	19.65	O
all	20.64	❑	21.25	◐	19.67	◐	21.19	◐	18.14	❑	20.37	◐
ne	[0.58]	(iii) b	[0.23]	(i) c	[1.07]	(iii) a		a	[0.26]	(i) b	[0.73]	(i) b
Z1	24.45		23.84	e	20.92	e	21.42	g	22.77	e	21.32	g
Z2	20.73		21.7	A	18.23	O p	19.71	O	21.24	I p	19.27	I
all	21.75		22.29	◐	18.96	◐	20.17	◐	21.66	◐	19.83	◐
ne		(iii) b	[0.58]	(iii) c	[0.37]	(iii) c	[0.46]	(i) a	[1.28]	(i) c		(i) a
	No. 41						**No. 43**				**No. 45**	

Wardie Road : December - February 1993-94

Z1	25.11	g	21.73	g	23.86	g	21.16	g	20.27	g	19.09	g
Z2	21.65	I	20.14	O p	18.52	O p	16.6	A	14.6	O	17.85	I
all	22.59	◐	20.57	◐	19.98	◐	17.84	◐	16.15	❑	18.19	◐
ne	[1.44]	b	[0.7]	(i) b		a		b	[0.38]	a		b
Z1	23.61	g	23.47	e	21.81	e	24.65	g	18.82	g	22.32	e
Z2	17.79	I	18.67	O	18.31	O	20.4	I	16.51	O	18.79	O
all	19.38	❑	19.98	◐	19.26	◐	21.56	◐	17.14	❑	19.76	◐
ne	[0.61]	(iii) b	[0.19]	(i) c	[0.94]	(iii) a		a	[0.27]	(i) b	[0.82]	(i) b
Z1	25.65		23.97	e	20.73	e	20.94	g	lost		21.99	g
Z2	24.1		21.18	A	15.19	O p	18.16	O			17.02	I
all	24.52		21.94	◐	16.71	◐	18.92	◐			18.38	◐
ne		(iii) b	[0.65]	(iii) c	[0.11]	(iii) c	[0.44]	(i) a	data			(i) a
	No. 41						**No. 43**				**No. 45**	

Wardie Road : March - May 1994

Z1	23.9	g	22.1	g	23.02	g	21.4	g	21.03	g	20.55	g
Z2	21.35	I	20.52	O p	19.67	O p	18.82	A	17.58	O	19.38	I
all	22.05	◐	20.95	◐	20.59	◐	19.52	◐	18.52	❑	19.7	◐
ne	[1.85]	b	[0.77]	(i) b		a		b	[0.72]	a		b
Z1	24.52	g	25.87	e	23.52	e	25.46	g	19.95	g	22.14	e
Z2	20.24	I	21.27	O	20.24	O	20.74	I	17.7	O	18.89	O
all	21.41	❑	22.53	◐	21.14	◐	22.03	◐	18.31	❑	19.75	◐
ne	[1.05]	(iii) b	[0.64]	(i) c	[1.55]	(iii) a		a	[0.52]	(i) b	[1.04]	(i) b
Z1	lost		24.13	e	20.4	e	20.98	g	lost		21.83	g
Z2			21.29	A	16.97	O p	19.23	O			18.68	I
all			22.07	◐	17.91	◐	19.71	◐			19.54	◐
ne	data		[1.15]	(iii) c	[0.56]	(iii) c	[0.41]	(i) a	data			(i) a
	No. 41						**No. 43**				**No. 45**	

☐ 7 best in terms of energy consumption

▨ 6 worst in terms of energy consumption

Appendix 4.3.d

Air temperatures (°C) and effective rates of air change (ac/h)

g	gas	I	home with infants.
e	electricity	O	home with old age pensioners only
p	pet	A	home with adults - no infants.
◑	home with smokers	☐	home with non-smokers
Z1	living room	all	all of house
Z2	rest of house	ne	effective rate of air change

(i)-(v) comfort on a scale where (i) is "very comfortable", (iii) is "comfortable" and (v) is "very uncomfortable".
a-c air quality scale (perception by MA) where a=fresh, b=tolerable, c=stuffy. (From 1992-93 questionnaire).

Glenburnie Place : September - November 1993

Z1	23.26	g	24.17	e	19.45	g	21.54	g	23.38		24.21	e
Z2	22.49	A p	21.6	O p	18.11	A	20.66	A	20.39		19.46	O p
all	22.7	◑	22.31	◑	18.48	☐	20.9	☐	21.21		20.76	◑
n^e	[1.77]	(i) b	[0.82]	(i) b		a	[1.05]	(ii) a		(iii) a	[1.49]	a
Z1	23.24	e	23.46	g	21.6	g	19.29	e	19.61	e	21.78	e
Z2	17.81	O	19.15	I	19.55	O	17.81	A	17.89	A	17.87	O
all	19.29	◑	20.33	☐	20.11	◑	18.22	◑	18.36	◑	18.94	◑
n^e	[0.67]	c	[0.83]	(i) a	1.22	(i) a	[0.27]	(iii) b		(ii) b	[0.34]	(iii) b
Z1	23.94	e	18.94	g	22.48	g	18.97	g	21.27	g	24.98	e
Z2	17.82	I p	13.27	O	20.96	O	18.54	A p	19.9	I	20.01	O p
all	19.49	◑	14.82	☐	21.37	◑	18.66	◑	20.41	◑	21.37	◑
n^e		(iii) b		(i) c	[1.58]	(i) c		(v) a	[2.22]	(i) a	[1.09]	(iii) b

No. 5 **No. 7** **No. 9**

Glenburnie Place : December - February 1993-94

Z1	22.77	g	24.2	e	18.27	g	20.67	g	22.49		23.94	e
Z2	22.5	A p	20.07	O p	16.39	A	19.68	A	18.08		18.42	O p
all	22.57	◑	21.2	◑	16.9	☐	19.95	☐	19.29		19.93	◑
n^e	[1.73]	(i) b	[0.68]	(i) b		a	[1.36]	(ii) a		(iii) a	[1.66]	a
Z1	25.79	e	23.69	g	21.8	g	18.77	e	18.48	e	20.21	e
Z2	17.75	O	16.23	I	20.11	O	17.39	A	17.64	A	13.48	O
all	20.23	◑	18.27	☐	20.57	◑	17.76	◑	17.87	◑	15.32	◑
n^e	[0.76]	c	[0.84]	(i) a	[1.31]	(i) a	[0.42]	(iii) b		(ii) b	[0.16]	(iii) b
Z1	24.45	e	19.62	g	23.35	g	20.41	g	22.11	g	24.31	e
Z2	14.71	I p	13.36	O	22.62	O	18.95	A p	20.92	I	18.18	O p
all	17.37	◑	15.07	☐	22.82	◑	19.35	◑	21.24	◑	19.85	◑
n^e		(iii) b		(i) c	[1.63]	(i) c		(v) a	[2.7]	(i) a	[0.89]	(iii) b

