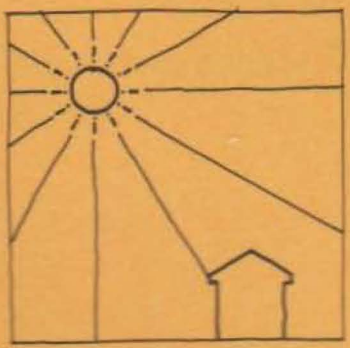
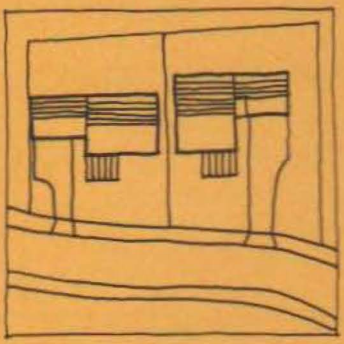
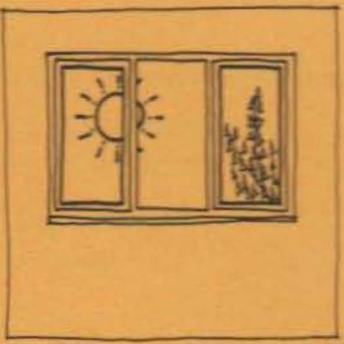
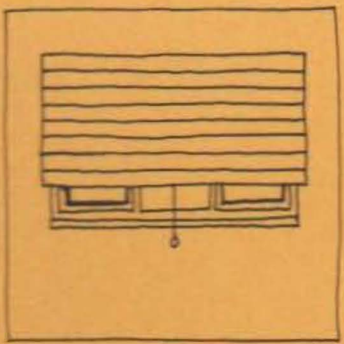
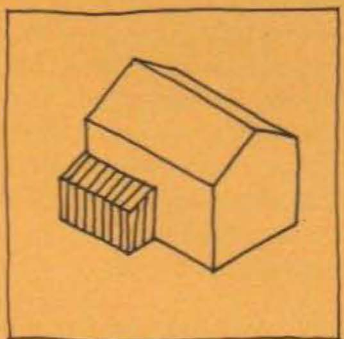
Exploiting sunshine in house design

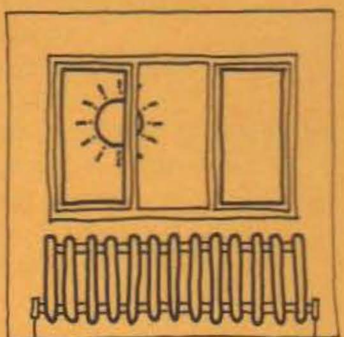


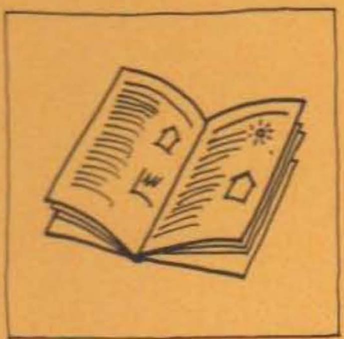












Prepared by Eclipse Research Consultants on behalf of the Building Research Establishment for the Department of Energy's Energy Technology Support Unit

Contents

Preface

Much has been written over the past decade and more on the importance of using energy efficiently in the buildings we live in. In addition to assessments of energy conservation measures, there has been a good deal of research into the potential for exploiting solar gains in housing. At the Building Research Establishment (as part of our work for the Department of Energy) we have been fortunate enough to be able to survey this information, digest it and then produce what we expect to be a useful handbook for UK house designers.

I can say that we *expect* it to be useful (rather than just *hope*) as we have also been able to try out a draft of this handbook on potential users. Their reactions were both helpful and encouraging. Comments we received on the contents and layout have helped to make it a better, more user friendly document. Other responses have confirmed our original views that such a book of design guidelines does not exist at present and that UK designers will be keen to use it.

The contents aim to help you, the designer, to produce better, more efficient houses. Initially you may not find the book makes your job any easier - it will probably raise problems that you haven't considered before - and it may make you think more deeply about the decisions you take. But our aim is to help you have a better understanding of the conflicting options that confront designers of low-energy housing. Then you can make up your own mind on how to produce better housing.

One final point - this is not a research document. The main authors of this handbook are both architects with practical experience of house building and of teaching architectural design. They've tried to provide you with sound information and concrete advice - whenever current understanding allows.

Building Research Establishment

May 1988

Introduction

This handbook summarises the best current information on designing windows and conservatories to be energy efficient. It draws particular attention to the value of using solar gains to offset heat losses. Design guidance is offered across a range of topics from site planning to the use of coated glass.

Our aim

In this handbook we attempt to draw together and to condense the best information and guidance currently available about the effect of glazing on the environmental performance and energy consumption of housing. In particular, we focus on what is known about using solar gain as a means of reducing fuel consumed for space heating. Special attention is given to making houses energy efficient by means of their siting, orientation, internal planning, and the location, size and specification of their windows. The potential of conservatories for energy saving is also discussed.

How to use this handbook

The arrangement of the handbook is based loosely around the RIBA Plan of Work, from site analysis and site layout to construction details and component specification, so presenting information in the order required to assist decision making.

Each section of the handbook is organised broadly on the following lines:

- general requirements are stated
- general principles are given
- facts and figures about cost and performance are described
- wherever possible each section or subsection is concluded by design guidance.

The design guidance of the handbook takes the form of summaries of the advantages and disadvantages of particular measures or components, together with simplified recommendations for designers to follow. Where appropriate, warnings are given about the limitations of this guidance and other publications giving more detailed information are cited.

The scope of the handbook

Over the past ten years, many design features for collecting, storing and distributing the sun's energy have been illustrated in the international literature on passive solar design. They include trombe walls, roof collectors and clerestoreys, as well as direct gain systems, conservatories as solar collectors and a variety of hybrid systems.

Not all of these so called "advanced" passive solar design options are applicable to UK circumstances because of climate, occupant behaviour, or people's expectations. Some remain experimental designs that have never been built and had their performance monitored in this country. Others, have been found to have practical disadvantages or to be so expensive to build that the additional capital cost of the solar features would not be recovered by the saving in conventional fuel.

Advanced passive solar designs also demand a level of simulation modelling to ascertain their internal comfort conditions and energy performance. This puts them beyond the scope of the simplified guidance of this handbook and consequently they are not dealt with here.

In this handbook attention is focused on optimising direct solar gain through windows, a feature common to all houses, and on the potential thermal benefits of conservatories.

The main topics of the handbook are:

- site layout, orientation, and solar access
- room arrangement
- window and conservatory location, sizing and construction
- selection and specification of building components
- responsive building services.

Our sources

The handbook draws on many sources

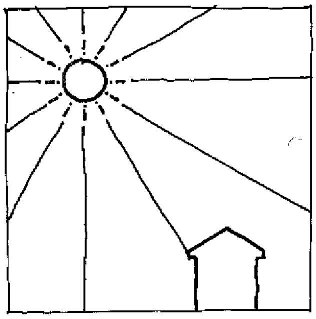
- statutory documents such as the Building Regulations, British Standards and codes of practice
- published advice on low energy design
- specialised research reports about experimental designs and computer simulations
- articles in the technical press
- trade literature.

Much of the advice comes from sources not easily accessible to practitioners:

- the simulated performance of house designs, commissioned from architects by the Energy Technology Support Unit of the Department of Energy, which were analysed using a thermal simulation model called SERI-RES
- simulated performance of a typical semi-detached house whose design parameters were systematically varied by the BRE and analysed using SERI-RES.
- monitoring studies of the performance and use of conventional and low energy designs, particularly
  - test cells
  - the Linford and Pennyland housing
  - an attached greenhouse at New Bradwell, Milton Keynes.

SECTION 1

Solar gain and energy efficient design



Why energy efficient design?

Energy is only one of a number of issues designers have to consider. Often it is by no means the most important. But in any design many decisions have to be taken about glazing. Although the reasons behind these decisions may have little or nothing to do with energy, there are important consequences for occupants' comfort and for energy consumption.

Increasingly, designers are being expected to be aware of energy issues. Both through the Building Regulations and accompanying British Standards, such as BS 8211,[1] they are being asked to design buildings that are energy efficient. However, while these documents set standards, they not provide detailed design guidance on, for example, how to design windows and conservatories that conserve energy. The handbook tries to fill this gap.

The design considerations described in this handbook are not new. As Barry Parker remarked around the turn of the century,

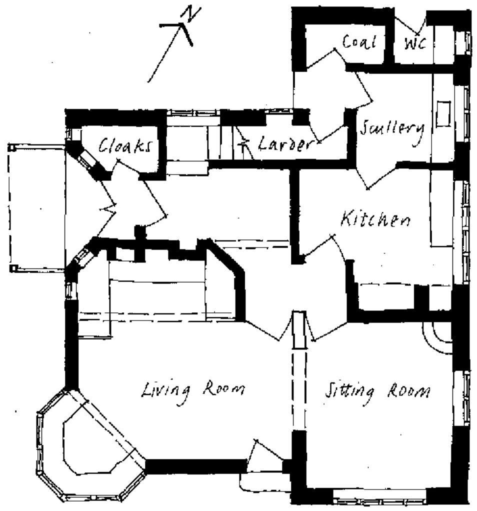
> *If we are to derived health and pleasure from the time we spend in our homes we can hardly attach too great an importance to the bringing of light and sunshine into the very hearts of them.*

And so in his influential designs, such as Figure 1,[2]

> *The sun, if it does shine, shines into the living room from morning to night.*

As long ago as the 1930s, the Royal Institute of British Architects felt obliged to offer guidelines[3] on the correct orientation of houses and avoidance of obstruction, see Figure 2, and observed,

> *Until the habit of thinking in terms of sunshine has been acquired, buildings will continue to deprive their occupants of values which might have been enjoyed without cost every day over the whole life of the building.*



Ground floor plan of the house at Briarside, Letchworth, by Barry Parker

Figure 1

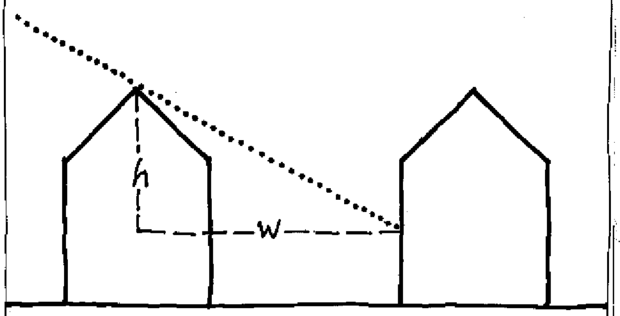


Illustration of overshading, taken from The Orientation of Buildings, RIBA, 1933.

Figure 2

---

[1] British Standards Institution, BS 8211, British standard code of practice for energy efficiency in housing, BSI, London.

[2] Hawkes, D, 1986, Modern country homes in England: the Arts and Craft architecture of Barry Parker, Cambridge University Press, Cambridge.

[3] Royal Institute of British Architects, 1933, The orientation of buildings, RIBA, London.

Recently, the importance of sunshine and orientation has been restated by the RIBA in its **Housing Design Brief**[1],

> *Living rooms and rear gardens should have a southerly aspect as far as possible and generally dwellings should be sited to maximise solar gain.*

What has changed over the past 50 years is both our understanding of the scientific principles involved and the glazing technology at our disposal. This makes exploiting sunshine to practical effect a more realistic objective for us than it was for our predecessors, however good their intentions.

---

[1] Institute of Housing & Royal Institute of British Architects, (undated), Housing design brief, RIBA Publications, London.

Twenty steps to energy efficiency in house design

The Building Regulations are concerned only with setting minimum standards below which designers may not fall. For those who decide to build to higher standards, there are many measures which may be taken to reduce the consumption of conventional fuels and to provide added comfort, amenity and enjoyment for occupants.

We list below the twenty most important measures which designers should consider to make their designs more energy efficient. These measures are listed in the order in which they need to be considered. Only those in bold type are covered in this handbook.

Site planning and house design

1. **Orientation**
   Lay site out to provide access for sunshine to as many houses as possible for as much of the year as possible
2. **Obstructions**
   Space houses to reduce overshading as far as possible
3. **Plan form**
   Use compact plan forms to minimise external surface areas
4. **Room arrangement**
   Place main living rooms on south facades with ancillary spaces and circulation areas on the north
5. **Buffer zones**
   Use conservatories and garages to create buffer zones protecting habitable rooms from cold external air

Building envelope

6. Draught lobbies
   Place draught lobbies on entrances whenever possible
7. Insulation
   Improve insulation values of the opaque elements of the external envelope - walls, floor and roof - wherever possible
   Take care to avoid cold bridges
8. **Windows**
   Specify high performance frames which achieve good weathertightness ratings and have thermal breaks if appropriate
   Specify double glazing or better, whenever possible, but especially on north, east and west-facing facades
   Reduce glazed areas on north-facing facades
   Locate windows to habitable rooms on south-facing facades
9. Ventilation control
   Improve air tightness and control of infiltration first by simple measures such as draughtstripping
   Follow up with more comprehensive measures, such as sealing around window frames
   Ensure adequate and controlled ventilation by specifying trickle ventilators
   Extract moisture from wet areas at source mechanically
10. **Shutters and blinds**
    Where appropriate, employ
    - **structural overhangs**
    - **external shutters**
      and
    - **internal blinds**

    to reduce unwanted summer heat gain and/or reduce night time heat loss

Building services

11. Heating system

Select an appropriate type

Central heating may not be necessary in a very well- insulated house. Individual room heaters may be more suitable

Match type of heating system - warm air or hot water - to thermal capacity of house - light or heavy-weight -to obtain proper response rate

12. Boiler type

Specify a high efficiency boiler if appropriate

Use a condensing boiler if occupancy pattern for house means that it is likely to be in condensing mode for high proportion of the time

13. Heating controls

Specify intelligent controls that can take account of

different temperature requirements in different zones

incidental and solar gains

and that can anticipate the effects on demand caused by changes in external temperatures

14. Heat emitters

Check where and whether radiators are required. Remember low energy designs need far less heat input.But the siting of emitters may be critical to feelings of comfort

15. Hot water cylinder

Specify a cylinder with thermostat and separate timer

Use highly insulated (preferably pre-insulated) cylinder

Appliances and components

16. Light fittings

Specify low energy high efficiency light fittings

17. Domestic appliances

Specify low energy domestic appliances, especially refrigerators and other electrical appliances

18. Mechanical ventilation

Consider using a mechanical ventilation system, especially if the building has been made airtight

If so, then employ roof space and/or conservatory for collecting pre-heated air

19. Heat recovery: space heating

Consider recovering heat from incidental and solar gains, employing mechanical ventilation and heat exchanger

20. Heat recovery: domestic hot water

Consider recovering heat from used hot water before discharge to drainage system

Why glazing?

The amount, type and position of glazed elements included in the external envelope of a house have a significant effect both on how comfortable it is to live in and on its space heating consumption.

Windows are a prime focus in energy efficient design. Traditionally they have been seen as the weak spot in the thermal envelope of a house, as the holes in its insulation. And it is true that there is hardly a quicker way to lose heat, and to reduce comfort conditions, than through a window composed of a single layer of glass. Glass conducts heat almost nine times faster than softwood and thirty-five times faster than expanded polystyrene of the same thickness.[1] Yet, despite repeated reductions to the rate at which external elements - walls and roofs - are allowed to lose heat under the Building Regulations, the only restriction on glazed elements is a limitation in their total area. Single glazing is still permitted as the minimum standard.

Windows do not have to be a weak spot in a house's thermal envelope. If they are orientated, sized and constructed correctly they can be thermally neutral, that is their heat losses may be balanced by their solar gains. Under some circumstances they may even become a net source of heat gain during part of the heating season.

The effect of windows on thermal performance becomes more important as insulation standards in houses are increased. In existing houses, up to 25% of heat escapes through windows.[2] In recent houses, constructed since the 1982 revisions to the insulation standards required under the Building Regulations, and with the maximum amount of single glazing permitted, 30- 35% of the heat can be lost this way. And another 15% will be lost through ventilation, mainly as heat flowing out through inadequately sealed cracks and gaps around window and door openings.

So, as the insulation values of other elements in the building envelope are improved, the importance of heat lost through windows and ventilation increases.

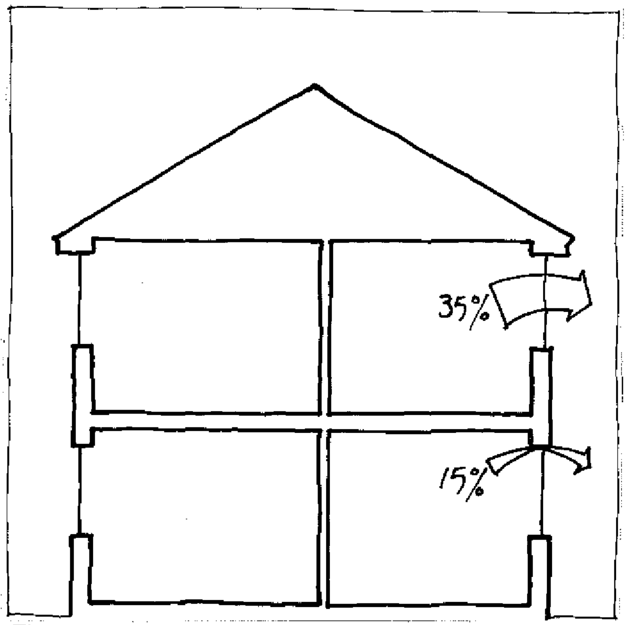


Figure 3

---

[1] Everett, A., 1978, Materials, Mitchell's Building Construction, Batsford, London.
[2] Energy Efficiency Office, 1986, Monergy News, Department of Energy, London.

This handbook describes how to improve the design of windows by focussing on the five energy-related functions they serve:

- collecting wanted solar gain during the heating season
- providing insulation and airtightness during the heating season
- offering natural ventilation, especially during temperate weather
- rejecting unwanted solar gain during the summer
- admitting daylight all the year round.

For the past century or more, windows have occupied a surprisingly stable proportion of exposed external wall area of British dwellings. As Figure 4 shows, this proportion has remained between 15% and 20% across housing types and over time.[3]

	%
Small narrow frontage terrace	14.5
Wider frontage terrace (no bay)	14.5
Wider frontage terrace with bay window	19.0
Private inter-war semi-detached	19.9
Large Victorian semi-detached	15.5
Modern detached	13.7

Percentage of external surface area (including roof) taken up by windows

Figure 4

Modern glazing technology now offers much more complex and sophisticated window systems than have previously been available. These hold out the promise, for example, of fully glazed south-facing facades that deliver a net energy gain all the year round.

Before they can decide whether to exploit this technology, either in the form of windows or conservatories, designers need to understand how glazing affects the performance of a house, in terms of both comfort and costs.

In this handbook, we try to help designers to respond positively to increasing pressures on them to provide glazed elements in housing that are attractive and serviceable without being an energy burden for occupants.

---

[3] Steadman, P. & Brown, F., 1987, Estimating the exposed surface area of the domestic stock, in Hawkes, D. et al, Energy and urban built form, Butterworths, London.