No. 5 **No. 7** **No. 9**

Glenburnie Place : March - May 1994

Z1	22.27	g	22.33	e	19.08	g	21.18	g	23.04		24.16	e
Z2	21.21	A p	19.92	O p	17.63	A	20.57	A	20.1		19.34	O p
all	21.5	◑	20.58	◑	18.03	☐	20.74	☐	20.91		20.66	◑
n^e	[1.86]	(i) b	[0.65]	(i) b		a	[1.21]	(ii) a		(iii) a	[1.28]	a
Z1	24.84	e	23.42	g	21.23	g	19.21	e	19.47	e	20.39	e
Z2	17.95	O	17.52	I	19.9	O	18.18	A	17.34	A	16.07	O
all	19.83	◑	19.13	☐	20.26	◑	18.46	◑	17.82	◑	17.25	◑
n^e	[0.8]	c	[1.26]	(i) a	[1]	(i) a	[0.31]	(iii) b		(ii) b	[0.47]	(iii) b
Z1	lost		lost		23.72	g	22.11	g	21.24	g	24.38	e
Z2					22.86	O	19.81	A p	19.67	I	19.2	O p
all					23.1	◑	20.44	◑	20.1	◑	20.62	◑
n^e	data		data		[2.16]	(i) c		(v) a	[2.7]	(i) a	[1.17]	(iii) b

No. 5 **No. 7** **No. 9**

☐ 7 best in terms of energy consumption ▨ 6 worst in terms of energy consumption

Appendix 4.4.a

TEMPERATURE DIFFERENCES

☐ flats that are best in terms of energy consumption
☐ flats that are worst in terms of energy consumption
☐ buffer spaces that are OK

actual temps	*temp difference*	
Temp in	BR1-V	Where : BR1 is temp in main bedroom
Veranda	V-To	K is temp in kitchen.
Temp in	K-C	To is outside temp.
Conserv	C-To	

Wardie Road : September - November 1992

18.31	2.82		17.95	4.05	15.66	2.3		15.9	3.03	12.69	4.24		14.75	5.33
V	10.23	▤	V	9.87	V	7.58	▤	V	7.82	V	4.61	▤	V	6.67
13	8.31	▤	12.75	9.23	12.02	7.17	▤	11.92	6.41	9.2	7.45	▤	12.81	6.8
C	4.29	▤	C	4.67	C	3.94	▤	C	3.84	C	1.12	▤	C	4.73
18	2.55		20.14	0.93	14.2	2.2		19.73	0.34	14.99	1.98		17.74	1.36
V	9.92	▤	V	12.06	V	6.12	▤	V	11.65	V	6.91	▤	V	9.66
12.17	7.77	▤	13.54	7.46	12.15	6.46	▤	13.44	6.7	10.74	6.61	▤	14.42	5
C	4.09	▤	C	5.46	C	4.07	▤	C	5.36	C	2.66	▤	C	6.34
16.38	3.27		16.14	5.16	14.16	3.74		17.89	2.41	15.34	6.84		13.9	4.91
V	8.3	▤	V	8.07	V	6.08	▤	V	9.81	V	7.25	▤	V	5.82
15.79	3.95	▤	14.53	6.76	10.41	8.99	▤	14.48	6.82	13.45	11.36	▤	13	5.39
C	7.71	▤	C	6.45	C	2.33	▤	C	6.4	C	5.37	▤	C	4.92

No. 41 **No. 43** **No. 45**

V : 9/18 (50%) OK C : 15/18 (83%) OK - only 1 opened up too much to kitchen (41/01)

Wardie Road : December - February 1992-93

16.72	4.59		15.77	6.13	13.33	4.25		9.63	7.99	10.26	5.46		12	6.95
V	11.89	▤	V	10.94	V	8.5	▤	V	4.8	V	5.43	▤	V	7.17
10.29	10.65	▤	8.7	13.22	9.36	9.55	▤	8.07	10.3	6.27	8.92	▤	11.25	7.58
C	5.46	▤	C	3.87	C	4.53	▤	C	3.24	C	1.45	▤	C	6.42
14.91	5.62		17.87	1.99	12.01	4.22		19.81	0.11	12.61	1.26		17.17	2.14
V	10.08	▤	V	13.04	V	7.18	▤	V	14.98	V	7.78	▤	V	12.34
6.28	12.79	▤	10.06	9.84	9.62	11.37	▤	12.26	8.05	7.76	9.1	▤	12.51	7.66
C	1.45	▤	C	5.23	C	4.79	▤	C	7.43	C	2.83	▤	C	7.68
14.46	10.65		12.91	7.91	11.45	6.39		16.04	2.63	11.9	9.29		10.84	7.18
V	9.63	▤	V	8.08	V	6.62	▤	V	11.21	V	7.07	▤	V	6.01
8.16	13.29	▤	12.43	8.88	7.74	11.71	▤	15.86	3.09	11.35	14.39	▤	11.24	6.87
C	3.33	▤	C	7.6	C	2.91	▤	C	11.03	C	6.52	▤	C	6.41

No. 41 **No. 43** **No. 45**

V : 13/18 (72%) OK C : 10/18 (56%) only 1 Conservatory opened up too much to kitchen (43/01)

Wardie Road : March - May 1993

19.11	2		17.6	4.67	16.54	1.68		15.86	3.1	12.71	4.46		14.38	5.3
V	10.65	▤	V	9.14	V	8.09	▤	V	7.4	V	4.25	▤	V	5.92
14.83	6.54	▤	14.21	7.99	14.53	5.13	▤	14.05	5.5	10.89	6.18	▤	14.76	5.14
C	6.37	▤	C	5.75	C	6.07	▤	C	5.59	C	2.63	▤	C	6.3
18.68	2.33		19.53	1.69	14.55	3.28		lost		14.72	2.62		18.46	0.59
V	10.22	▤	V	11.07	V	9.69	▤		data	V	6.26	▤	V	10
13.79	6.01	▤	14.55	7.05	14.77	7.06	▤	15.5	5.05	12.6	5.3	▤	16.2	3.45
C	5.33	▤	C	6.09	C	9.91	▤	C	7.04	C	4.14	▤	C	7.74
17.87	4.86		15.98	4.8	14.98	4.2		15.64	3.76	15.51	5.93		14.43	4.78
V	9.41	▤	V	7.52	V	6.51	▤	V	7.18	V	7.05	▤	V	5.97
12.35	9.37	▤	15.79	6.03	11.96	8.34	▤	14.53	6.58	14.95	9.32	▤	14.85	4.57
C	3.89	▤	C	7.33	C	3.5	▤	C	6.07	C	6.49	▤	C	6.39

No. 41 **No. 43** **No. 45**

V : 11/18 (61%) OK - 2 verandas opened up to bedroom on a frequent basis (11%).

C : 14/18 (78%) OK - no conservatories opened up too much to kitchen.