Why solar gain?

All houses have windows for daylight, ventilation and view. So all houses benefit to some extent from solar radiation. In energy efficient design, the aim is to maximise solar gain when it is wanted and to exclude it when it is not.

The potential of solar radiation.

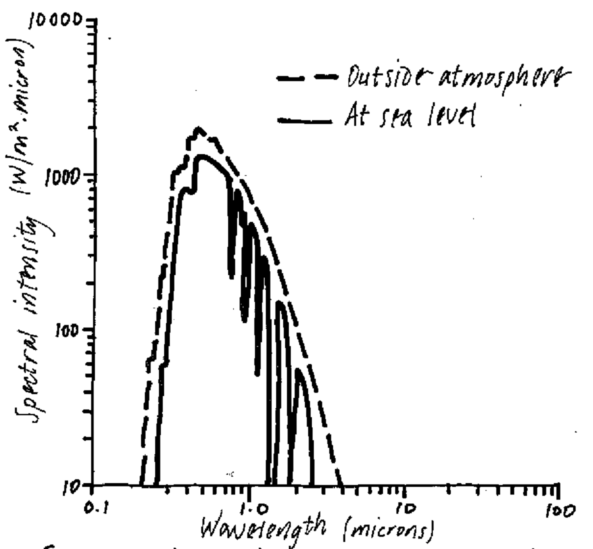
Solar energy is plentiful. 0.01% of the total amount which lands on the earth's surface would meet the world's present needs.[1] The solar energy falling on the UK in a year is 80 times our annual energy needs. And, in any year, a typical house in Britain receives more solar energy than the total energy consumption of its household.[2]

However, while solar energy is fairly predictable from year to year, it can vary considerably from day to day. It is also at its maximum during the summer, whereas demand for energy is greatest in the winter. Nevertheless, recent research and demonstration work undertaken for the Department of Energy suggests that, if careful considered and integrated into design, solar gains can, on average, contribute a third of total heating needs.[3] In small well-insulated houses, the potential for using solar energy is less because gains from occupancy can be enough to meet most of the heating requirement.

Factors affecting incident solar radiation

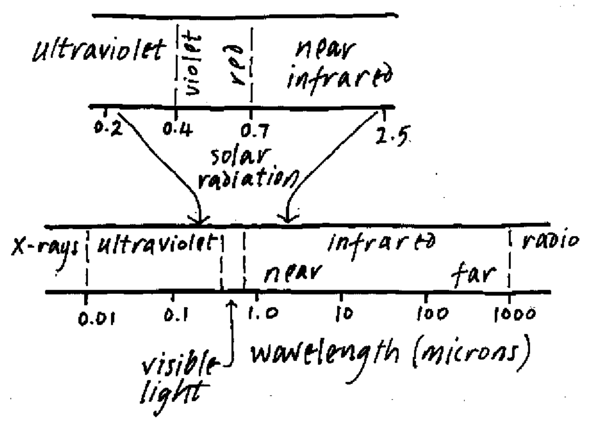
Solar radiation is the radiant energy emitted by the outer layer of the sun called the photosphere. The character of the radiation is determined largely by the temperature of the photosphere, about 5,500°C.

Solar radiation can be divided into three components on the basis of wavelength. The visible component spans a wavelength range from about 0.4 to 0.7 microns. (A micron is one millionth of a meter.) The wavelengths of visible light are distinguished by their colours from red at the longest wavelength (0.7 microns) to violet at the shortest (0.4 microns). Ultraviolet (beyond violet) is radiation of a wavelength that begins at violet and extends to shorter wavelengths, down to about 0.01 microns. Infrared (below red) is radiation with wavelengths longer than that of red. Solar radiation is often called short wavelength radiation to distinguish it from the radiation emitted from objects that are much cooler than the sun, which is referred to as long wavelength radiation.



Spectral intensity of solar radiation

Figure 5



The electromagnetic spectrum.
The upper diagram is an enlargement of the part that predominates in solar radiation.

Figure 6

---

[1] Department of Energy, 1975, Solar energy: its potential contribution within the United Kingdom, HMSO, London.
[2] Department of Energy & Central Office of Information, 1980, Energy - a key resource, Department of Energy, London.
[3] US & UK Departments of Energy, 1985, US/UK Energy R & D: Passive solar design.

Extraterrestrial radiation is the amount of solar energy that reaches the limit of the earth's atmosphere. measured perpendicular to the direction of the radiation. This is fairly constant, at about 1.4 kW/m^2, see Figure 7, varying only because of the elliptical orbit of the earth which results in the sun being closer to the earth in December and further away in June.

The 23° 27' tilt in the earth's axis, Figure 8, accounts for the change in radiation intensity, length of day and seasonal climate. If the axis were at right angles to the plane, there would be no seasonal changes in the weather.

Figure 9 shows the average daily solar radiation on a horizontal surface for various latitudes in the absence of atmosphere.

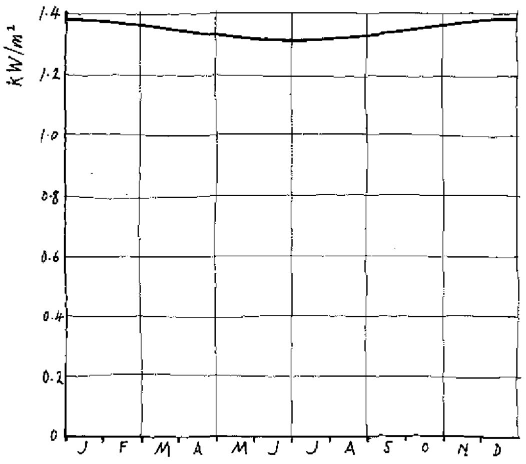
Once solar radiation reaches the earth's atmosphere it is

- partly absorbed (15%)
- partly reflected (6%)
- partly transmitted to the earth's surface (79%).

Some of the transmitted radiation is diffused by the particles of the atmosphere and reaches the ground as diffuse radiation, and some is transmitted direct. **Global radiation** is the sum of the direct and diffuse radiation reaching the ground, measured on a horizontal surface. The amount of global radiation received on the earth's surface is not constant but varies according to:

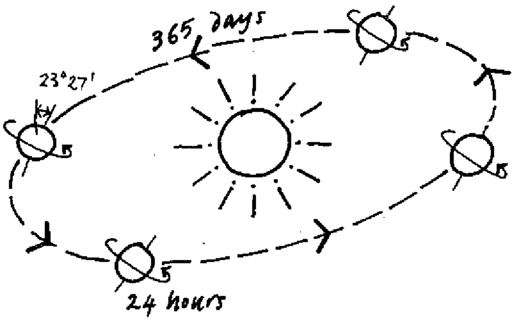
- the place,
- the season
- the time of day,
- meteorological conditions.

For any location, cloudless days provide the most solar radiation. But even totally cloudy days can provide useful radiation, up to about a third of that available on a cloudless day at the same time of year.



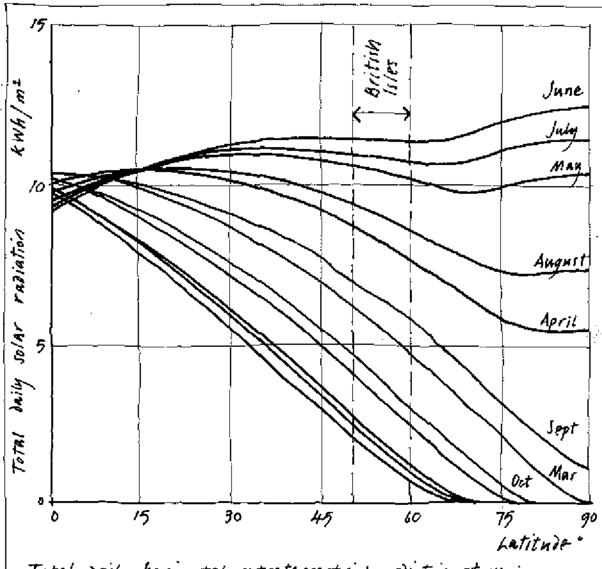
Variation of extraterrestrial radiation according to time of year

Figure 7



The axis of the earth's rotation is tilted at an angle of 23°27' to the plane of its orbit around the sun

Figure 8



Total daily horizontal extraterrestrial radiation at various latitudes, shown as monthly average

Figure 9

In addition to the direct and diffuse radiation, the vertical surfaces of buildings receive some reflected radiation, depending on the ground reflectance value, see Figure 10.

The apparent path of the sun

Seen from a position on the earth's surface the sun appears to travel in an arc across the sky. This apparent path determines:

- the hours of direct sunlight which a window or conservatory receives
- the angle of incidence of the sun's rays
- the overshading characteristics of a site and its surroundings.

The path of the sun varies with the seasons and with the latitude. At any given time the position of the sun may be defined by its angles of azimuth and altitude. The azimuth is the angle between true south and a point on the horizon directly below the sun; the altitude is the vertical angle between the horizon and the sun, as shown in Figure 11.

As the sun paths in Figure 12 show, in the summer the sun rises north of east and sets north of west. In the winter, it rises south of east later in the morning, travels in a lower arc, and sets south of west earlier in the evening.

The height of the sun at midday at the equinoxes (21 March and 23 September when the length of day and night are approximately equal) can be calculated by the formula:

$$h = 90^\circ - \phi$$

where ϕ is the latitude of the place. Thus for places with the latitude 51° North, the height of the sun at midday is 39°. At the summer solstice (22 June, the longest day) the height of the sun is given by the formula:

$$h = 90^\circ - \phi + 23^\circ 27'$$

At the winter solstice (21 December, the shortest day) the formula is:

$$h = 90^\circ - \phi - 23^\circ 27'$$

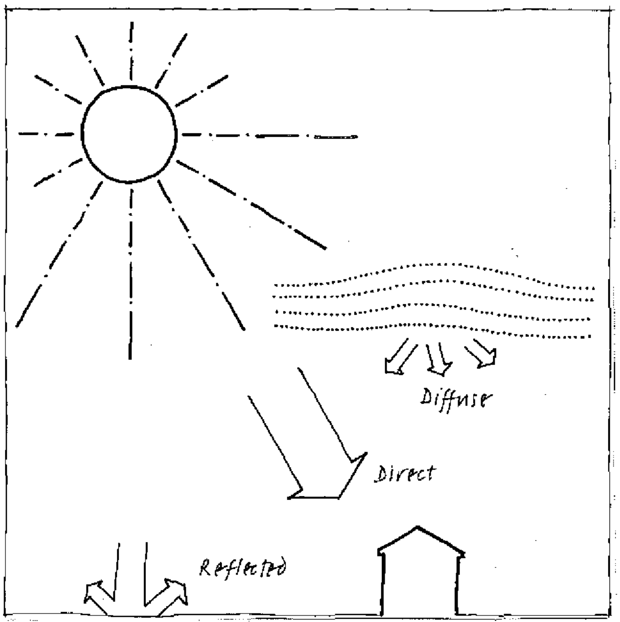
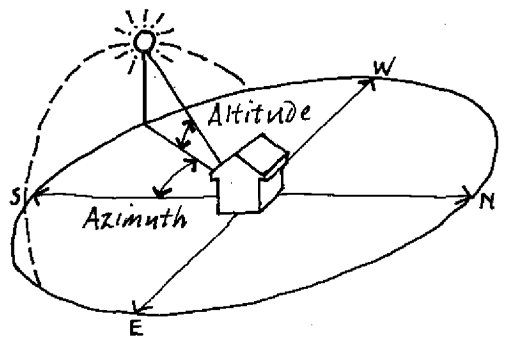
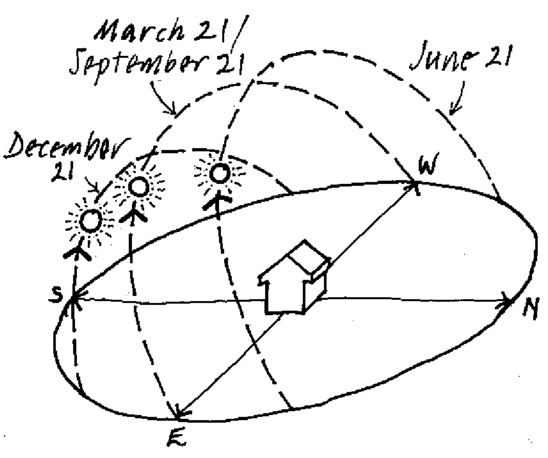


Figure 10



Altitude and azimuth angles

Figure 11



The apparent path of the sun at the equinoxes (March 21, September 21) and the solstices (June 21, December 21)

Figure 12

Figures 13 and 14 (overleaf) show examples of sun path diagrams in the form of stereographic projections for London and Glasgow. These are taken from **BSI DD67:1980 Basic data for the design of buildings - sunlight**. Such diagrams enable the sun's altitude and azimuth angles to be read off, for a given location, at any time of day and any time of year. The numbers around the outside edge show the azimuth angle relative to an observer facing north, and the concentric lines show the altitude.

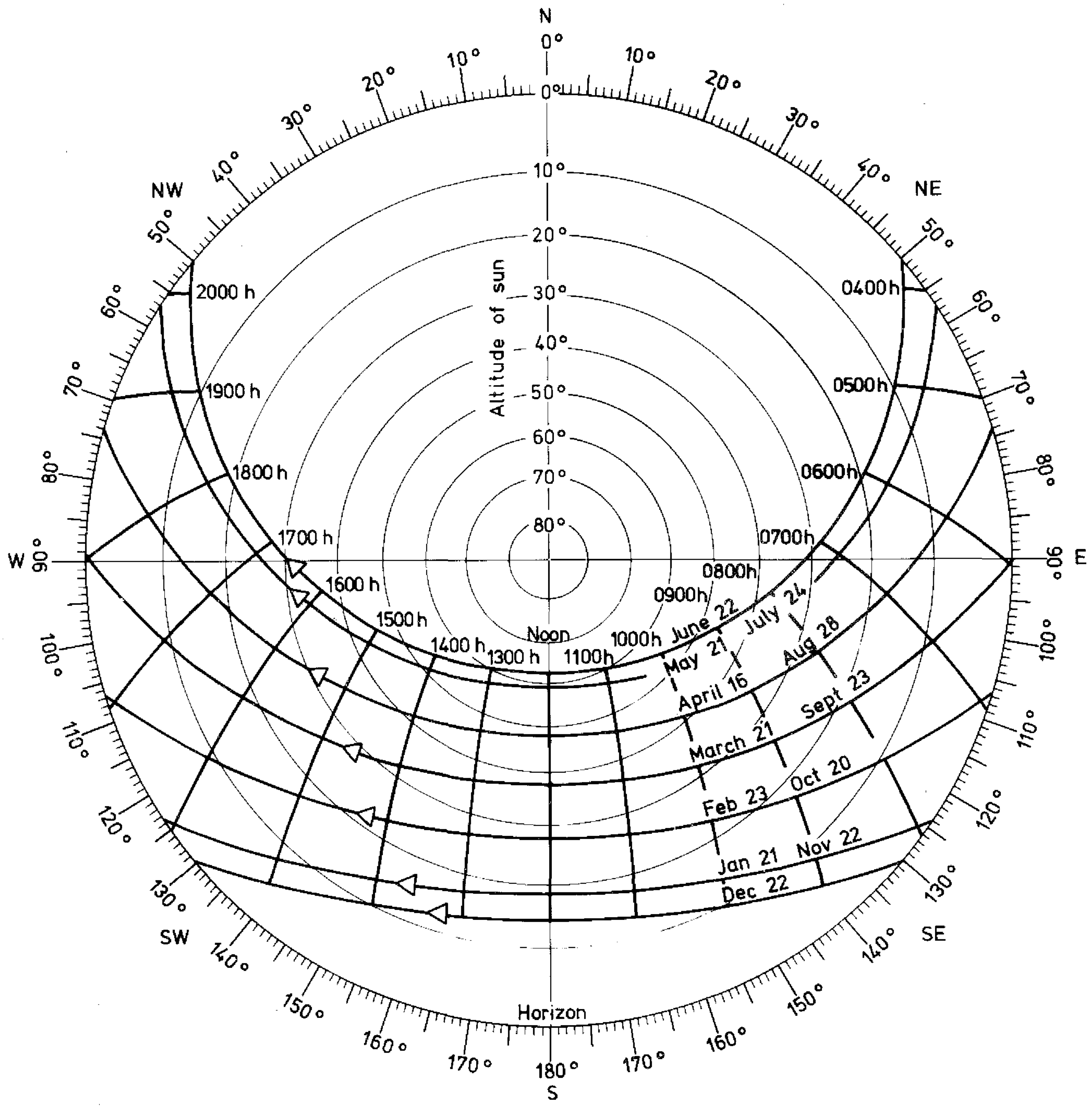
For example consider June 22. The sun rises before 4.00 am at 50° east of north, and by 5.00 am it is 10° above the horizon. It is 60° above the horizon between 11.00 and 1.00 pm. It sets after 8.00 pm.

It can be seen from the stereographic projection that the altitude of the sun does not change at a constant rate, but that the year is divided into four distinct periods:

- two, around the summer and winter solstices, where the maximum altitude of the sun changes only slowly from day to day
- two, around the spring and autumn equinoxes, where the maximum altitude of the sun changes rapidly from day to day.

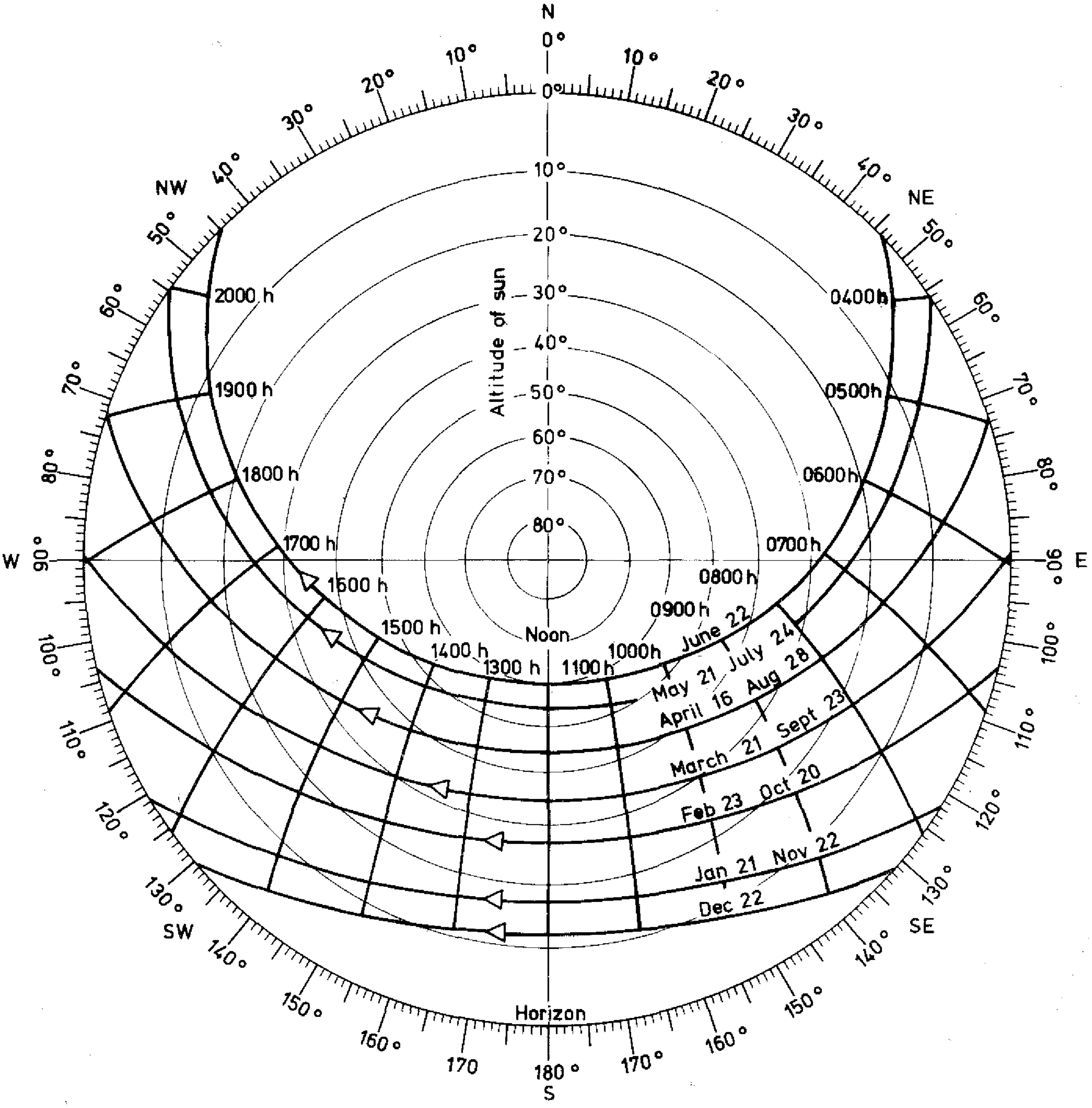
Sun path diagrams, such as the stereographic projection, may be used:

- to examine overshading in site layouts
- to check periods of direct sunlight for facades with particular orientations
- to investigate the effect of shading devices.



Stereographic sunpath for London (latitude 51 ° 30 'N)

Figure 13



Stereographic sunpath for Glasgow (latitude 55° 52'N)

Figure 14

Solar energy in the British Isles

The total amount of solar energy (diffuse, direct and reflected) and the **angle of incidence** (the angle between the direction of the sun's radiation and a line perpendicular to the surface of the building) of the direct radiation that reaches a building are determined by:

- its latitude
- the season
- meteorological conditions.

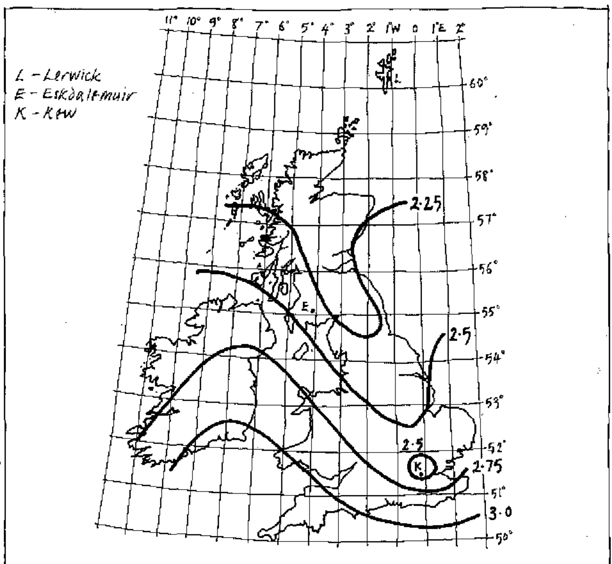
Figure 15 shows that the south of Britain receives about one and a half times as much solar radiation on a horizontal surface as the north.

For any given facade of a building, the total radiation will depend on the facade's orientation and the degree to which the radiation is obstructed by surrounding topography, buildings or plants.

Where solar radiation penetrates via windows to heat a space directly, insolation on vertical surfaces is the important consideration. Figure 16 shows the total solar radiation in kWh/m^2 for Kew on vertical surfaces with different orientations on a clear day.

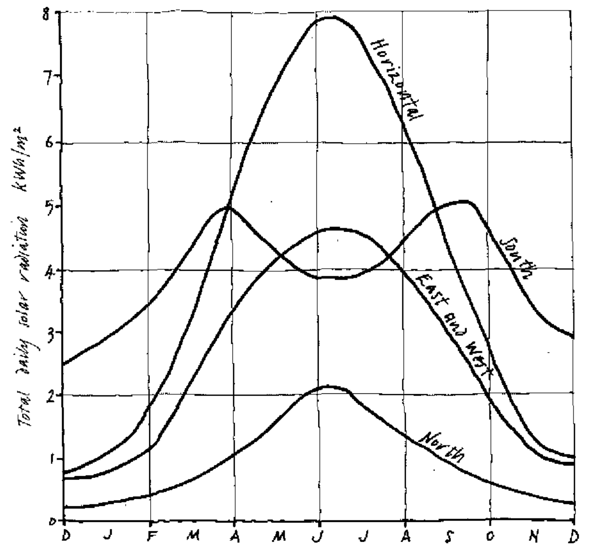
There are three main conclusions to be drawn from this graph:

- the high altitude of the sun in summer results in a large angle of incidence of the direct radiation, and this in turn prevents a peak in incident solar energy on south facing facades from occurring between May and August. This helps to reduce the risk of summer overheating in houses with large south facing windows
- on clear days in the heating season a horizontal surface receives less solar radiation than a south facing vertical one
- the summer peak in solar radiation on a horizontal surface helps to explain gross summer overheating in south facing conservatories with unshaded sloping glazed roofs.



Global solar radiation: annual mean of daily amount (kWh/m²)

Figure 15



Total daily solar radiation incident on various surface orientations for a clear day in Kew, ground reflection included.

Figure 16

In contrast with Figure 16 which assumes clear skies, Figure 17 shows the total radiation on vertical surfaces at each of the four cardinal orientations for all months of the year except June, July and August, for three locations in the British Isles. These amounts have been calculated from measurements of solar radiation on horizontal surfaces made during the period 1966-1975.

Another way of gaining a broad understanding of the potential contribution which solar radiation can make to reducing fuel consumption in a particular locality is to compare solar radiation on a horizontal surface with the number of **degree days**. Degree days record the daily difference between a base temperature, often taken as 15.5°C in the UK, and the 24 hour mean ambient temperature when it falls below the base temperature. Daily totals may be added to give the monthly total, and monthly totals added to give the annual total.

Figure 18 shows the "crude solar viability" indices calculated by Oppenheim[1]. These appear to be based on the following calculation:

1 For each month calculate

$$\frac{\text{(daily solar radiation on a horizontal surface x number of days)}}{\text{(number of degree days divided by 30)}}$$

2 Add the monthly totals for the year excluding June, July and August to find the crude solar viability indices for each location.

It is disputable just what these indices show. This is because the index becomes meaningless when extreme conditions are used. For example, if the number of degree days were to approach zero, the solar viability index would get very large. Yet in a location with zero degree days there would be no potential at all for solar gains since there would be no heating requirement. Conversely, if the number of degree days were to approach a very large number, implying a long cold winter, then solar gains would be increasingly viable and the index should enlarge to show this trend, yet in fact it decreases.

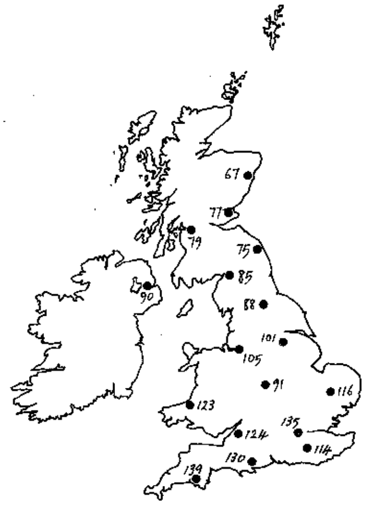
This index represents the British climate as:

- becoming more severe from west to east
- becoming sunnier from north to south.

Location	Orientation			
	N	S	E	W
Kew	194	504	338	338
Eskdalemuir	176	451	304	304
Lerwick	160	407	279	279

Total solar radiation on vertical surfaces at cardinal orientations for the period September to May, based on 1966-1975 data, kWh/m²

Figure 17



Crude solar viability indices for various locations

Figure 18

---

[1] Oppenheim, D., 1981, Small solar buildings in cool northern climates, Architectural Press, London.

As latitude increases the length of the days is longer during the winter (giving rise to the midnight sun at very high latitudes) so that solar radiation occurs for longer periods. However ambient temperatures are lower in the north, and although the heating season therefore extends into the sunnier spring and autumn weather, the amount of heat lost through windows is increased. Thus the energy balance between heat losses and solar gains is poorer in the north than the south, see Figure 19.[1]

Another factor which may militate against the use of solar radiation in the north is that the effect of obstructions is greater there because the sun is at a lower altitude during the heating season than in the south.

On the basis of computer simulations, it has been suggested[2], [3] that in Scotland glazing areas may need to be smaller than in the south of England. So, for example, it has been proposed that in the Shetland Isles the area of south-facing glazing should be 20% smaller than for a comparable house at Kew.

At present, it is probably safest to conclude that it is too early to judge precisely how design recommendations for direct solar gains should be varied to exploit solar radiation in different locations within the British Isles.

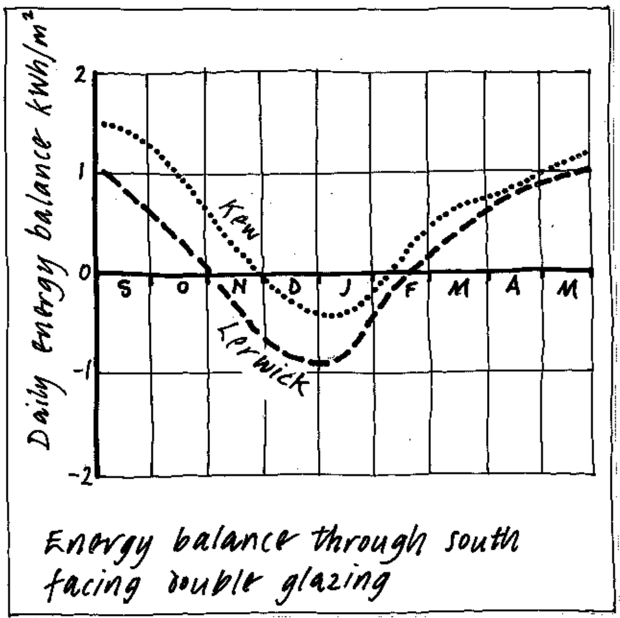


Figure 19

---

[1] Bartholomew, D., 1984, Possibilities for passive solar designs in Scotland, Occasional Paper ETSU L14, Energy Technology Support Unit, Harwell.

[2] Porteous, C., 1985, Partial solar heating for Hebridean housing using sunspaces and air collectors, The sun at work in Britain, No. 20, UK-ISES, London.

[3] Millbank, N., 1986, The potential for passive solar energy in UK housing, PD 102/86, Building Research Establishment, Garston, Watford.

Solar gain and glazing

If the sun's energy is to be used for heating, a building has to have a means of collecting it. Glass has particular properties which allow it to do this - by trapping heat from the sun.

Solar transmission through glass

When solar radiation meets a transparent element such as glass, it is

- partly reflected
- partly absorbed
- partly transmitted.

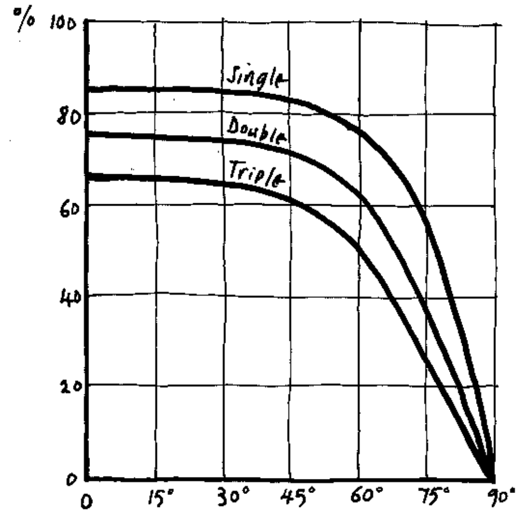
The fraction absorbed is re-emitted as longwave radiation from each side of the glass. The sum of the fractions directly transmitted and of those re-emitted inward constitutes the total transmission through the glass.

The proportion of solar radiation falling on a glass surface which is transmitted is dependent on two factors:

- the altitude of the sun and the orientation and inclination of the surface; these three result in the angle of incidence of the direct solar radiation falling on the glass
- the physical properties of the transparent material.

Figure 20 shows that the proportion of energy transmitted changes little within angles of incidence from zero to 45°, and then begins to decrease rapidly as the angle of incidence increases towards 90°.

Figures 21 to 24 illustrate the relative proportions of reflected, absorbed and transmitted radiation for various glazing arrangements. Body tinting and/or coatings applied to the glass modify the transmission properties.



Percentage of solar radiant heat transmitted at various angles of incidence

Figure 20

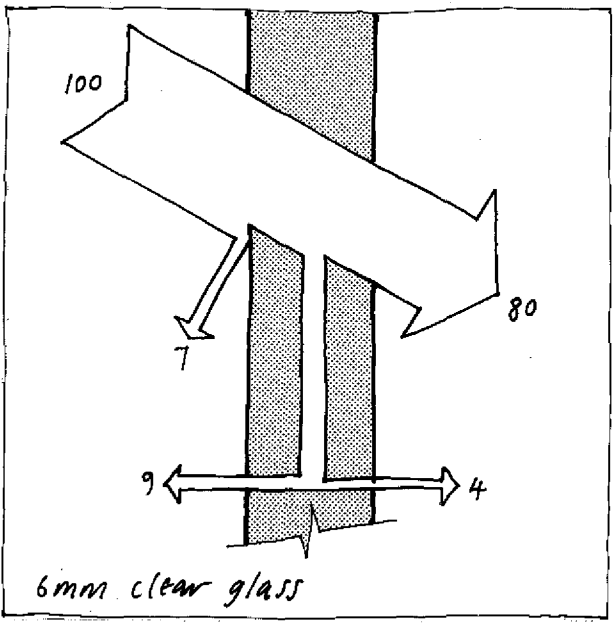


Figure 21

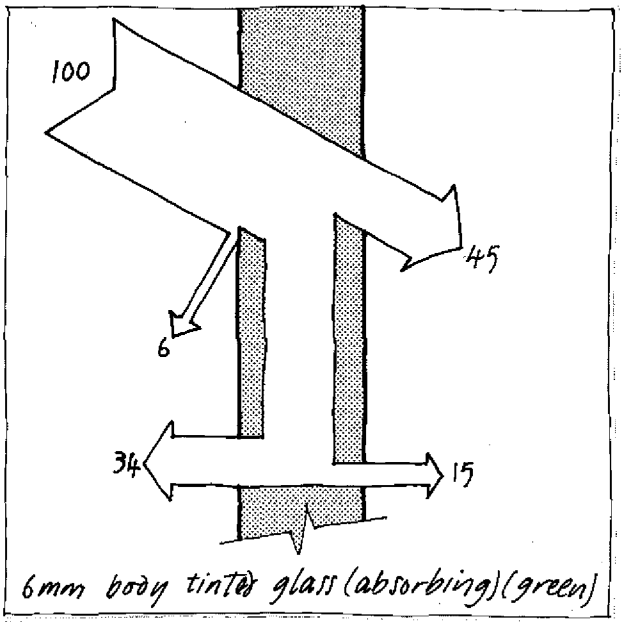


Figure 22

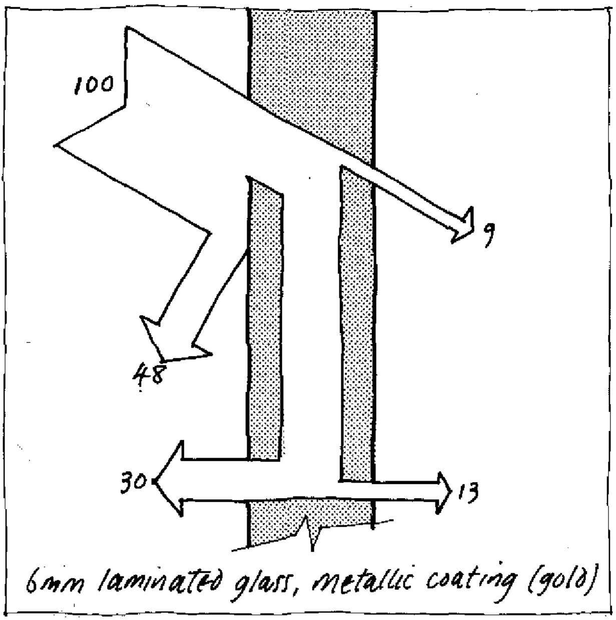


Figure 23

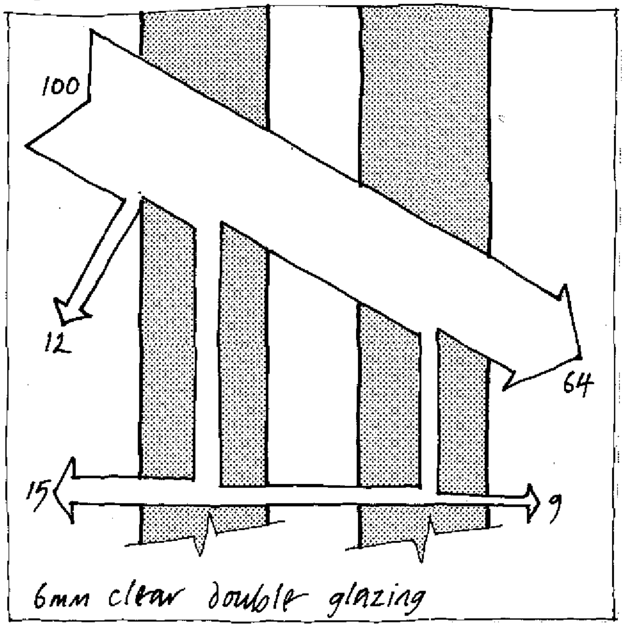


Figure 24

The angle at which sunlight intercepts a window also determines the solar aperture or projected area of the window. This is the area of a window projected onto a plane perpendicular to the sun's rays. The projected area becomes smaller as the angle of incidence increases. The amount of energy transmitted is therefore reduced owing to the decreased area exposed, as shown in Figures 25 and 26. The projected area is also affected by the position of the glass in relation to the face of the external wall, i.e. by the depth of reveal and frame thickness.