Appendix 4.4.b

TEMPERATURE DIFFERENCES

☐ flats that are best in terms of energy consumption

▨ flats that are worst in terms of energy consumption

▤ buffer spaces 'OK' - i.e. temp difference > 3K

actual temps	*temp difference*	
Temp in	BR1-V	Where : BR1 is temp in main bedroom
Veranda	V-To	K is temp in kitchen.
Temp in	K-C	To is outside temp.
Conserv	C-To	

Glenburnie Place : September - November 1992

15.55	6.62		13.66	5.8	15.02	2.47		15.17	5.62	12.26	5.06		14.94	3.37
V	9.28	▤	V	7.39	V	6.94	▤	V	7.09	V	5.99	▤	V	6.86
16.4	6.96	▤	12.48	8.79	13.91	4.17	▤	14.16	6.2	12.66	5.06	▤	15.11	3.5
C	10.13	▤	C	6.21	C	5.83	▤	C	6.08	C	6.39	▤	C	7.03
13.68	4.97		13.38	3.28	15.32	2.07		14.87	2.16	15.79	2.22		13.98	3.03
V	7.41	▤	V	7.11	V	7.24	▤	V	6.79	V	7.71	▤	V	5.9
10.78	10.14	▤	10.85	7.77	14.48	3.63	▤	15.5	1.5	14.64	6.38	▤	15.23	3.35
C	4.51	▤	C	4.58	C	6.4	▤	C	7.42	C	6.56	▤	C	7.15
11.06	3.9		11.4	4.3	15.95	3.84		15.7	2.74	13.84	5.93		15.49	2.04
V	4.79	▤	V	5.13	V	7.87	▤	V	7.62	V	5.76	▤	V	7.41
11.01	4.81	▤	9.17	7.78	13.83	7.9	▤	16.05	2.83	15.52	5.46	▤	13.37	6.27
C	4.74	▤	C	2.9	C	5.75	▤	C	7.97	C	7.44	▤	C	5.29

No. 5 **No. 7** **No. 9**

C : 16/18 (87%) OK V : 12/18 (67%) OK

Glenburnie Place : December - February 1992-93

16.16	6.37		12.01	7.96	10.77	5.42		12.19	8.49	11.02	7.91		13.38	5.83
V	11.33	▤	V	7.18	V	5.94	▤	V	7.36	V	6.19	▤	V	8.55
16.82	6.31	▤	10.44	11.58	9.94	7	▤	11.39	8.85	12.61	7.16	▤	16.2	3.25
C	11.99	▤	C	5.61	C	5.11	▤	C	6.56	C	7.78	▤	C	11.37
14.29	4.31		12.11	3.5	13.69	4.74		12.18	6.25	12.88	6.9		11.45	4.15
V	9.46	▤	V	7.28	V	8.86	▤	V	7.35	V	8.05	▤	V	6.62
12.11	10.21	▤	8.59	9.21	12.57	6.38	▤	12.64	5.92	12.57	9.01	▤	12.48	5.08
C	7.28	▤	C	3.76	C	7.74	▤	C	7.81	C	7.74	▤	C	7.65
11.15	3.13		10.52	5.52	13.46	7.24		15.8	4.4	10.93	8.3		11.88	5.85
V	6.32	▤	V	5.69	V	8.63	▤	V	8.97	V	6.1	▤	V	7.05
10.77	5.15	▤	7.94	9.91	10.27	13.4	▤	15.56	3.44	14.26	6.37	▤	10.98	8.79
C	5.94	▤	C	3.11	C	5.44	▤	C	10.73	C	9.43	▤	C	6.15

No. 5 **No. 7** **No. 9**

100% success (1 borderline No. 9 2/2)

Glenburnie Place : March - May 1992-93

18.9	3.3		16.58	4.07	15.89	2.62		16.3	3.9	15.49	5.39		16.81	1.87
V	10.44	▤	V	8.12	V	7.43	▤	V	7.84	V	7.03	▤	V	8.35
18	4.28	▤	14.34	6.08	14.5	3.08	▤	14.89	5.54	16.09	5.16	▤	16.48	2.77
C	9.55	▤	C	5.88	C	6.04	▤	C	6.43	C	7.63	▤	C	8.03
17.6	0.85		16.31	2.44	17.62	2.05		16.55	2.07	17.18	2.12		15.38	2.25
V	9.14	▤	V	7.85	V	9.22	▤	V	8.09	V	8.72	▤	V	6.29
15.87	4.73	▤	12.98	6.31	16.54	3.71	▤	16.24	2.34	14.75	5.55	▤	16.13	2.71
C	7.41	▤	C	4.52	C	8.14	▤	C	7.78	C	6.29	▤	C	7.67
16.02	3.23		14.85	2.39	18.25	3.48		16.5	2.12	14.84	4.59		16.65	2.04
V	7.56	▤	V	6.39	V	9.79	▤	V	8.04	V	6.38	▤	V	8.19
14.98	5.5	▤	11.95	6.39	14.45	8.33	▤	17.01	2.25	16.13	3.77	▤	14.41	5.07
C	6.52	▤	C	3.49	C	5.99	▤	C	8.55	C	7.67	▤	C	5.95

No. 5 **No. 7** **No. 9**

C : 14/18 (78%) V : 6/18 (33%) usually Bedrooms too hot.

Appendix 4.4.c

TEMPERATURE DIFFERENCES

☐ flats that are best in terms of energy consumption
☐ flats that are worst in terms of energy consumption
☐ buffer spaces that are OK

actual temps	*temp difference*
Temp in	BR1-V
Veranda	V-To
Temp in	K-C
Conserv	C-To

Where : BR1 is temp in main bedroom
K is temp in kitchen.
To is outside temp.

Wardie Road : September - November 1993

18.94	2.94		17.44	4.49	17.58	1.29		16.48	2.29	12.84	4.51		14.85	6.55
V	10.69	▤	V	9.18	V	9.33	▤	V	8.23	V	4.59	▤	V	6.6
14.52	7.09	▤	12.58	9.4	14.03	5.97	▤	12.64	7.07	9.57	7.18	▤	13.4	8.14
C	6.27	▤	C	4.33	C	5.78	▤	C	4.39	C	1.32	▤	C	5.15
18.37	2.77		20.1	0.83	14.65	3.07		lost		15.12	2.93		18.15	1.1
V	10.12	▤	V	11.85	V	6.4	▤		data	V	6.87	▤	open	9.9
13.22	6.27	▤	14.04	7.15	13.72	6.69	▤	15.89	4.31	11.5	6.42	▤	15.62	4.21
C	4.97	▤	C	5.79	C	5.47	▤	C	5.97	C	3.25	▤	C	7.37
17.87	4.829		16.26	5.28	15.23	2.91		16.13	3.5	19.2	2.3		16.51	3.38
V	9.62	▤	V	8.01	V	6.98	▤	V	7.88	V	7.25	▤	V	4.56
11.53	9.8	▤	15.69	6.38	10.35	8.74	▤	14.18	7.59	18.08	3.61	▤	15.79	3.64
C	3.28	▤	C	7.44	C	2.1	▤	C	5.94	C	6.13	▤	C	3.84
		No. 41					**No. 43**					**No. 45**		