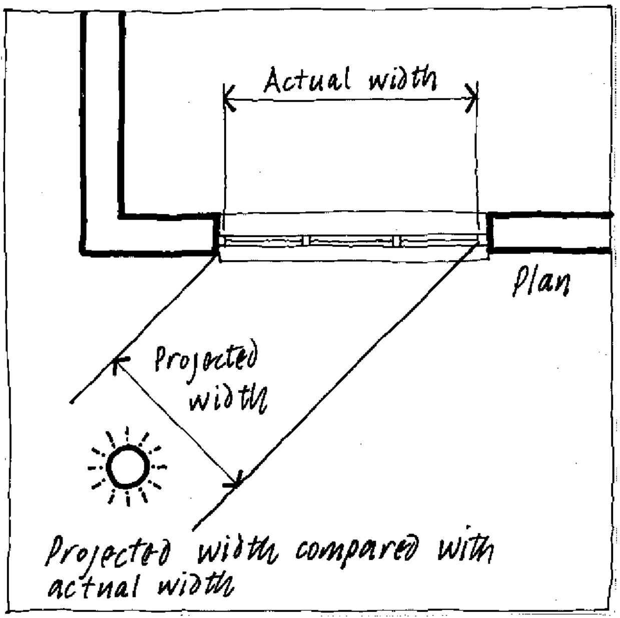


Figure 25

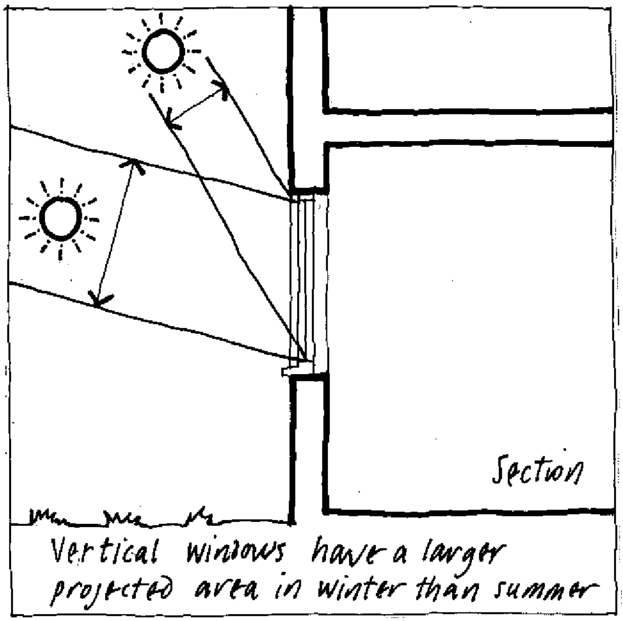


Figure 26

Capturing solar radiation: the greenhouse effect in buildings

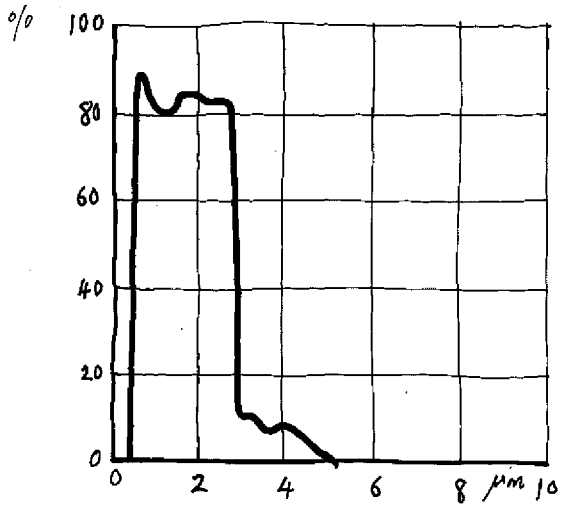
The process by which solar energy appears as useful heat in a house is a complex one. When the suns rays strike a window, part of the visible radiation and infrared is transmitted through the glass. This is then absorbed by the opaque surfaces within the room, such as the furniture, walls and floor, depending on their absorption characteristics. These become warm, and in turn emit infrared radiation at long wavelengths in all directions.

When the long wavelength radiation strikes a window from the inside, it is partially reflected and partially absorbed, because glass is almost opaque to radiation at wavelengths longer than about 2.5 microns. The absorbed fraction is re- emitted on either side of the glass. Some radiation is therefore trapped inside, resulting in an increase in the internal temperature. This phenomenon is known as the greenhouse effect.

Figure 27 shows the spectral curve of the energy transmission of 6mm glass, Figure 28 shows the spectral curve of the energy emission of plaster, and Figure 29 shows the superimposition of these two curves, illustrating the greenhouse effect, with the hatched part representing the trapped solar energy.

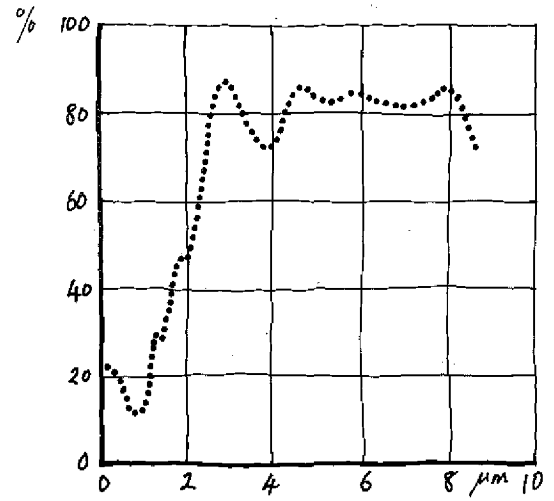
Solar gain as useful heat

During the heating season the greenhouse effect offers the possibility of reducing the amount of heat required from the house heating system. It has been calculated that, on average, about 16% of the energy requirements in existing houses are met directly by the sun, see Figure 30.[1] But this proportion can vary greatly, depending on orientation, insulation levels, and infiltration rates.



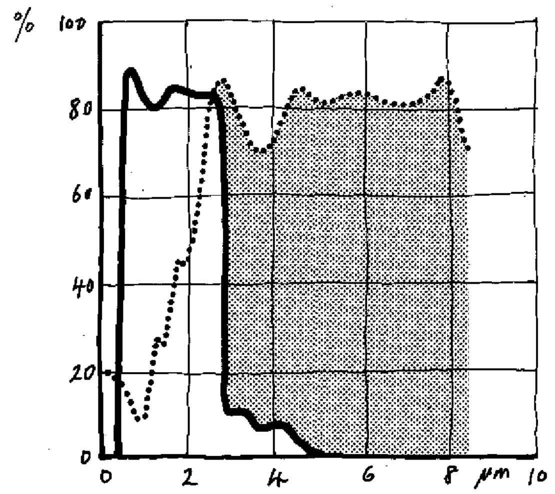
Percentage of solar energy transmitted through 6mm glass at various wavelengths

Figure 27



Energy emitted by plaster at various wavelengths

Figure 28



Superimposition of two graphs above illustrates the trapped energy

Figure 29

---

[1] Milbank, N., 1986, The potential for passive solar energy in UK housing, PD102/86, Building Research Establishment, Garston, Watford.

Simple and complex passive solar designs

A great deal has been researched and written about the potential for raising the proportion of space heating provided by solar energy above the levels usual in conventional housing, and many different types of system have been invented to exploit solar energy, see Figure 31.

In the UK climate, the potential for many of these systems is limited by the need for sophisticated control devices such as insulating shutters to reduce heat loss at times of low or zero solar gains (for example at night) and/or shading devices or blinds to prevent glare and overheating in summer. In advanced passive solar designs such devices and their means of operation are an integral part of exploiting solar energy because they allow window sizes to be increased to benefit from solar gains without incurring negative side effects.

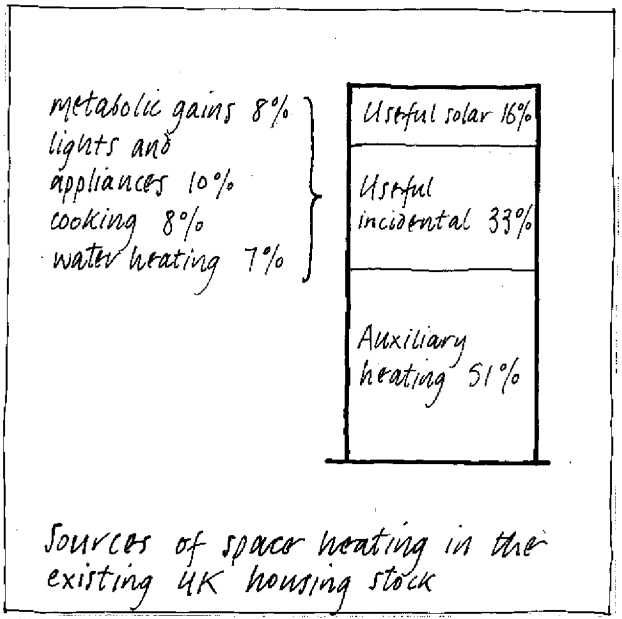
Although advice is offered in this handbook on the design of such devices (because some designers will want to employ them in their schemes), it is not necessary to adopt complex solutions to design a house that benefits from solar gains. Simple options are available. These are, in passive solar terms:

- **direct gain** where solar radiation penetrates through windows to heat the house directly
- **isolated gain** where solar radiation is collected outside a room space, for example in a conservatory, and transferred as required.

All houses can maximise the benefit from passive solar heating by careful attention to certain design parameters:

- site layout to minimise overshading
- orientation to maximise the potential for solar gains
- room layout with main habitable rooms on the south
- window location, area, and glazing type
- heating system controls which react quickly to solar and other incidental gains.

These are the main topics covered in the rest of the handbook.



Sources of space heating in the existing UK housing stock

Figure 30

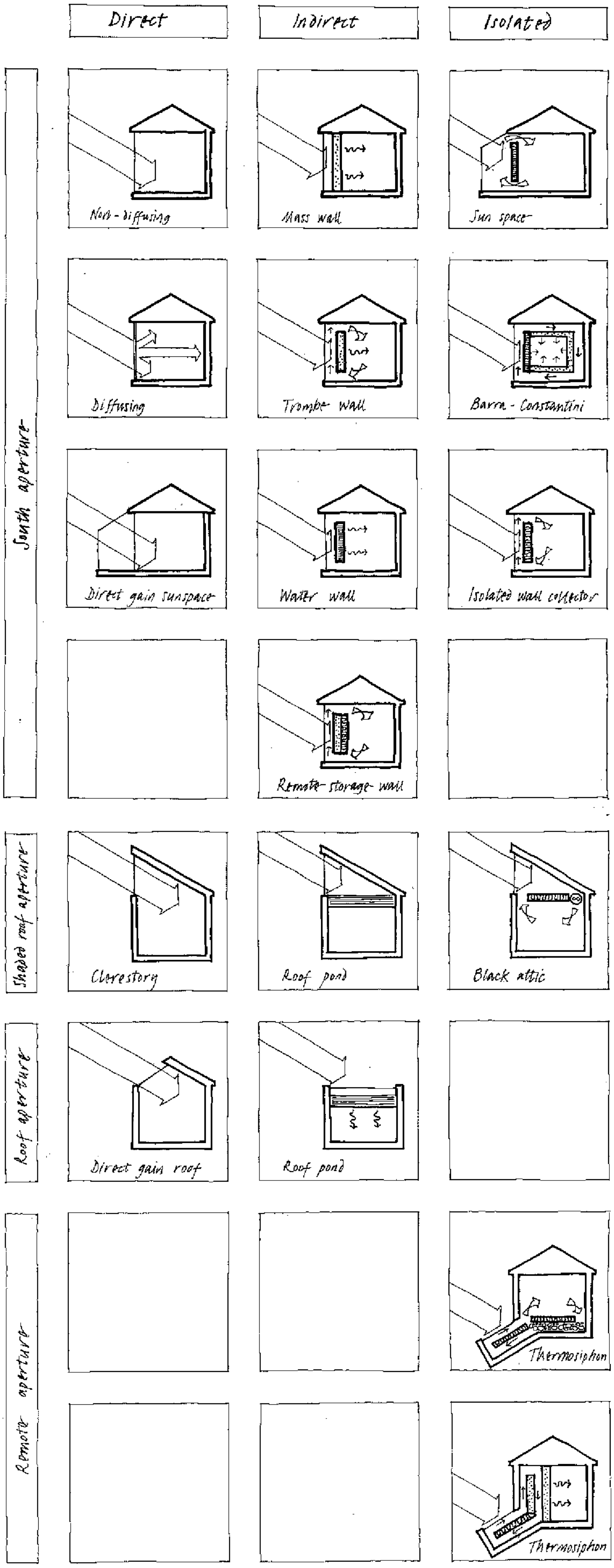
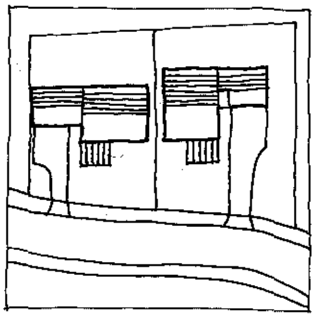

Direct
Indirect
Isolated
South aperture
Non-diffusing
Mass wall
Sun space
Diffusing
Trombe wall
Barra - Constantini
Direct gain sunspace
Water wall
Isolated wall collector
Remote storage wall
Shaded roof aperture
Clerestory
Roof pond
Black attic
Roof aperture
Direct gain roof
Roof pond
Remote aperture
Thermosiphon
Thermosiphon

Figure 31

SECTION 2

Site layout and house planning



Site planning and solar radiation

The layout of buildings on a site, their relations to each other and to other features of their natural and built surroundings can all affect the extent to which solar radiation can be exploited.

General requirements

Planning the layout of houses on a site is influenced by a wide range of constraints, most of which lie outside designers' control, such as:

- the shape, topography and existing landscape of the site
- the position and type of the surroundings including adjoining buildings
- the location of the site access.

Within these constraints, the layout must be planned to satisfy a wide range of requirements, that include:

- the density of the development
- the mix of house types
- vehicular circulation
- parking provision
- height restrictions
- building lines
- privacy distances
- tree preservation.

By their handling of these, designers can safeguard or prejudice the extent to which sunlight can be exploited on a site.

Sunlight

BSI's **Draft for Development DD67: 1980 Basic data for the design of buildings - sunlight** recommends that main living rooms receive sunlight for at least part of the day, see page 41. To meet this recommendation, let alone make use of direct solar radiation for heating, consideration must be given in the design of site layouts to:

- the orientation of houses to benefit from solar gain,
- the avoidance of overshading from, for example, other buildings and trees.

Orientation

The effect of orientation on the auxiliary heating demands of a conventional house and a solar house, as predicted by the computer simulation program SERI-RES, are shown in Figure 37.[1] These simulations are based on houses built at Linford, Milton Keynes. The solar house represents the houses as they were designed with large south-facing windows and small north facing ones. The conventional house is the same but with the glazing equally distributed on the north and south facades. Both houses are on unobstructed sites.

The results of the simulations show that:

- orientation has a large effect on the performance of a house which relies on southerly-facing glazing to exploit solar gain. Changing the orientation of the solar house from due south to due west increases its annual auxiliary space heating load by 17%
- the conventional house is relatively insensitive to orientation. Changing the orientation of the conventional house from due south to due west increases the space heating load by only 3%.

One of the main conclusions that can be drawn from these findings is that houses with large southerly-facing windows are more sensitive to changes in orientation than conventional ones.

Orientation, as it relates specifically to window location, is discussed in more detail on page 44.

---

[1] NBA Tectonics, 1986, A study of passive solar estate layout, Report to the Energy Technology Support Unit, Report no. ETSU-S-1126, 1986.

Overshading, house spacing and privacy distances

Apart from existing features of the natural and built surroundings, the other factors which can contribute to overshading are:

- house spacing
- site slope
- roof shape.

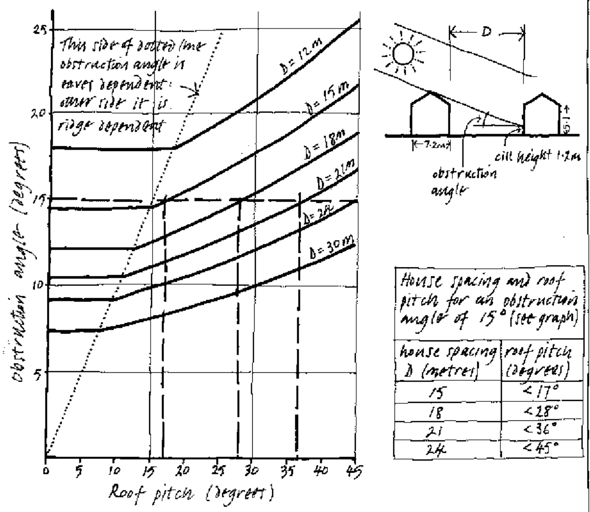
House spacing is likely to be determined by the distances needed to maintain privacy between opposing house facades containing the main habitable rooms. There are no national standards for privacy distances, and advice should be obtained from the local planning authority. Acceptable privacy distances are likely to fall within the range 18m to 27m.

In order to minimise overshading of south-facing elevations, houses need to be set out so that they do not cast excessive shadows over one another. In the NBA Tectonics study mentioned above, calculations were made to explore the relationship between privacy distances, roof angles and resulting obstruction angles. Figure 32 shows the results of overshading calculations in the case of two parallel rows of two-storey terrace houses of medium depth (7.2m) on a flat site. It gives, for various privacy distances (D) and various roof pitches, the resulting angle of obstruction.

The effect of overshading by detached houses was also studied by NBA Tectonics. They used the simulation model SERI-RES to look at the effect on auxiliary space heating load of overshading a south-facing house by a row of detached houses to the south of it. The results showed that for houses of a given plan area (104m^2), roof pitch (30°), and privacy distance (21m), set out 7.2m apart, no difference could be discerned between two layouts:

- one with the houses directly opposite each other
- one with them offset.

For a given roof pitch, narrow frontage houses block less solar radiation than wide frontage ones. And, for a square plan, a pyramid roof blocks less radiation than dual pitch. The direction of a dual pitch roof was found to make little difference. In all these comparisons, unless the houses being shaded rely heavily upon the contribution of solar radiation for their heating, the differences found are insignificant. Even for the Linford passive solar houses, the effect of overshading on increased space heating load was less than 0.5% for any of the cases described.



House spacing and roof pitch for an obstruction angle of 15° (see graph)

house spacing D (metres)	roof pitch (degrees)
15	< 17°
18	< 28°
21	< 36°
24	< 45°

Overshading: the relation between privacy distances, house spacing and obstruction angles

Figure 32

Techniques for assessing overshading

A graphical method using **shadow prints**, Figures 33 and 34, was developed and applied in the layout of the Pennyland low energy houses in Milton Keynes, to help avoid overshading.[1] Its aim was to ensure that of the total incident solar radiation falling on the south facing windows there was no more than a 10% reduction caused by overshading from the other houses between November and March.