C: 16/18 (89%) OK V : 8/17 (47%) + 4 Borderline (23%)

Wardie Road : December - February 1993-94

14.96	6.79		13.14	8.35	14.91	2.97		12.58	5.06	8.49	6.31		9.54	8.63
V	11.71	▤	V	9.89	V	11.66	▤	V	9.33	V	5.25	▤	V	6.29
11.43	10.56	▤	7.67	13.4	10.26	9.16	▤	6.96	11.31	4.86	9.42	▤	8.27	10.1
C	8.18	▤	C	4.42	C	7.01	▤	C	3.71	C	1.61	▤	C	5.02
12.35	7.14		16.24	2.93	10.45	5.39		lost		9.8	5.6		14.72	3.24
V	9.6	▤	V	13.29	V	7.2	▤		data	V	6.55	▤	V	11.47
8.23	9.4	▤	9.32	10.19	10.01	11.06	▤	12.81	8.2	7	9.1	▤	11.38	7.57
C	5.28	▤	C	6.37	C	6.76	▤	C	9.56	C	3.75	▤	C	8.13
14.87	9.46		12.63	7.47	10.99	3.98		11.61	6.42	lost			9.85	7.78
V	11.62	▤	V	9.38	V	7.74	▤	V	8.37			▤	V	6.6
8.18	17.65	▤	11.86	9.3	5.35	10.86	▤	9.42	11.6			▤	8.18	9.24
C	4.93	▤	C	8.61	C	2.1	▤	C	5.99	data		▤	C	4.93
		No. 41					**No. 43**					**No. 45**		

C : 15/17 (88%) OK V : 14/16 (88%) OK

Wardie Road : March - May 1994

18.82	2.77		17.69	4.16	17.56	1.5		16.92	2.23	14.21	3.6		15.86	3.91
V	10.86	▤	V	9.73		9.6	▤		8.96		6.25	▤		7.9
15.96	5.77	▤	13.8	7.66	14.54	6.03	▤	13.34	6.2	11.04	6.42	▤	13.21	6.48
C	8	▤	C	5.84		6.58	▤		5.38		3.08	▤		5.25
18.55	2.7		20.92	0.7	15.47	3.17		lost		15.5	2.51		17.9	0.86
V	10.59	▤	V	12.96		7.51	▤		data		7.54	▤		9.34
12.82	7.1	▤	14.3	7.78	15.21	7.15	▤	15.01	5.84	12.46	5.71	▤	15.28	4.17
C	4.86	▤	C	6.34		7.25	▤		7.05		4.5	▤		7.32
lost			16.83	3.91	15.09	1.74		15.94	3.3	lost			13.87	5.23
		▤	V	8.87		7.13	▤		7.98			▤		5.91
		▤	15.31	6.27	10.4	7.45	▤	13.66	7.88			▤	12.84	6.1
data		▤	C	7.35		2.44	▤		5.7	data		▤		4.88
		No. 41					**No. 43**					**No. 45**		

C : 15/16 (94%) OK V : 7/15 (47%) + 3 Borderline.

Appendix 4.4.d

TEMPERATURE DIFFERENCES

☐ flats that are best in terms of energy consumption

☐ flats that are worst in terms of energy consumption

☐ buffer spaces that are OK

actual temps	*temp difference*	
Temp in	BR1-V	Where : BR1 is temp in main bedroom
Veranda	V-To	K is temp in kitchen.
Temp in	K-C	To is outside temp.
Conserv	C-To	

Glenburnie Place : September - November 1993

19.18	3.64		17.77	4.41	16.9	1.51		16.94	4.17	17.13	3.52		18.87	0.55
V	10.93		V	9.52	V	8.65		V	8.69	V	8.88		V	8.95
18.25	4.93		13.51	9.7	13.93	4.74		13.3	7.64	15.33	5.6		17.4	2.24
C	10		C	5.26	C	5.68		C	5.05	C	6.83		C	4.48
17.24	0.28		17.46	2.02	18.86	1.04		16.42	3.14	14.86	3.21		15.24	2.92
V	8.99		V	9.21	V	10.61		V	8.16	V	6.61		V	6.99
14.19	4.35		13.79	6.28	16.68	3.23		15.39	2.16	13.28	5.08		15.53	4.58
C	5.94		C	5.54	C	8.43		C	7.14	C	5.03		C	7.28
14.17	4.57		9.91	3.84	8.66	2.72		14.97	3.86	17.7	2.24		18.81	1.24
V	9.34		V	5.07	V	10.41		V	6.72	V	9.45		V	10.56
9.33	9.44		5.7	8.78	14.09	7.3		16.33	2.72	16.53	3.87		13.5	6.95
C	4.5		C	0.87	C	5.84		C	8.08	C	8.28		C	5.25

No. 5 **No. 7** **No. 9**

V : 9/18 (51%) OK - 2V fully open to inside.

C : 14/18 (78%) OK - 1V fully open to outside.

Glenburnie Place : December - February 1993-94

14.49	7.98		12.41	8.16	11.23	5.42		12.25	7.75	10.53	7.75		13.46	5.67
V	11.24		V	9.16	V	7.98		V	9.11	V	7.28		V	10.21
14.08	9.27		7.83	14.13	9.56	7.49		8.34	11.58	12.48	6.79		12.97	5.86
C	10.83		C	4.58	C	6.31		C	5.2	C	9.23		C	9.72
14.4	2.5		11.85	3.92	15.61	4.77		10.51	7.43	10.23	6.69		9.52	4.2
V	11.16		V	8.6	V	12.36		V	7.26	V	6.98		V	6.27
8.78	9.85		8.5	9.75	15.48	5.06		8.66	8.98	8.91	9.33		10.57	4.54
C	5.53		C	5.25	C	12.23		C	5.41	C	5.66		C	7.32
11.54	3.35		9.18	4.26	15.71	5.86		10.74	8.06	13.18	7.67		11.3	6.86
V	7.9		V	5.34	V	12.46		V	8.35	V	9.93		V	8.05
7.08	9.45		6.4	8.38	11.34	12.95		10.46	9.31	15.9	5.75		9.09	9.33
C	3.43		C	2.75	C	8.09		C	8.07	C	12.65		C	5.84

No. 5 **No. 7** **No. 9**

C & V : 17/18 (94%) OK as buffers.

Glenburnie Place : March - May 1994

18.38	2.87		15.27	5.27	14.39	3.45		15.67	5.43	15.64	4.28		15.67	3.6
V	10.42		V	7.31	V	6.43		V	7.71	V	7.68		V	7.71
17.6	4.7		14.9	7.17	15.63	2.74		15.32	5.52	17.19	3.99		17.31	2.09
C	9.64		C	6.94	C	7.67		C	7.36	C	9.23		C	9.35
17.41	0.12		15.48	2.19	15.71	4.12		11.95	6.53	14.51	3.15		13.97	2.14
V	9.45		V	7.52	V	8.71		V	4.94	V	6.55		V	6.01
13.74	5.15		13.26	5.85	17.7	2.72		13.59	4.55	15.95	2.38		15.01	2.55
C	5.78		C	5.3	C	10.7		C	6.58	C	7.99		C	7.05
lost			lost		20.27	2.49		17.32	2.39	16.19	3.51		14.78	4.32
					V	10.81		V	7.86	V	8.23		V	6.82
					17.16	6.9		16.83	3.49	17.65	2.64		14.81	5.05
data			data		C	7.7		C	7.37	C	9.69		C	6.85

No. 5 **No. 7** **No. 9**

V : 10/16 (63%) OK

C :10/16 (63%) OK

Appendix 4.4.e

SUMMARY OF BUFFERING EFFECT : 1992 - 93

Glenburnie Place & Wardie Road

	Sept - Nov	Dec - Feb	Mar - May	
BRI - V (W)	3.86	5.9	2.82	**Glenburnie**
BR1 - V (SE)	2.97	5.26	3.53	**Wardie**
K - C (E)	5.66	7.61	4.64	**Glenburnie**
K - C (NW)	7.15	9.85	6.37	**Wardie**
V-to (W)	6.91	7.61	8.08	**Glenburnie**
V-to (SE)	8.25	9.04	8.02	**Wardie**
C-to (E)	6.24	7.3	6.86	**Glenburnie**
C-to (NW)	4.69	5.12	5.92	**Wardie**
BR1-to (W)	10.77	13.51	10.9	**Glenburnie**
BR1-to (SE)	11.22	14.3	11.55	**Wardie**
K-to (E)	11.9	14.91	11.5	**Glenburnie**
K-to (NW)	11.84	14.97	12.29	**Wardie**