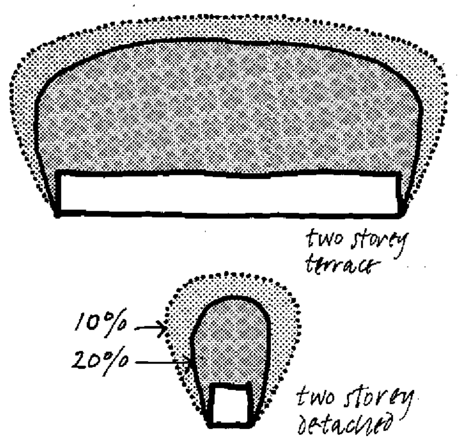
There is also a rule of thumb which can be used for this purpose. This is considered to be equivalent to the 10% shadow print, and is based on a geometrical method. The rule is that the midwinter sun should just graze the roofline of one row of houses in order to penetrate the ground floor windows of the next row.

The formula given on page 12 shows that the midwinter sun is at an angle of $90° - 23°27' - \phi$ where ϕ is the latitude. For Kew at a latitude of 51°29' the maximum midwinter altitude of the sun is 15°04'.

If appropriate, Figure 32 may now be used. The box within the figure shows the relationship between privacy distance and roof pitch for an angle of obstruction of 15°. In particular it illustrates that decisions about roof pitch influence overshading, particularly at close spacing.

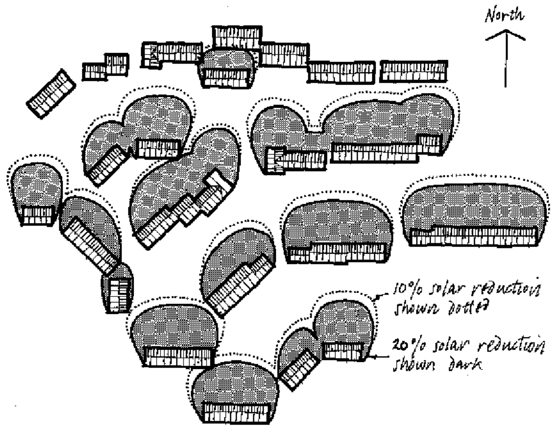
In the case of dwellings which do not fit the dimensions in Figure 32 (for example bungalows, three storey houses, shallow depth houses) or which are on sloping sites, a simple sectional drawing may be prepared using the appropriate sun angle projected from the sill of the shaded house.

In the North of Britain where the maximum midwinter altitude of the sun will be lower (1° lower than at Kew for each degree of latitude north of Kew) even greater attention will have to be paid to avoiding overshading.



Shadow prints for 10% and 20% reduction in incident solar radiation

Figure 33



Pennyland Estate, Milton Keynes: site layout plan showing use of shadow prints

Figure 34

---

[1] Lowe, R., Chapman, J. and Everett, R., 1985, The Pennyland project, Report by the Open University Research Group to the Energy Technology Support Unit, reference ETSU-S-1046, Harwell.

Other techniques for assessing overshading include

- **shadow masks** with a stereographic sun path diagram to plot obstructions (Figures 35 and 36)
- a **solar envelope** used to define a volume that can be occupied without causing overshading
- photographic methods
- a heliodon used with a physical block model to cast shadows and allow rapid exploration of alternative arrangements
- computer-based graphical methods offering the same facilities as the heliodon.

The interaction of orientation and overshading

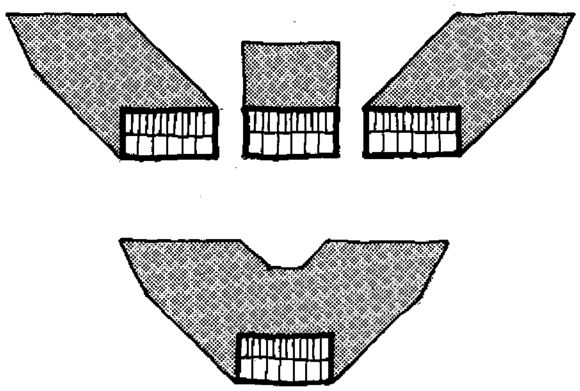
It has already been shown above that houses which rely on solar gains are more affected by changes in orientation than conventional houses. Similarly they are more likely to be affected by overshading. And overshading and orientation can interact in their effects on solar gains.

The interaction between orientation and overshading was explored in the NBA Tectonics study by simulating the case where a conventional house and a solar house are shaded by a continuous terrace at specific angles of obstruction, across a range of orientations from due west to due east. Figure 37, compiled from the study, shows some of the results, from which the following conclusions may be drawn:

- for both the conventional and the passive solar house the effect of obstructions is greatest when the houses are orientated due south
- the effect of overshading is greater for the solar house than for the conventional house for all orientations.

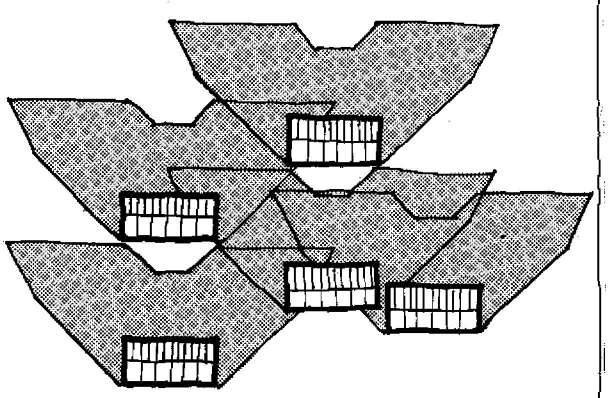
Other conclusions drawn from the study were:

- for the conventional house once an obstruction angle of 20° is reached it ceases to be beneficial to orientate it towards south
- for the passive solar house it continues to be beneficial to orientate it towards south up to and including an angle of obstruction of 50°.



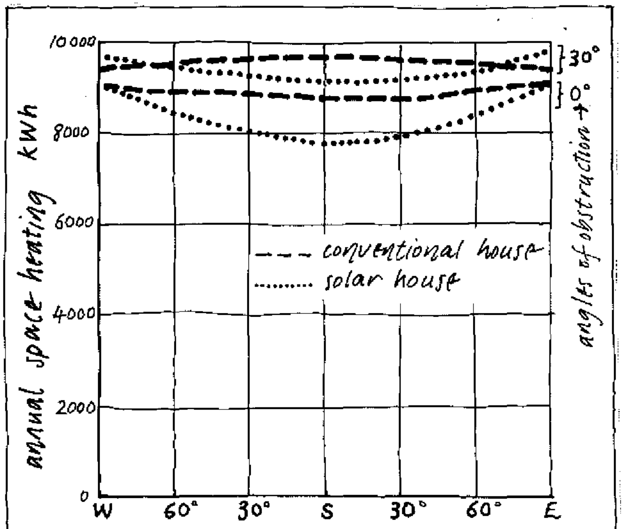
Shadow mask: shadows are plotted at, for example 0900, 1200 and 1500 on 21 Dec. then combined to form a shadow mask

Figure 35



Shadow masks used to set out a site layout to avoid overshading

Figure 36



The effect of orientation and overshading on auxiliary space heating consumption

Figure 37

Microclimatic planning and solar access

The microclimate of a site can be assessed, and this is usually done with a view to planning the layout to create a sheltered environment, particularly in terms of wind protection. If wind speeds around buildings are decreased then:

- infiltration into and heat loss from a building can be reduced
- the external ambient temperature can be raised

The relationship between the benefits of designing for solar access and those of designing to enhance the microclimate remains unquantified. It is possible that there may be conflict between some solar recommendations and some microclimatic ones. For example, the spacing requirements for solar access may conflict with the microclimatic requirements for wind protection. In such cases a trade-off will have to be made between the conflicting recommendations.

Points to remember

- **sites should be assessed for their potential to provide layouts with good solar access**
- **sites should be planned to enhance the access of sunlight to habitable rooms**
- **as many houses as possible should be of a southerly orientation**
- **as many houses as possible should be placed to avoid causing overshading and being overshaded**
- **bungalows and low density housing at the south of developments will allow solar access to the houses at the north**
- **tall buildings should be positioned where they will cause least overshading, by being to the north, at corners of developments and at road intersections**
- **terraces, which are the least flexible house form, should be positioned first and given the most favourable orientations; semi-detached or detached houses are more flexible and may be placed on roads with less favourable orientations.**
- **avoid locating terraces to have gardens which are north- facing and in permanent shade**
- **some occupants may prefer a sunny outlook to a sunny interior**
- **any new trees should be carefully selected and positioned to prevent overshading.**

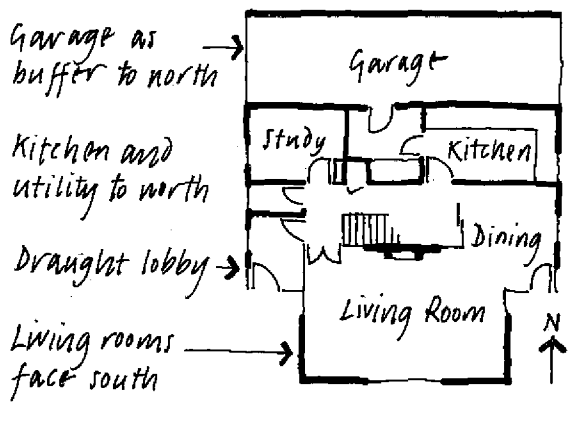
Room arrangement

The orientations given to rooms within a house will affect both how comfortable and pleasant they are to live in and the energy consumption of the house.

There is no one set arrangement of rooms in a house that will best exploit solar energy. In each case, their arrangement will be influenced by a host of factors beyond those concerned just with comfort and energy efficiency, such as:

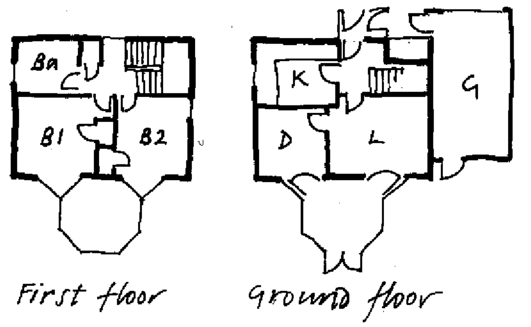
- house type - detached, semi-detached, terraced, bungalow, etc
- floor area, especially as this relates to frontage and depth of plan
- specific siting and planning considerations, particularly:
  - density of development
  - access
  - view
  - privacy
  - external noise sources.

Designers' handling of these other factors will affect the extent to which they can take advantage of the solar energy available. The general rule to follow is - arrange rooms to exploit the position of the sun as it changes throughout the day.



A ground floor planned to conserve energy and benefit from sunshine

Figure 38



A house planned with:

- main living rooms face south
- kitchen, bathroom, stairs to north
- draught lobby
- garage as buffer
- conservatory

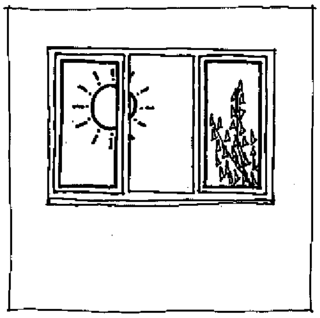
Figure 39

Points to remember

- place habitable rooms on southerly-facing elevations whenever possible
- place ancillary and circulation spaces on northerly-facing elevations
- locate principal bedroom(s) to catch early morning sun
- locate principal living room(s) to catch late afternoon/early evening sun
- if necessary, link the living room with dining room rather than the dining room with the kitchen, in order to promote useful transfer of solar energy within habitable spaces
- locate the kitchen (or kitchen/dining room) to prevent prolonged exposure to direct sunshine and so avoid overheating caused by solar energy *plus* high internal heat gains
- use buffer spaces and lobbies, perhaps in the form of conservatories, to protect entrances wherever possible
- use external accommodation, such as garages, to act as buffer zones on northerly-facing facades.

SECTION 3

Windows



Window systems

The specification of a window system - its type of frame and type of glass - affects its performance and influences both comfort and energy consumption in the house.

General requirements

The specification of a window system affects how well it performs in providing:

- sunlight
- daylight
- sound insulation
- thermal insulation
- ventilation
- weathertightness.

Of these requirements, for a given window size,

- sunlight, daylight and sound insulation are influenced mostly by the choice of glazing
- ventilation and weathertightness are influenced by the choice of frame and
- thermal insulation is influenced by both glazing and frame specifications.

Sound insulation

Requirements for sound insulation

- between dwellings
- between a dwelling and an external source

may affect your choice of window construction. Advice on **Keeping noise out of your house** is available in the Glazing Manual[1] and in BS Code of Practice 153 Part 3: 1972 Windows and rooflights - sound insulation.

The Building Regulations

Part L of the Building Regulations, which deals with the conservation of heat and power, makes no direct stipulation about window construction. Instead there are restrictions on the total area of window allowed, depending on the specification of the glazing type, see page 50.

---

[1] The Glass and Glazing Federation, 1988, The Glazing Manual, G&GF, London.

Thermal performance of windows

Conventionally windows are regarded as weak links in the thermal integrity of the external envelope of houses because they lose more heat than the walls:

- by conduction through the frames
- by conduction and radiation through the glazing
- by unwanted infiltration losses due to gaps around opening lights and cracks between the frame and wall through cold bridging across the structural opening.

The level of heat losses through a window depends on its:

- exposure
- size
- frame type
- glazing specification.

Under some circumstances, solar gains through windows are also important. The energy balance between heat losses and solar gains is discussed on page 44.

Window frame performance

The thermal performance of a window frame depends on:

- its degree of exposure
- the rate at which it conducts heat
- its weathertightness.

Exposure

Figure 40 gives values showing the influence of exposure on the thermal transmittance (U-value) of windows with different frame materials. The more exposed a window is, the poorer its U-value becomes.

Conductivity

The rate at which heat is conducted through a frame depends on its material and detailing. Wood and UPVC are poor conductors of heat while aluminium and steel are relatively good ones. Hollow plastic frames are also poor conductors but metal reinforcements in them may provide extra paths for conductive losses.

Some frames include a thermal barrier or break between the component in contact with warm room air and those in contact with cold outside air. Where metal frames are selected, types with a thermal break will not only reduce heat loss but also reduce the risk of condensation on the frame itself.

Figure 40 gives the thermal transmittance of different frame materials according to the proportion of window area that they represent. It shows that the proportion of window opening taken up by a frame has a considerable influence on the overall U-value of a window.

Frame type	Percentage of area occupied by frame	U-value for stated exposure W/m² °K					
		Single			Double		
		Sheltered	Normal	Severe	Sheltered	Normal	Severe
Wood	10	4·7	5·3	6·3	2·8	3·0	3·2
	20	4·5	5·0	5·9	2·7	2·9	3·2
	30	4·2	4·7	5·5	2·7	2·9	3·1
Aluminium	10	5·3	6·0	7·1	3·3	3·6	4·1
	20	5·6	6·4	7·5	3·9	4·3	4·8
	30	5·9	6·7	7·9	4·4	4·9	5·6
Aluminium (thermal break)	10	5·1	5·7	6·7	3·1	3·3	3·7
	20	5·2	5·8	6·8	3·4	3·7	4·0
	30	5·2	5·8	6·8	3·7	4·0	4·4

Figure 40

Weathertightness

Weathertightness requirements for windows are set out in BS 6375 Part 1: 1983 **The performance of windows** which gives separate classifications for:

- air permeability
- watertightness
- wind resistance.

The purpose of these classifications is to assist in the choice of windows for particular exposure conditions.

Figure 41 shows classifications based on testing procedures laid down in BS 5368 **Methods for testing windows**.

Air permeability BS 6375 Part 1			
	Acceptable levels for pressures		
Test pressure	Opening light	Fixed light	Classification
150 Pa	16m³/h/m	1 m³/h	I
200 Pa	16m³/h/m	1 m³/h	II
300 Pa	16m³/h/m	1 m³/h	III
600 Pa	16m³/h/m	1 m³/h	IV

Levels relate to air passing from outside to inside, per metre run of perimeter

Watertightness		Wind resistance	
Classification		Classification	No permanent damage should occur, and maximum deflection is specified.
50 Pa	In each case no water leakage should occur	1200 Pa	
100 Pa			
200 Pa		over 1200 Pa	
300 Pa			

Figure 41

Selecting window frames

A frame should be selected in accordance with BS 6375 when stringent levels of performance are required. For example, where exposure is severe, a window achieving the specified levels of performance at the following pressures should be chosen:

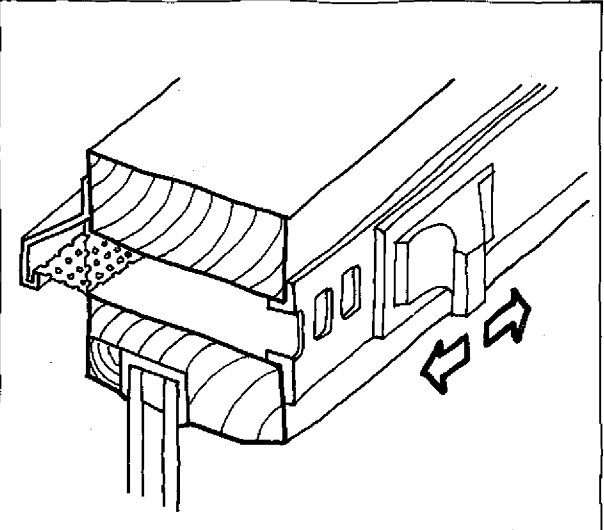
- at 600Pa in the air permeability test
- at 300Pa in the watertightness test
- at 2,300Pa in the wind resistance test.

Even in a moderate or sheltered situation, where wind speeds are unlikely to cause permanent damage that would reduce the performance of the window, there are still benefits in selecting a window with a performance higher than laid down in BS 6375:

- unwanted infiltration of cold air and loss of warm air will be reduced
- draughts will be reduced, with the result that comfort conditions can be reached at lower air temperatures.

If window frames are specified whose performance has a high rating in wind resistance and air permeability tests, it is not possible to rely on adventitious ventilation around opening lights to provide sufficient air changes in the house. Instead specific arrangements have to be be made to enable ventilation to occur. Adequate provision should be made in the frames, in the form of controlled or trickle ventilators, to provide ventilation that can be regulated *when windows are closed*, see Figure 42. Mechanical extracts should be fitted in kitchens and bathrooms to remove steam before it condenses and provides the conditions necessary for mould growth.[1] A humidistat can be installed to measure the relative humidity of the air and keep the extractor running until moisture content is below the level set.

In fitting windows into the structure, care should be taken to avoid cold bridges. Whenever possible, a form of construction should be chosen at lintels, sills and jambs which has the same U-value as the remainder of the wall. Local use of thermal insulation can be used to reduce cold bridging when, for example, steel lintels are used which would otherwise provide a direct path between inside and outside, see Figures 43 and 44.



Hit-and-miss trickle ventilator fitted in the head of a window frame

Figure 42

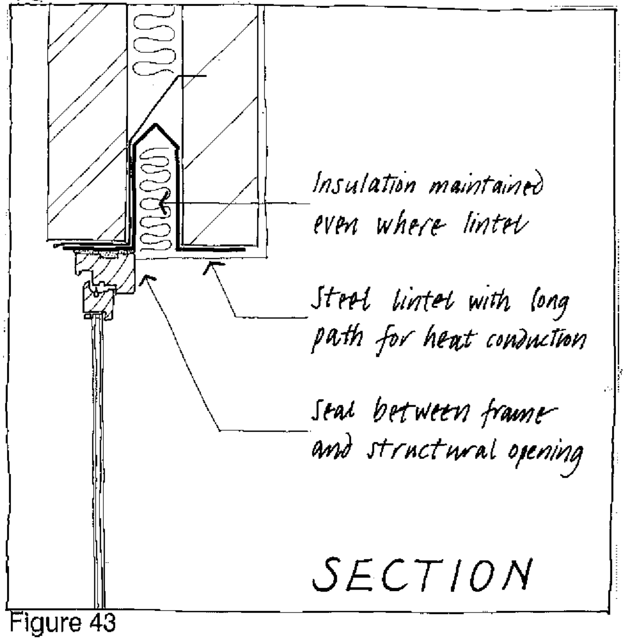


Figure 43

Advantages of higher performance frames
- reduced heat loss through frame
- reduced risk of condensation on the frame itself
- reduced infiltration through opening lights
- greater occupant comfort through reduced draughts

Disadvantages of higher performance frames
- increased cost
- need to consider ventilation: reliance on adventitious infiltration no longer possible

---

[1] Building Research Establishment, 1985, Surface condensation and mould growth in traditionally-built dwellings, BRE Digest 297, BRE, Garston, Watford.

Selecting glazing

Standards for glazing are set down in BS 6262 **Code of Practice for Glazing for Buildings** and in the **Glazing Manual.**

Glass is a dense material which is a poor insulator - it conducts indoor heat outwards in winter and outdoor heat inwards in summer. However its surface resistances are high so use of double or triple glazing provides improved thermal insulation. The U-values for a variety of glass types are given in Figure 45. The rate of heat loss through a single pane of glass (U-value 5.6 W/m^{2}K) is about ten times that through a wall insulated to the 1985 Building Regulations standard (U-value 0.6).

Heat losses through the glass are not the only consideration in selecting glazing. The orientation of the window (see page 44), the severity of the seasons (see page 17), and the heat gained from lighting, people and equipment also need to be taken into account.

For windows which receive direct sunlight, the **shading coefficient** can be important, see Figure 46. This is a relative measure of the amount of solar energy that is transmitted to the interior. Glass which transmits 87% of the total incident solar radiation is taken as the base for comparing other glass types (this corresponds with clear glass of between 3mm and 4mm thick). This is given a shading coefficient of 1.00. The shading coefficient of a glass provides a comparison between its solar radiation transmission and that of single glazing. So, just as its U-value is a measure of the amount of heat transmitted by a window to the outside, the shading coefficient of its glass indicates the proportion of incident solar radiation admitted relative to single glazing.

Designers who want to take advantage of solar gains for heating need to select glazing which

- has low heat losses
  and
- maintains a high transmission of solar energy.

The relationship between these two factors forms the basis for calculating what is known as the **energy balance** of a window, see page 44.

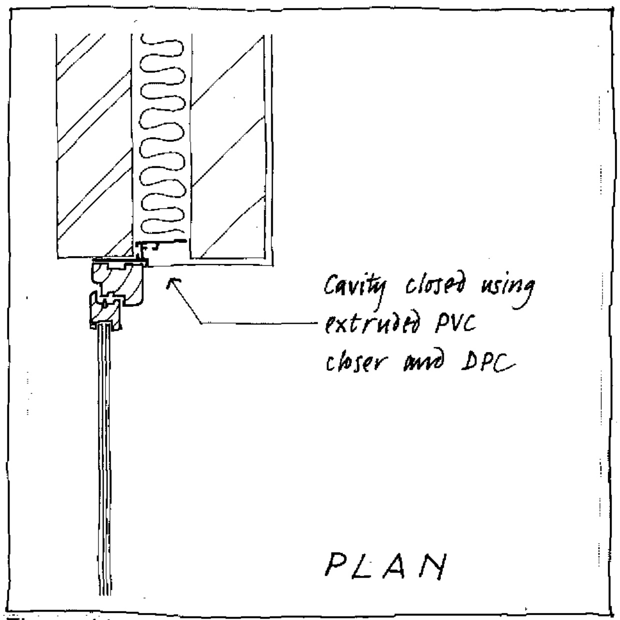


Figure 44

	U-values for stated exposure		
	Sheltered	Normal	Severe
Single glazing	5.0	5.6	6.7
Double glazing with airspace			
25mm or more	2.8	2.9	3.2
12mm or more	2.8	3.0	3.3
6 mm or more	3.2	3.4	3.8
3 mm or more	3.6	4.0	4.4
Triple glazing with airspace			
25mm or more	1.9	2.0	2.1
12 mm or more	2.0	2.1	2.2
6 mm or more	2.3	2.5	2.6
3 mm or more	2.8	3.0	3.3

Figure 45

	Standard U-value	Shading coefficient
Single glazing 4mm	5.6	.98
6mm	5.6	.95
Double glazing 4mm	3.0	.87
6mm	3.0	.82
Double low-E 4mm	2.0	.75
6mm	2.0	.72

Thermal transmittance (U-value in W/m^2 K) and shading coefficient for various glass types

Figure 46

How to improve the thermal performance of windows

The balance between the heat losses and solar gains of a single glazed window is poor throughout the heating season, whatever its orientation. But the thermal performance of glazing can be improved to levels above that of a single pane of glass by the following means:

- multiple glazing - adding one or more layers of glass
- coated glasses
- gas-filled cavities.

Multiple glazing

Multiple glazing improves the insulating properties of a window by adding a layer (or layers) of trapped air and introducing additional glass with surface resistances. But solar transmission is also slightly reduced.

If the panes of glass are not hermetically sealed at their edges, water vapour can condense on the inside of the outer pane as it does on single glazing. Such units should have their cavity ventilated to the outside to reduce the likelihood of condensation.

Factory sealed units contain dry air so that condensation cannot form inside the cavity and dust cannot enter. Variations in the external air pressure and temperature subject the units to stresses which, in time, tend to break down their edge seals.

In sealed units, heat has to be transferred by radiation and convection to cross the air space(s). So the width of the air space in multiple glazing affects thermal transmittance. The optimum width of cavity for all types of glass is about 20mm, see Figure 47. Beyond this size, a wider cavity allows air to circulate more freely. When this happens, air in contact with the warm sheet of glass rises and air in contact with the cold sheet settles. So a cyclical movement of air is established. This moving air transports the heat from the warm to the cold glass.

Figure 47 shows, among other things, that:

- double glazing with a 15mm air space is equivalent to triple glazing with air spaces of 3mm
- low emissivity double glazing is better than triple glazing for cavity widths above 8mm (and will be lighter in weight and of less overall thickness)

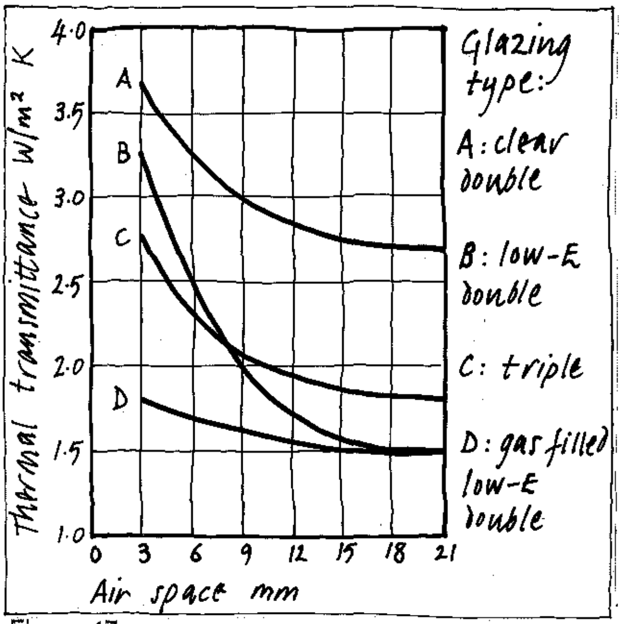


Figure 47

- triple glazing composed of 6+4+6+4+6 (total width 26mm) has a better U-value than double glazing of the same overall width composed of 6+14+6, although it will be heavier and more expensive.

Installing double or triple glazing improves the energy balance and therefore the thermal performance of a window. It also improves occupants' comfort. Because multiple glazing results in higher temperatures in the inner pane of glass, the amount of heat radiated back into a room will be greater than with single glazing. So it is no longer uncomfortable to be be near a window on cold days, see Figure 48. Comfort conditions can also be achieved at lower room air temperatures which can lead to energy savings.

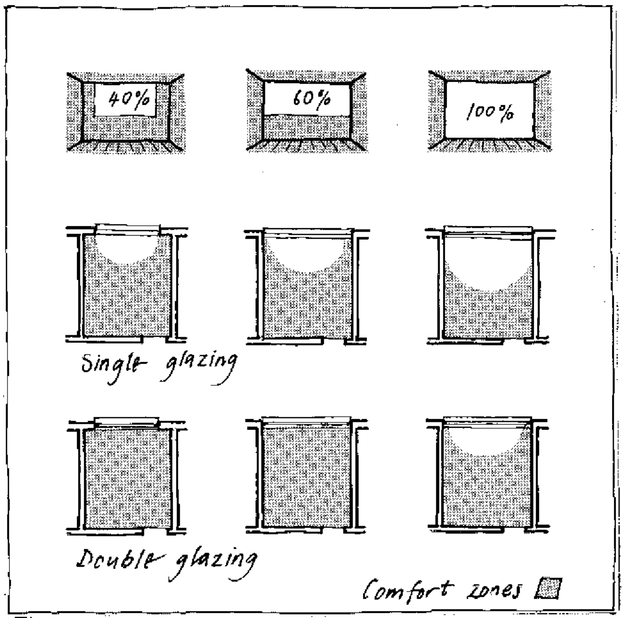


Figure 48

Advantages of multiple glazing

- energy savings
- reduced risk of condensation
- improved comfort with space being used more efficiently closer to windows with less fear of down draughts or cold radiant effects
- no need to place heat emitters under windows
- reduced heat emitter size
- reduced space heating pipe runs
- reduced boiler capacity possible
- Savings made on the cost of the heating system may help to offset the cost of the improved glazing.

Disadvantages of multiple glazing

- increased cost (but see above)
- slightly decreased solar and daylight transmission
- limited life of sealed unit with risk of condensation between the panes
- increased replacement cost
- possibly larger frame sizes and/or heavier frames
- increased likelihood of thermal breakage due to higher glass temperature in the presence of direct sunlight.

Coated glasses

The heat absorbing and radiating characteristics (termed **emittance**) of the two glass surfaces facing towards the air cavity will affect the rate at which heat is radiated across it. Special coatings applied to the surface of glass can reduce its **emissivity** and so improve its insulation value.

Low emissivity coatings, commonly called low-E, maintain a high transmission in the short wavelength end of the spectrum where solar radiation is concentrated and so allow a high proportion of it to pass through. This short wavelength radiation is absorbed by the floor, walls and furnishings of the room, and then re-radiated at longer wavelengths. A low emissivity coating causes long wavelength radiation to be reflected back into the room and so reduces outward heat losses.

The U-value of a double glazing unit with low emissivity coating is about 2.0 W/m^{2}K compared with 3.0 for its clear glass equivalent. Low emissivity coatings result in a surface temperature of the inner pane of glass only 1 or 2°C below room temperature, so improving comfort, see Figure 49.

The light transmission of a sealed coated unit is in the range 60-75% as compared with 75-80% for an ordinary sealed unit. This small reduction in light transmission has a negligible effect on the level of daylight.

Glazing type	U-value W/m^{2}K	Surface temperature °C	
		Night	Day
Single	5.6	0	0.4
Double	3.0	9.2	10.1
Triple	2.0	12.8	14.2
Low-E Double Argon filled	1.6	14.2	16.3

Surface temperature of the inner pane with inside environmental temperature 20°C and outside temperature -10°C, assuming 100 W/m^2 solar radiation

Figure 49

Advantages of coated glasses

- Used in double glazing, these can achieve the same or lower U- values as triple glazing without the associated reduction in solar transmission
- If they replace the need for extra layers of glass, they eliminate framing problems
- comfort conditions can be reached at lower air temperatures

Disadvantages of coated glasses

- increased capital cost
- increased replacement cost

Gas-filled cavities

By filling the cavities of multiple glazing units with certain gases, such as argon, their insulation is improved. The mix of gases in the air space affects the rate of heat transfer. For example, heat flow through a multiple glazed unit is reduced by 14% when the air space is filled with Krypton. A reduction of as much as 20% may be possible by using carbon dioxide.

Points to remember

- **use window frames with high rated performances for wind resistance and air permeability wherever costs allow**
- **specify controlled or trickle ventilators when using windows with high wind resistance and low air permeability**
- **use frame materials with low thermal conductivity. Where frame materials with high thermal conductivity have to employed, specify types which include a thermal break**
- **avoid cold bridging when fitting windows into the external envelope**
- **use double glazing or better (eg. low-E glass) for large glazed areas such as picture windows, french windows and patio doors to reduce heat loss and improve comfort**
- **use double glazing or better for rooflights to reduce heat loss and avoid condensation.**

Window orientation

Decisions about the orientation of windows affect the energy consumption of a house. But what specifications for windows should be used and where should they be positioned to minimise consumption?

General requirements

The 1985 Building Regulations make no stipulations about window orientation. But the **BSI's DD67: 1980 Basic data for the design of buildings - sunlight** recommends that living rooms, and possibly bedrooms, should receive three hours of sunlight on March 1st. This is intended as a minimum. Where circumstances permit or where solar heat is to be used in the winter, then **DD67** recommends that a more generous provision (preferably based on statistical expectation of hours of sunlight) should be considered.

If fuller use is to be made of solar energy by the **direct gain** method, prolonged exposure to intense sunshine in rooms used as collection spaces will occur. This can have effects on both occupants and their possessions, see page 58.

In spaces that receive sunshine, windows should also be located to give solar radiation access to sufficient **thermal mass** (see page 80) so that energy can be stored:

- to even out excessive swings in daily temperature at any time of year
  and
- to avoid summer overheating.

The energy balance of windows

The location of windows should also be considered in terms of their **energy balance**. This depends on the rate of heat loss through a window minus any heat gains through it. Windows with different orientations have very different energy balances because of the varying quantities of **direct** and **diffuse** solar radiation falling on them. The daily energy balances for unobstructed vertical single glazing for different orientations are shown in Figures 50 to 53. These diagrams are drawn from Wilberforce's theoretical study based on meteorological data for Bracknell (51° 23'N, 0° 47'W) during the period 1967 to 1973.[1] An internal temperature of 18°C, averaged over 24 hours, with curtains not closed at night, has been assumed.

---

[1] Wilberforce, R., 1976, The energy balance of windows, Building Services Engineer, Vol. 43, No. 12, pages 241-243.

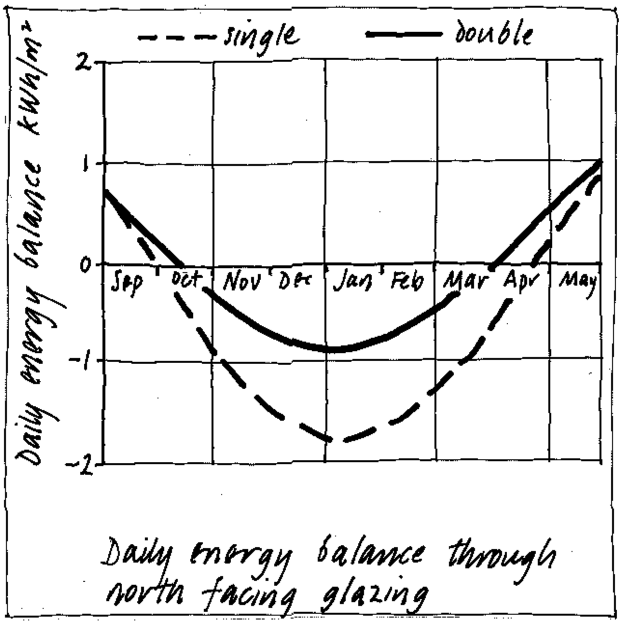


Figure 50

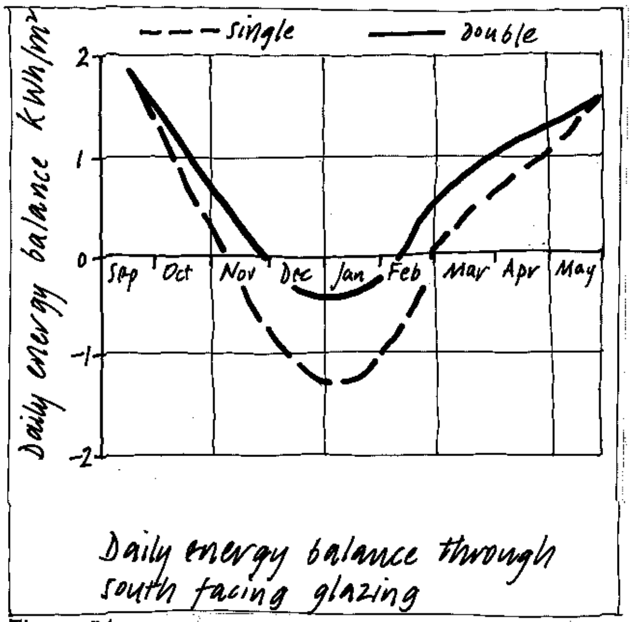


Figure 51

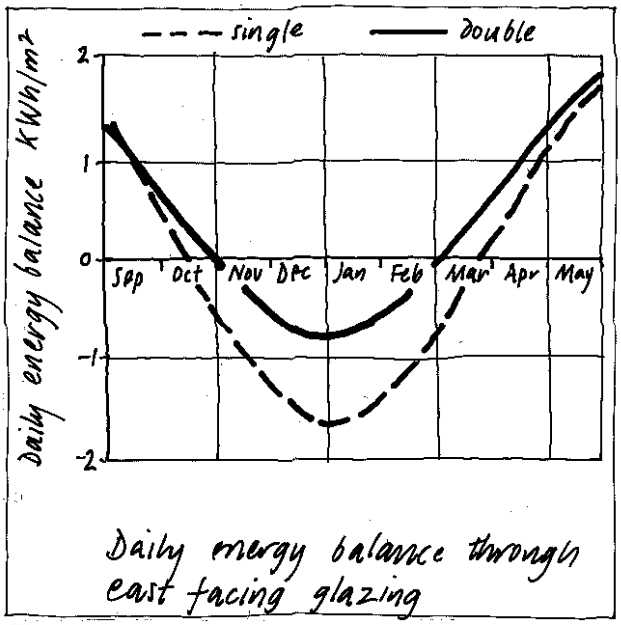


Figure 52

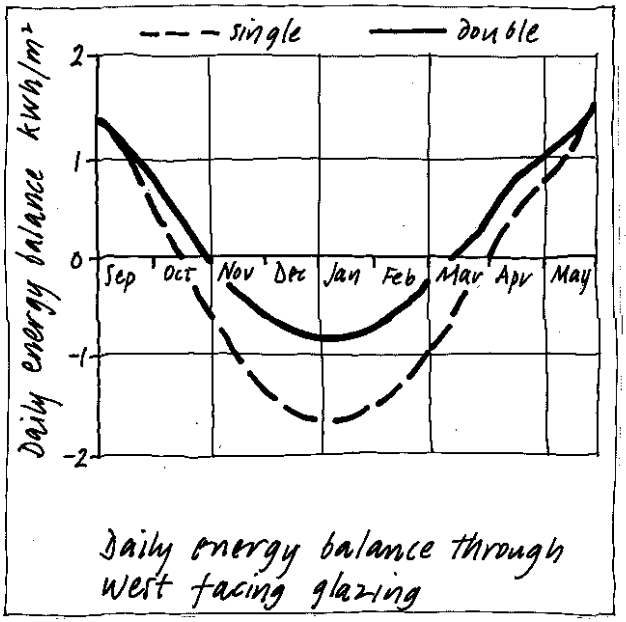
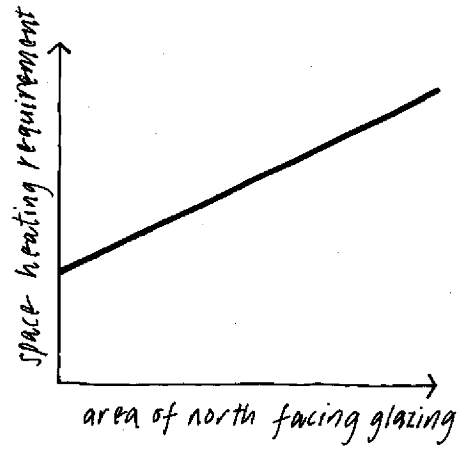


Figure 53

North-facing windows

These have a **negative** energy balance, see Figure 50, because over the heating season they allow more heat to escape from inside the house than they admit from diffuse solar radiation. Computer modelling conducted for ETSU shows a distinct relationship between a house's area of north-facing glazing and its requirement for auxiliary heating, see Figure 54.[1] If the area of north-facing glazing is reduced, the requirement for auxiliary heating drops significantly.