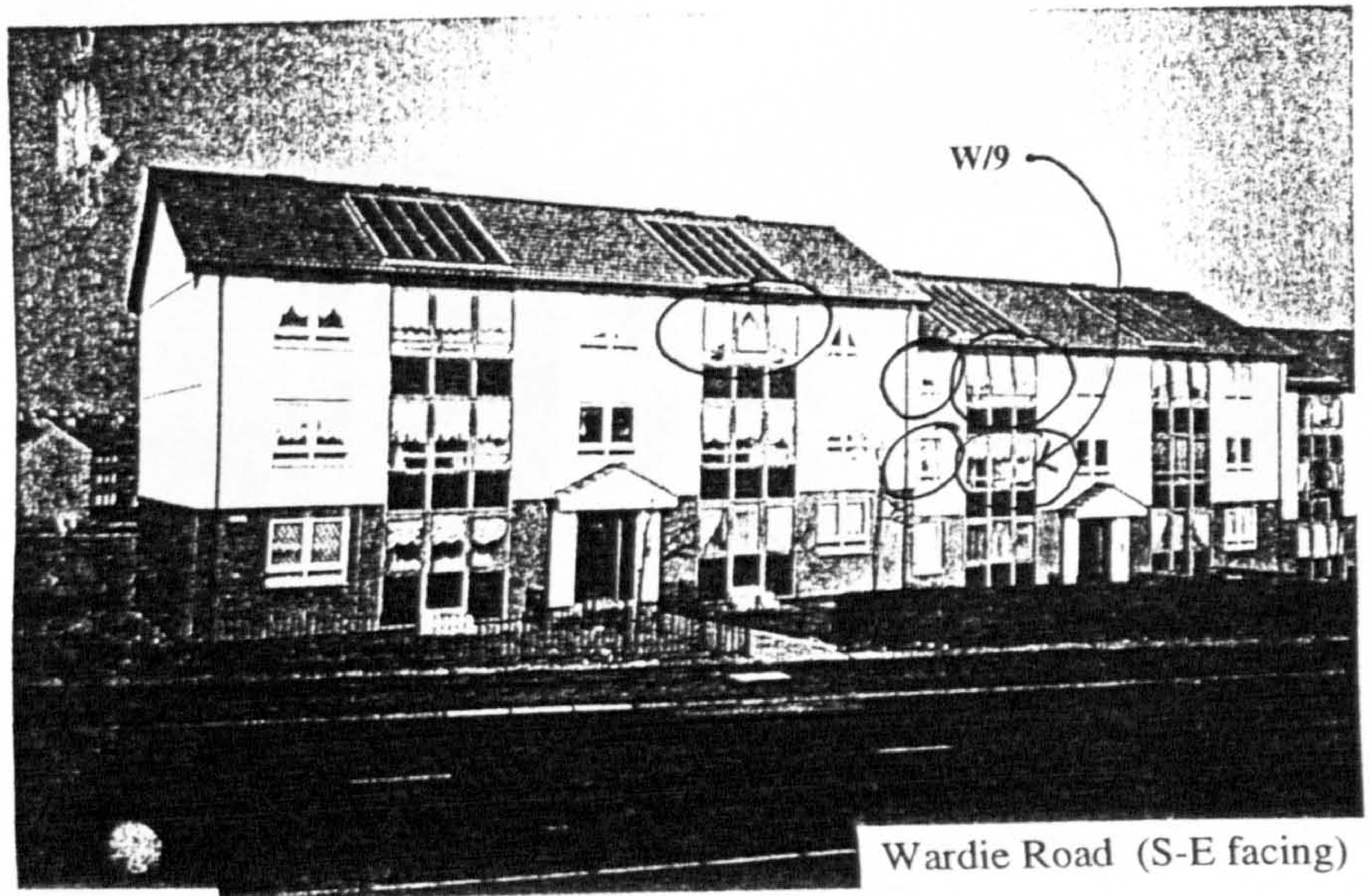
SUMMARY OF BUFFERING EFFECT : 1993 - 94

Glenburnie Place & Wardie Road

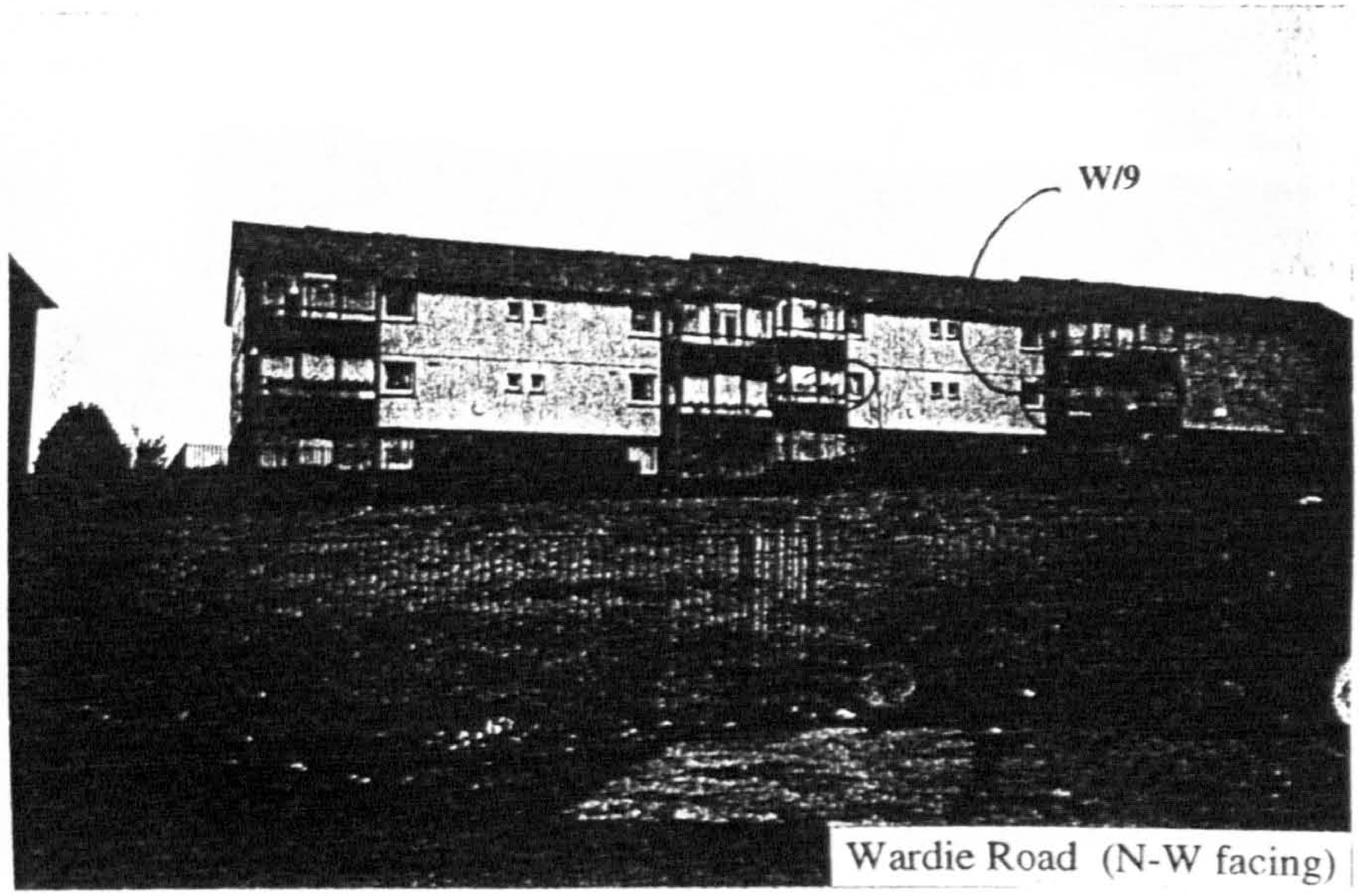
	Sept - Nov	Dec - Feb	Mar - May	
BRI - V (W)	2.7	6.02	3.49	**Glenburnie**
BR1 - V (SE)	3	6.1	2.82	**Wardie**
K - C (E)	5.53	8.77	4.16	**Glenburnie**
K - C (NW)	6.65	9.94	6.5	**Wardie**
V-to (W)	8.76	8.87	7.76	**Glenburnie**
V-to (SE)	8.12	9.12	8.74	**Wardie**
C-to (E)	6.25	7.12	7.83	**Glenburnie**
C-to (NW)	4.93	5.67	5.74	**Wardie**
BR1-to (W)	11.46	14.89	11.25	**Glenburnie**
BR1-to (SE)	11.12	15.22	11.56	**Wardie**
K-to (E)	11.78	15.89	11.99	**Glenburnie**
K-to (NW)	11.58	15.61	12.24	**Wardie**

BR1 - V	Main Bedroom - Veranda Temperature Difference (K).
K - C	Kitchen - Conservatory Temperature Difference (K)
V - to	Veranda - Outside
C - to	Conservatory - Outside Temperature Diffence (K)
BR1 - to	Kitchen - Outside Temperature Difference (K)
K - to	Kitchen - Outside Temperature Difference (K)
(W)	West facing
(SE)	South - East facing
(E)	East facing
(NW)	North - West facing