The clear message from this piece of computer modelling is that, where possible, windows placed on the north side of a house should be kept to a minimum. In practice, the size of north-facing windows is likely to be affected by factors other than energy consumption, such as daylighting and ventilation requirements, the need for views, and external appearance.



The relationship between north facing glazing and space heating requirement

Figure 54

South-facing windows

Over the heating season, south-facing windows which are double glazed or better can have a **positive** energy balance. Even if it is not possible to fit glazing of this quality, it can still be desirable to concentrate any large areas of glazing on the south side of a house because windows in this position benefit most from solar gain, see Figure 17.

The extent to which a south-facing window makes a positive contribution to reducing requirements for auxilary heating in a house depends on:

- its construction - single/double glazing, frame type, weatherstripping, see page 37
- its area, see page 50
- how people use it (particularly for ventilation) and
- the temperature and duration of heating maintained within the room.

Wilberforce's theoretical study, like CAP Scientific's computer modelling conducted for the Energy Technology Support Unit, suggests that double glazed south-facing windows in a house heated to a constant temperature can be a source of net energy gain for ten months of the year, see Figure 51. Only December and January show net energy losses. But even these windows, which have a net positive *annual* energy balance, lose energy in the middle of the heating season.

[1] Energy Technology Support Unit, 1984, Passive solar study group: windows, ETSU, Harwell.

East and west-facing windows

Windows with these orientations receive 35% less solar radiation than south-facing ones in total during the heating season, see Figure 17. Because of this, they are net energy losers over the whole of the heating season, see Figures 52 and 53, unless low-E double or triple glazing is specified. To reduce energy consumption, windows placed on east and west elevations should be kept to a minimum - unless their area is thoughtfully considered and their specification up-graded so as to improve their energy balance.

"Effective U-values"

The glazing areas permitted by the 1985 Building Regulations, see page 50, are calculated on the basis of conventional U- values. These only take account of heat loss through a window due to conduction from its warm to its cold side. No consideration is given in the Regulations to other factors which affect a window's energy balance.

The concept of modified or effective U-values has been developed, and popularised in the UK by Pilkingtons, to provide a simple method of recognising the significance of two way energy flows across a window. An effective U-value is a conventional one modified to allow for usable solar radiation falling through a window during the heating season.

Figure 55 shows Pilkington's original estimates of the effective U-values of different window systems in relation to orientation.[1] Figure 56 shows the results of their more recent calculations to model the same effect.[2] Here the equation employed contained a utilisation factor to allow secondary influences (such as thermal storage and mass, ventilation rates, internal gains and heating schedules) to be taken into account.

The two Figures differ as to the precise degree of difference between conventional and effective U-values. But they agree about the direction of the effect. As before, these studies offer a clear message. They both suggest that, once the influence of solar radiation is included, south (or southerly) facing glazing has a much superior energy balance to other orientations.

Glazing type	U-value W/m^{2}K	Effective U-value W/m^{2}K
Single	5.6	North 4.4 South 2.6 East 3.8 West 3.8
Double	3.0	North 1.9 South 0.7 East 1.7 West 1.7
Double with low emissivity coating	1.9	North 1.0 South 0.1 East 0.8 West 0.8

Figure 55

Glazing type	U-value W/m^{2}K	Effective U-value W/m^{2}K
Single	5.6	N 4.7 NE/NW 4.6 E/W 4.2 SE/SW 3.5 S 3.2
Double glazing, heat reflecting	1.6	N 0.8 NE/NW 0.8 E/W 0.4 SE/SW -0.1 S -0.4

Latitude 51.5°N, Radiation Sept-April 375 kWh/m^2
Degree Days 2710, Solar utilisation factor 60%

Figure 56

---

[1] Button, D., 1982, Energy options for housing design: glazing options, Journal of the Royal Institute of British Architects, Vol. 89, No. 10.

[2] Owens, P., 1984, Low emissivity coatings on glass in windows, UK-ISES Conference Proceedings (C38), Coatings for energy efficiency and solar applications, pages 11-21.

Orientation and energy consumption

Southerly orientations, free from obstructions and overshading by trees or other buildings, are to be preferred if maximum use is to be made of solar radiation during the winter. Of course, not all windows can face south. Neither can they be completely unobstructed. The effects of other orientations and of various degrees of skyline obstruction are shown in Figure 57.

This figure is based on computer simulations of the Linford houses at Milton Keynes conducted by CAP Scientific. These suggest that windows intended to provide useful solar gain should preferably be orientated within 30° of south.[1] Where this is not possible, orientations up to 45° either side of south realise half the possible solar gain. Modest obstructions, of up to 10°, are not significant. But, once the angle of obstruction has reached 25°, the potential solar benefits are reduced to less than half the unobstructed value.

However, other computer simulations of a conventional and a passive solar house conducted by BRE suggest that domestic energy consumption is fairly insensitive to variations in orientation between +/−45° of south.[2] Such variations alter the total amount of solar radiation falling through windows by only about 5 to 10%. Similar conclusions about the relative unimportance of orientation for energy consumption were drawn from a third set of computer simulations of low energy houses conducted for BRE by CAP Scientific[3] and from studies of the passive solar houses at Pennyland in Milton Keynes by the Energy Research Group of the Open University[4], see Figure 58.

The orientation of a house has less effect on its energy consumption than the levels of insulation specified for the opaque elements in its external envelope. In addition, computer simulations, conducted by CAP Scientific for the BRE study of low energy houses cited earlier, suggest that the effect of changes in orientation on consumption is reduced as the insulation value of the opaque elements is increased.

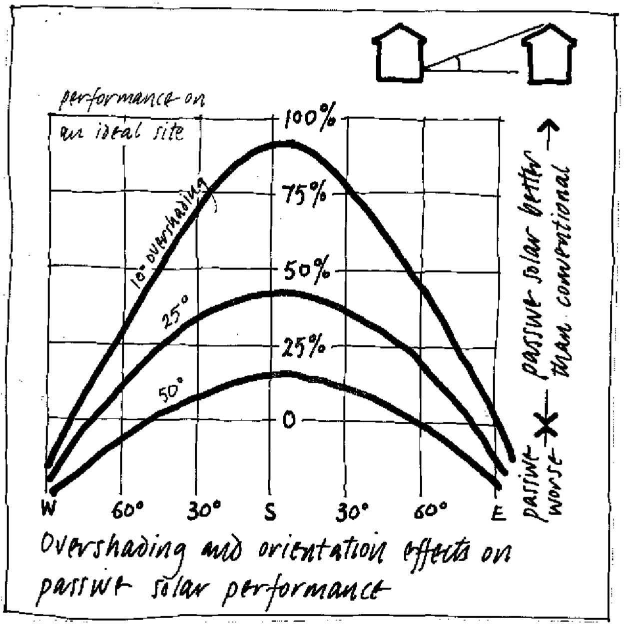


Figure 57

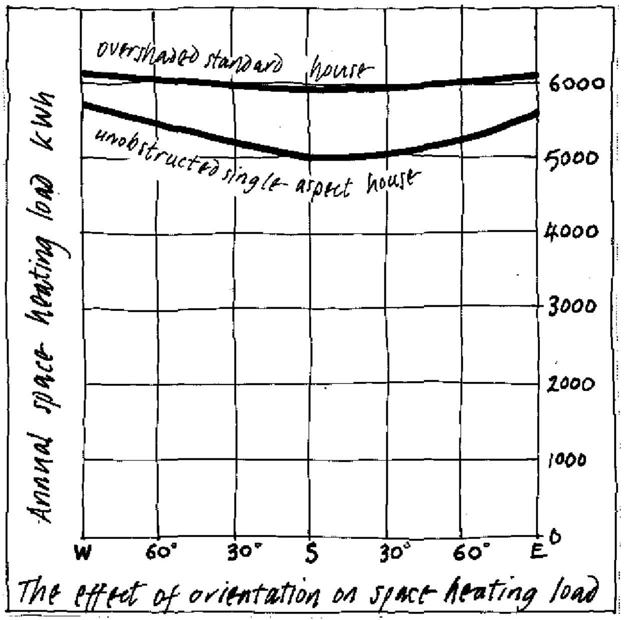


Figure 58

---

[1] Milbank, N., 1986, The potential for passive solar energy in UK housing, PD 102/86, Building Research Establishment, Garston, Watford.

[2] Bloomfield, D., 1987, IEA Task VIII - Documentation of parametric study, Building Research Establishment, Garston, Watford.

[3] Nielsen, O., 1984, Options on energy, Architects Journal, Vol. 179, No. 21, pages 47-62.

[4] Lowe, R., Chapman, J. and Everett, R., 1985, The Pennyland project, Report by the Open University Energy Research Group to the Energy Technology Support Unit, Contract No. E5A/CON/1046/174/040.

The findings of all these computer simulations of the effect of orientation on energy consumption are not unequivocal. This is not surprising. The studies are not strictly comparable. They each model different houses. And each set of simulations is based on slightly different sets of assumptions. At present, it is probably safest to conclude that orientation can be important, depending on how window area is distributed between elevations, see page 50. But it may be less important than the U-value of walls and roofs. And it seems to become less important as these values are improved.

Points to remember

- where possible, orientate windows to have the most positive energy balance by placing them on southerly facades
- windows whose orientations give them a poor energy balance should have their specification up-graded
- use windows with a high energy performance (see page 41) whenever costs allow. However, when they do not, consider using such windows in this order of priority:
  - for all north (or northerly) facing glazing to improve its energy balance
  - next for all east or west facing glazing
  - then for glazing to south (or southerly) facing habitable rooms, especially the main living room
  - lastly for glazing to south (or southerly) facing bedrooms and ancillary spaces.

Window area

The glazing placed on each elevation will have different effects on energy consumption, depending on its area and its orientation. How much glazing should be put on each facade to optimise energy consumption?

The Building Regulations

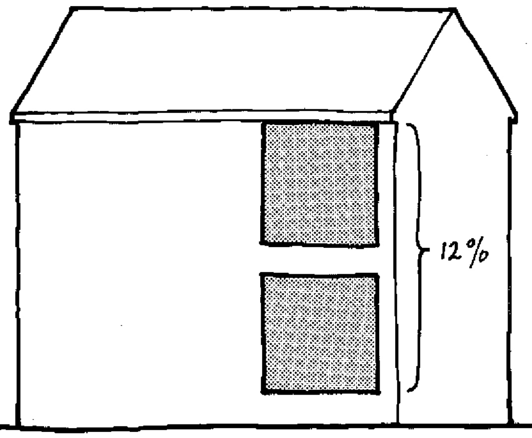
No stipulations are made in the Building Regulations 1985 about about permitted areas of glazing for different orientations. Instead Part L of the Regulations simply states that, where single glazing is installed, the aggregated area of windows and rooflights shall be no more than 12% of external wall area, Figure 59.

Table 1 in Section A 1.1 of Part L2/3 stipulates that areas which are double glazed may have up to twice the single glazed area, see Figure 60. Likewise areas which are double glazed with a low emissivity coating or triple glazed may have up to three times the permitted single glazed area, see Figure 61. The areas used in this calculation should be those between the finished internal faces of the building. Section A 1.1 of Part L2/3 specifies the other conditions governing this calculation.

Procedure 3 of the Regulations describes calculated trade-offs which permit other ways of increasing window areas. This involves:

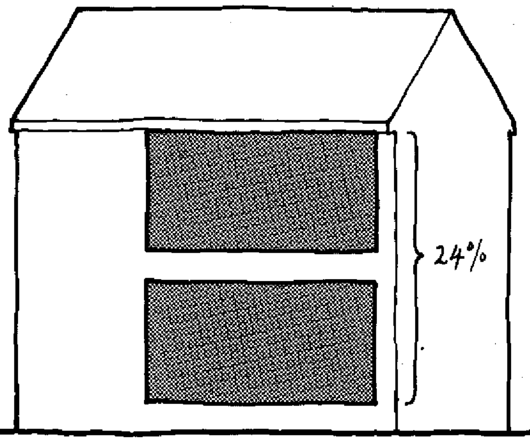
- first calculating the rate of heat loss through elements of the building allowed if the stipulated U-values and percentage glazed areas are followed
- this establishes the *allowable heat losses* through the fabric elements
- then larger areas of (for example, double) glazing can be proposed which do not exceed the allowable heat loss.

Trade-offs can also be made between walls and roof U-values so long as the allowable heat loss is not exceeded. A similar trade-off can be made between glazed and opaque areas. So, if a proposed wall construction has a better U-value than that required by the Regulations, the percentage of glazing may be increased to the point at which the calculated rate of heat loss is no greater than if the stipulated maximum U-values of opaque and glazed elements had been used. In practice, this means that where triple glazing is employed (and depending on how window area is distributed between elevations), the Regulations may allow completely glazed south-facing facades to be used, see page 55.



Single glazing, front and rear walls identical, gable walls blank

Figure 59



Double glazing, front and rear walls identical, gable walls blank

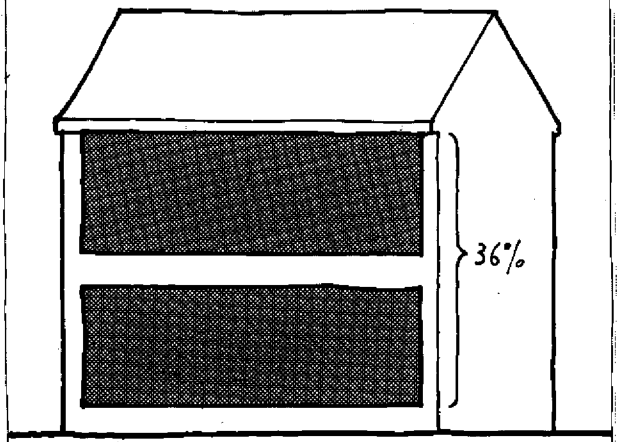
Figure 60

The lintel, jamb and sill of a window must either be designed to comply with the U-value of the remainder of the wall or be included as part of the window area, see Section A 1.1 (f).

Building costs and window area

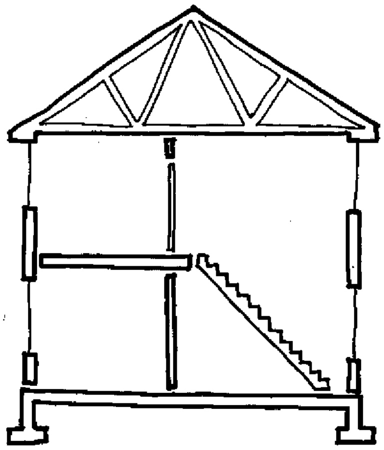
So the 1985 Building Regulations contain procedures which allow the glazed area, as a percentage of the external envelope of a house, to be increased. But is it worthwhile to do so?

Davis, Belfield & Everest have produced an elemental breakdown of building costs for housing[1], see Figure 62. This shows that opaque elements in external walls typically account for appproximately 10 to 20% of total construction costs. Windows and external doors usually only account for half or a third as much, ie. between about 5 to 15%. However, in the passive solar designs produced for ETSU's House Design Studies[1], the total cost of windows was about the same as the total cost for the opaque wall elements.



Triple glazing, front and rear walls identical, gable walls blank

Figure 61



	conventional housing	passive solar designs	D,B and E's guidelines
roof	9 to 12·9	7·8 to 19	8 to 16
internal doors	3.6 to 6.9	3.7 to 9·6	3.5 to 7
upper floors	3.9 to 9	4·5 to 7·8	5 to 11
external walls	7·1 to 19·1	7·8 to 22·1	11·5 to 22·5
staircases	1·4 to 4·2	1·7 to 5.3	1·5 to 3·5
windows and external doors	6·2 to 14·9	5.1 to 19.2	6·5 to 9·5
internal walls	3·4 to 7	3.1 to 8	9 to 17
party walls	1·9 to 9.2	1·3 to 9·6	
substructure, ground floor	8·5 to 15·6	8·5 to 15·9	8·5 to 15
mechanical services	14·1 to 22·6	13·1 to 22·8	15 to 19
electrical services	2·8 to 5·3	2·8 to 5	3 to 6
sundries	4·5 to 8·1	4·2 to 7·9	

Percentage elemental breakdown of building costs, prepared by D, B and E.