Appendix 6.1

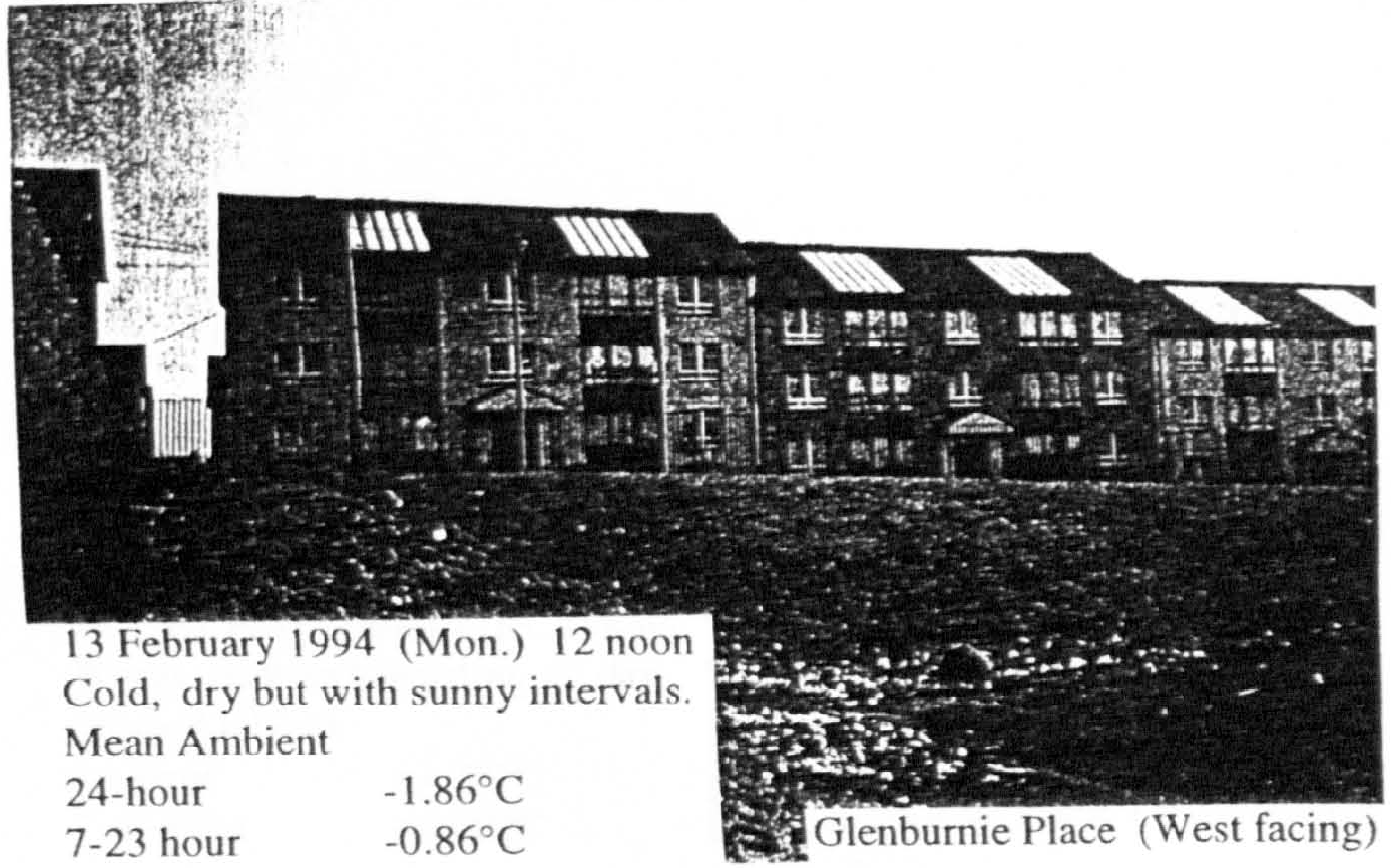


Wardie Road (S-E facing)



Wardie Road (N-W facing)

Windows ajar are circled.



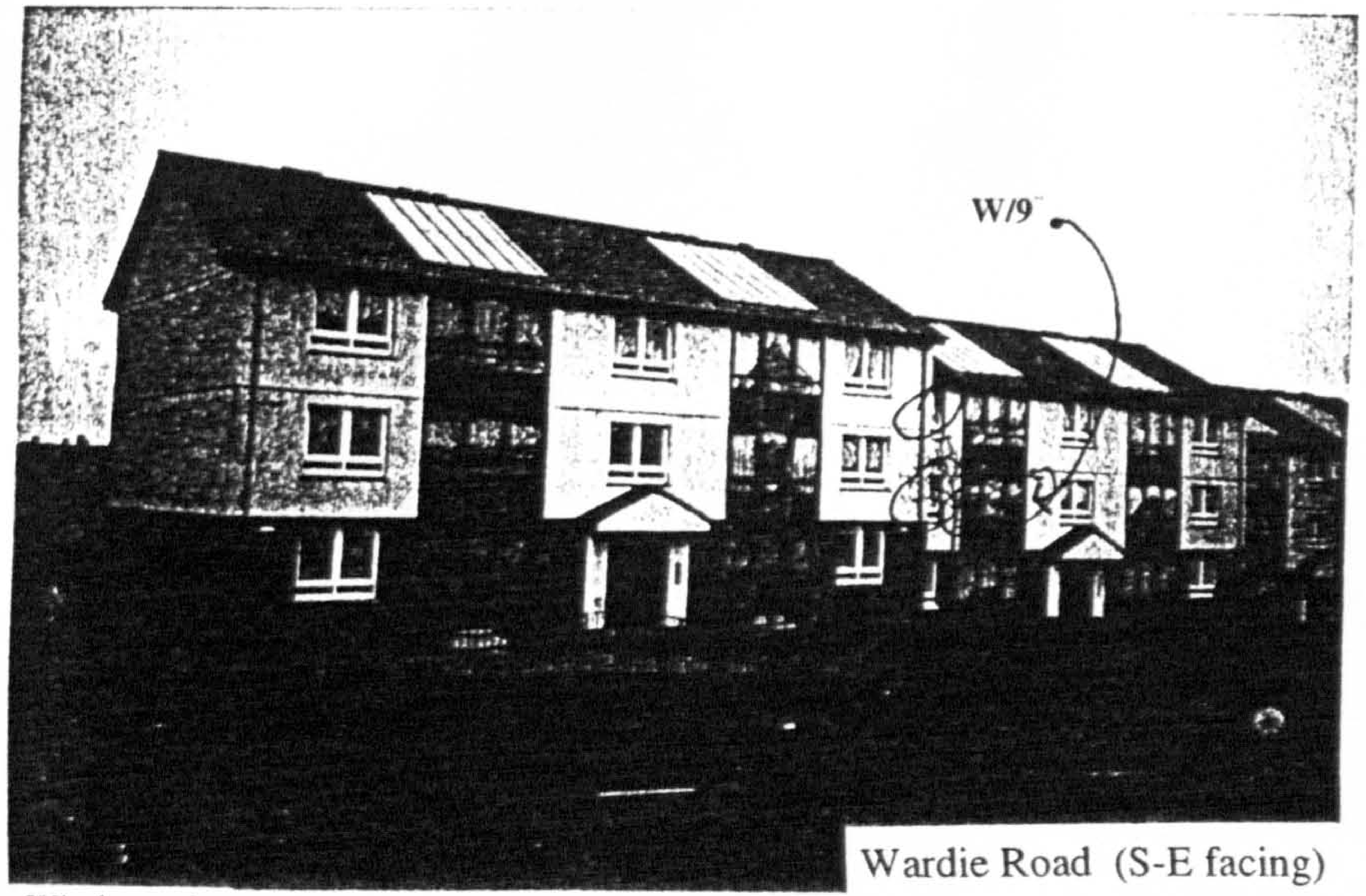
Glenburnie Place (West facing)

Glenburnie Place (East facing)

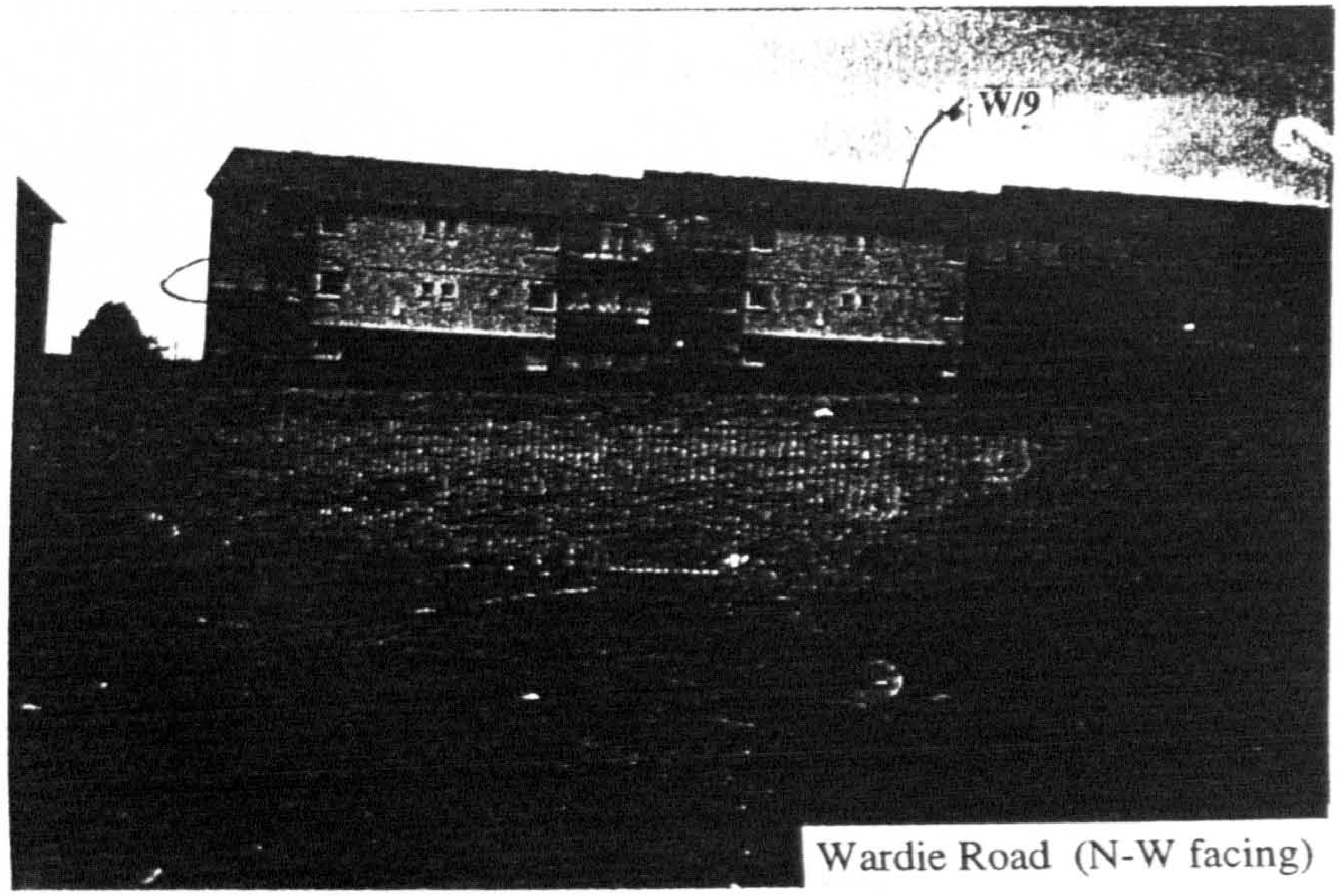
13 February 1994 (Mon.) 12 noon
Cold, dry but with sunny intervals.
Mean Ambient

24-hour	-1.86°C
7-23 hour	-0.86°C

Appendix 6.1

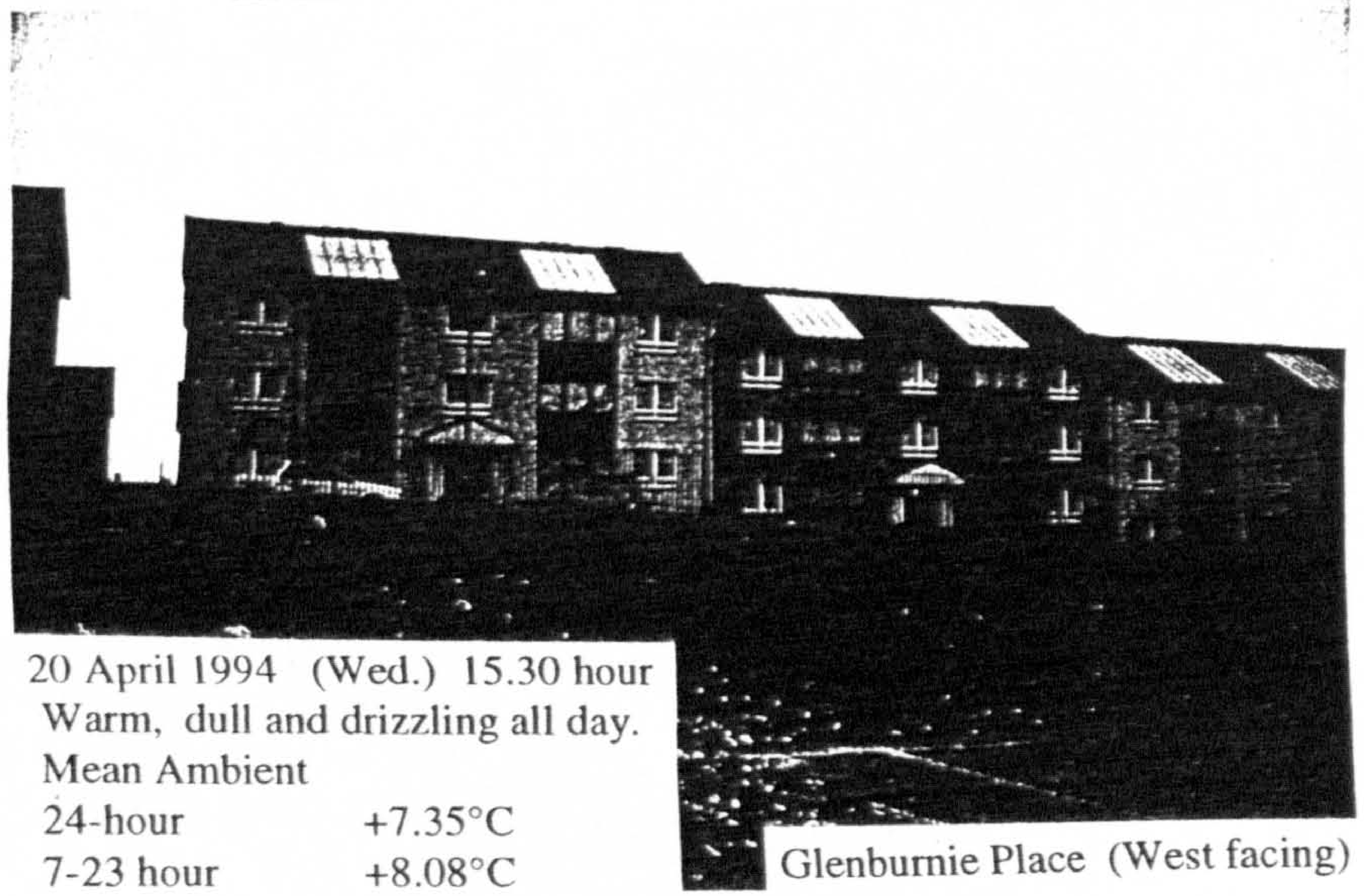


Wardie Road (S-E facing)



Wardie Road (N-W facing)

Windows ajar
are circled.



Glenburnie Place (West facing)

Glenburnie Place (East facing)

20 April 1994 (Wed.) 15.30 hour
Warm, dull and drizzling all day.
Mean Ambient
24-hour +7.35°C
7-23 hour +8.08°C