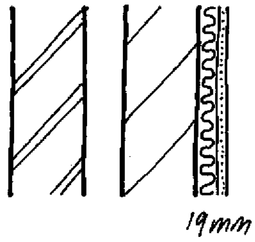
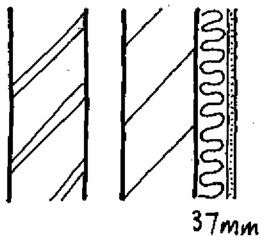
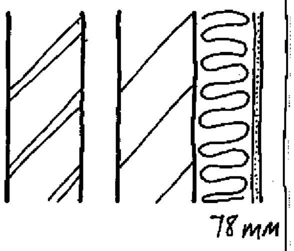
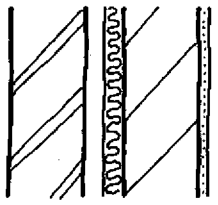
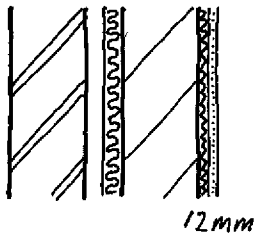
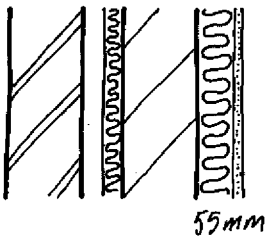
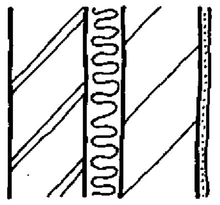
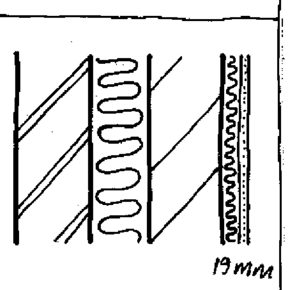
Figure 62

Traditionally, windows occupy about 15 to 20% of the exposed wall area of British dwellings, see Figure 4. Any increase in this proportion is likely to increase building costs. Even single glazing in a standard softwood frame is 1.5 times more expensive per square metre than the insulated wall it replaces.

---

[1] Davis, Belfield & Everest Consultancy Group, 1986, Newbuild design studies: summary of quantitative data from the cost analysis project, Report to the Energy Technology Support Unit, DB&E, London.

Improving the insulation value of a wall from 0.6 to 0.3 W/m^{2}K increases its cost by about 15%, see Figure 63. Improving the insulation value of glazing is more expensive, as Davis, Belfield & Everest's costed comparison of window systems shows, see Figure 64. Double glazing in a standard softwood frame can cost up to half as much again. However, the cost of windows installed in a cavity wall decreases as the window area increases, see Figure 65. As these figures reveal, there are no grounds - at least in terms of initial costs - for increasing window area as a proportion of the external envelope.

	U = 0·6	U = 0·45	U = 0·3
Clear cavity Brick, 50mm cavity, 100mm lightweight block, dry lining with eps insulation backed plasterboard: insulation thickness varies as shown	 19mm £55	 37mm £57	 78mm £62
Partially filled cavity Brick, 25mm clear cavity, 25mm eps insulation, 100mm lightweight block, plaster. Plaster replaced by dry lining with insulation backing of thickness shown	 £53	 12mm £59	 55mm £61
Fully filled cavity Brick 50mm cavity filled with fibreglass insulation 100mm lightweight block. Cavity increased to 75mm and insulated dry lining added	Wall specified already achieves U = 0·45 ⟶	 £52	 19mm £63

Costed comparisons of cavity wall constructions in £/m^2 (at July 1987 prices) for various U-values, and assuming a lightweight block with a thermal conductivity of 0.17m^{2}K/W

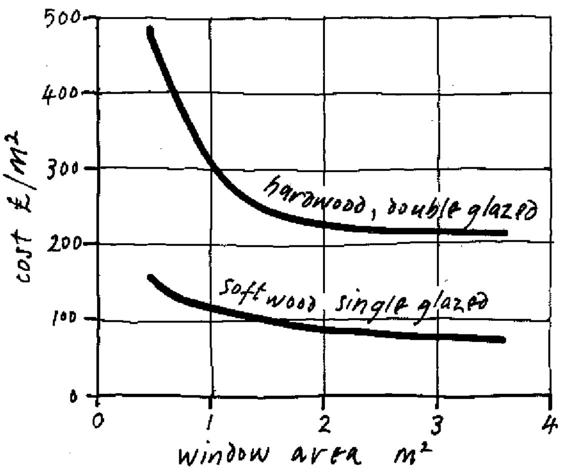
Figure 63

The optimum area for south-facing glazing

Nevertheless, is it worth increasing south-facing window area in an attempt to cut running costs by reducing expenditure on energy?

Single glazing on a south facade is a net heat loser over the heating season in houses with typical internal temperatures. So there are no grounds for increasing south-facing window area if single glazing is installed.

Double glazing (or single glazing where night insulating shutters are consistently operated) is thermally neutral over the whole of the heating season, ie. heat loss and gains are approximately equal. So varying the proportion of double glazing in a well-insulated south-facing facade is unlike to have a dramatic effect on a house's annual heating requirement.



Cost in £/m² of installing a window in a cavity masonry wall (July 1987 prices)

Figure 65

Glazing type	Timber				Metal				Plastic	
	Softwood		Hardwood		Aluminium		Steel		UPVC	
	standard	high perf	standard	high perf.	standard	high perf.	standard	high perf	standard	high perf.
Single	50 to 60	73 to 83		91 to 115	82 to 128	96 to 131	100 to 110	158 to 194	104 to 128	
Double	72 to 90	79 to 99		97 to 121	101 to 146	116 to 146	117 to 149	181 to 222	136 to 164	163 to 199
Double, low-E		103 to 124		121 to 182		119 to 146				204 to 250
Double, low-E, gas filled		109 to 195		127 to 276		134 to 163				326 to 398
Triple and quadruple	no figures available									

Costs in £ of glazed windows, assuming 1200mm x 1200mm window (July 1987)

Figure 64

BRE has conducted computer simulations of the effect of increasing the glazed percentage of a south-facing elevation for a conventional, private developer's middle market semi-detached house of 80m^2, see Figure 66.[1] Here the original south-facing elevation contains 18% glazing and the house is assumed to be heated between 07.00-23.00 and sited at Kew. Figure 67 shows the results of this modelling. Increasing the south-facing window area to 30% (of the south-facing wall) brought a 1% reduction in annual heating requirement. Increasing it to 50% brought about a 4% reduction.

From the slope of the graph in Figure 67, there would appear to be no obvious optimum area for double glazing on south- facing facades. With each increase in area, a small improvement in energy consumption is obtained.

Similar predictions of the effect of increasing south-facing window area on energy consumption have been published by Pilkingtons[2] *for one room* of a house sited in Glasgow, see Figure 68.

These two studies are not directly comparable. They employ different computer models to simulate different situations, using different assumptions. But they suggest similar conclusions about south-facing window area. They broadly agree about the direction of the effect.

Both predict only modest energy savings. Energy consumption is suggested to be fairly insensitive to changes in the area of south-facing windows where double glazing is used. As Figure 67 shows, with triple glazing, the savings are more significant.

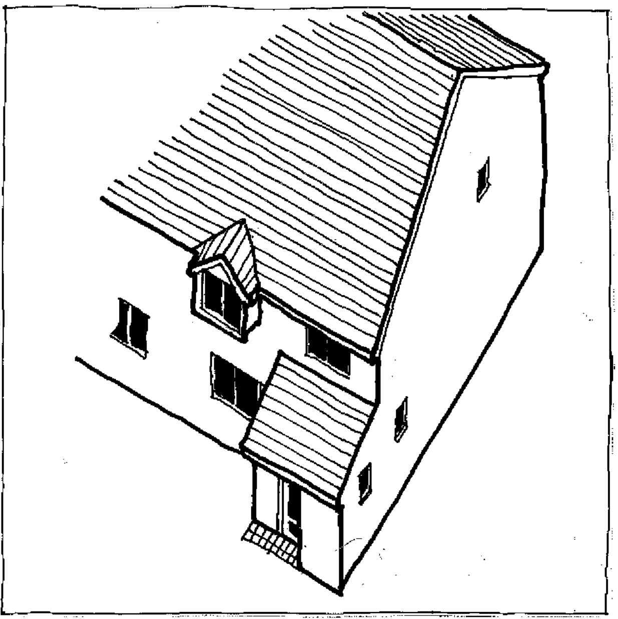


Figure 66

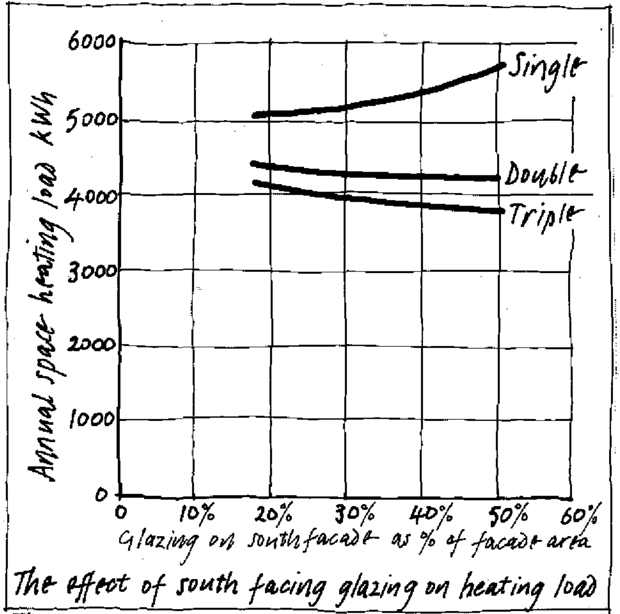


Figure 67

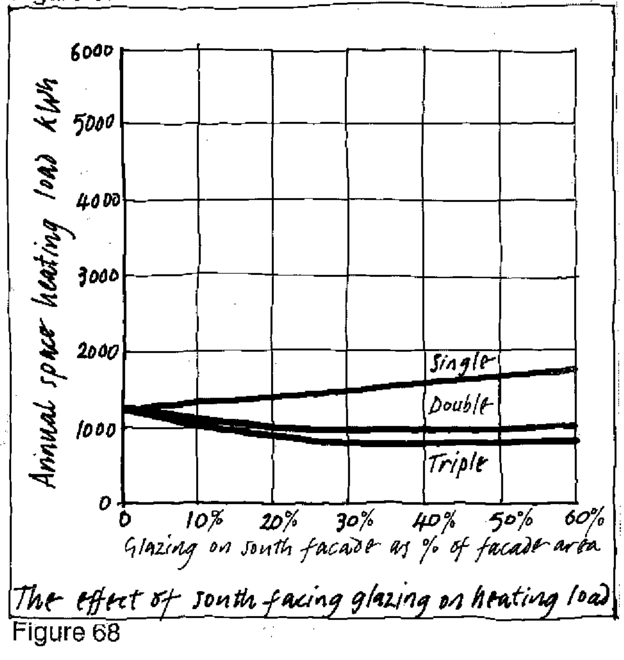


Figure 68

---

[1] Bloomfield, D., 1987, IEA Task VIII - Documentation of parametric study, Building Research Establishment, Garston, Watford.

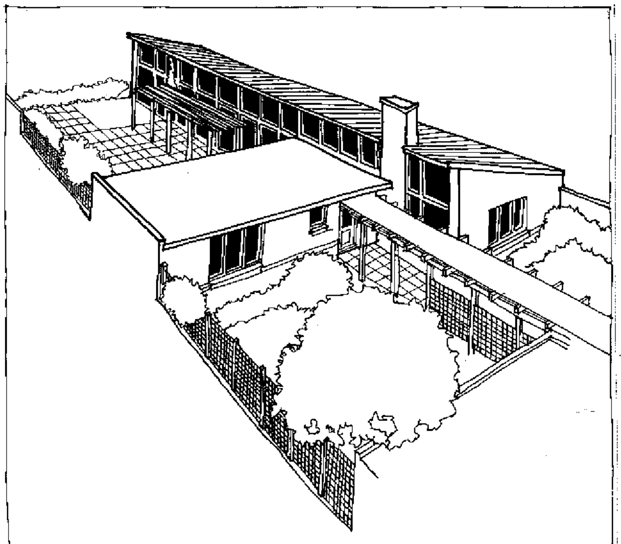
[2] Button, D., 1982, Energy options for housing design: glazing options, Journal of the Royal Institute of British Architects, Vol. 89, No. 10.

Computer simulations conducted for the Haslam Homes house at Energy World, Milton Keynes, see Figure 69, predict that, once designers have access to window systems with:

- U-values of about 0.5W/m^{2}K (such as quadruple glazing argon filled sealed units) and
- a solar transmission of 0.5,

then any increase in the area of south-facing glazing up to 100% may reduce annual energy consumption.[1]

In practice, factors other than energy consumption are likely to be just, if not more, critical in deciding window area. For example, where south-facing walls have more than 20% glazing, the BRE's simulations cited above predict that overheating may, on occasion, be severe for buildings of conventional British construction - unless specific measures are taken to prevent or control it, see page 80.



The Solaire, architects Feilden Clegg Design

Figure 69

The balance between north and south-facing glazing

The simulation studies cited so far suggest that there is little value in increasing either:

- a house's overall area of glazing
  or
- simply the glazed percentage of its south-facing elevation.

But, if the overall area of glazing is kept constant, is it worth:

- reducing the area facing north
  and
- redistributing the saved glazing from the north to the south?

This strategy was adopted by Greenberg & Hawkes in their design to reduce the energy consumption of Wimpey's Supawarm houses.[2] Their design had less glazing than the Wimpey original, resulting in a cheaper building envelope. North- facing glazing was also reduced, leaving a greater proportion to be orientated to the south, see Figure 70. Computer simulation showed that selective double glazing to the north and east windows was more cost effective than including the south-facing ones as well.

Wimpey Supawarm house, modified.

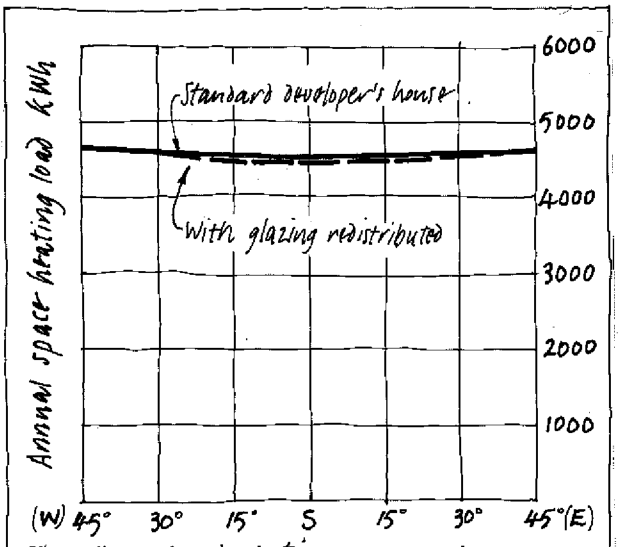
Figure 70

---

[1] Littler, J. & Ruyssevelt, P., 1986, The role of thermal mass in UK housing, in The efficient use of energy in buildings, 2nd UK-ISES Conference (C46), UK-ISES, London.

BRE has also conducted computer simulations to test the effect of this strategy.[1] The standard developer's house (described earlier, see page 54) originally had equal areas of glazing on its north and south elevations. BRE modelled the effect of reducing the northern window area to 10%. This led to a predicted saving of 0.4% of the annual heating requirement. Transferring the window area taken from the north to the south-facing elevation produced a further reduction of 2%.

So a small cut in consumption (which requires no additional initial cost) can be achieved by reducing north-facing glazing and redistributing the window area saved to an elevation facing due south. But, for other orientations, this strategy is more questionable. For houses orientated up to +/-45° of south, reductions in consumption will still be made but they will be smaller, falling to 1.5% at 45° in the south of England. For houses orientated more than +/-45° of south, redistributing glazing area in this way will worsen energy performance, see Figure 71.



The effect of orientation on annual space heating load for two glazing arrangements

Figure 71

Points to remember

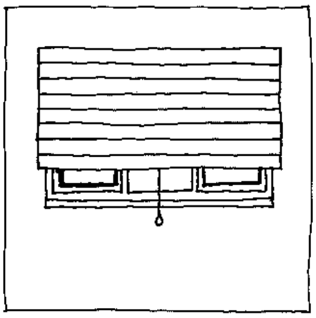
- The proper orientation of windows to minimise energy consumption does not presume any increase in total window area. The issue is the correct distribution of window area between elevations. Therefore, proper orientation need not result in additional construction costs. It may even cut them by leading to a cheaper external envelope due to reduced overall glazed area.
- Other tentative conclusions can be drawn from of the computer modelling work cited above
- where windows specified are single glazed or ordinary double glazing, there are no energy or cost grounds for increasing the glazed proportion of a building's external envelope
- where windows specified are double glazed or better, energy consumption will not be dramatically affected by decisions about the percentage of glazing in a south-facing elevation (but overheating may be)
- it is more important to reduce the area of north-facing glazing than to increase the area facing south
- in a dual aspect house, window area may be taken from one elevation and usefully redistributed to another but only if the facade with increased glazing is orientated within 45° of south.

---

[1] Greenberg, S. and Hawkes, D., 1984, Report on Wimpey passive design study, ETSU Passive Solar Programme, Greenberg & Hawkes, London.

SECTION 4

Glass shading, insulation and thermal mass



Overheating and the effects of direct sunshine

Sunshine is not always wanted inside houses, especially in the summer. And, even during the heating season, sitting in direct sunshine is not always a pleasant experience. Consideration should be given to steps to avoid both these conditions.

General requirement

One of the main challenges of exploiting solar energy is controlling daily and seasonal fluctuations in air temperature in rooms that are sunlit. If this is not done successfully, important consequences can follow:

- occupants become uncomfortable on clear, sunny days - especially during the summer but even during the heating season
- they may pull curtains or blinds - if they do this during the heating season, potentially useful solar gain may be lost
- they may open windows to induce extra ventilation - if they do this during the heating season, purchased heat *and* potentially useful solar gain is lost.

This unwanted chain of events can be avoid by a combination of design strategies:

- properly sized windows
- shading, preferably external
- a balanced use of thermal mass
- a responsive heating system and controls.

Summer overheating

Overheating due to solar gains has not been reported as a major problem in Britain in houses with conventional areas of glazing, see page 55. And there is little documented evidence about this phenomenon in houses with enlarged southerly-facing windows. There is, however, evidence of very high temperatures in conservatories, see page 91.

In the Pennyland scheme (currently the only reported monitoring in this country of houses with increased southerly glazing), it was concluded that summertime overheating is not a significant problem where:

- glazing is 40% or less of the south facade and
- buildings are of medium weight construction.[1]

---

[1] Lowe, R., Chapman, J and Everett, R., 1985, The Pennyland project, Open University Energy Research Group, Report for the Energy Technology Support Unit, Contract No. E5A/CON/1946/174/040.

However, computer simulations conducted by BRE suggest that overheating is likely to be severe (defined as above 25°C for 10% of the time) in south-facing living rooms where

- windows are more than 20% of the wall area and
- the building is of conventional masonry construction.[1] Large windows on the east and west facades are also predicted to cause overheating problems at specific times of the day.

The effects of direct sunshine

Southerly-facing glazing, even if it does not produce overheating (in terms of excessive air temperatures), may cause other adverse effects:

- discomfort to occupants (glare or heat stress)
- fading or even fire risk to furniture and fittings

because of the intensity of direct sunshine.

The former can be dealt with, like overheating, by the use of shading devices. To avoid the latter, textured window glass (such as hand-spun bullion and Flemish glass panes) should not be specified for doors or windows subject to direct sunshine.[2]

Points to remember

- **if large areas of glazing are incorporated in east, west or south-facing elevations - whether as windows or in attached or integral conservatories - then shading devices should be fitted, either externally or internally, see pages 64-78.**
- **such devices will prove particularly worthwhile, both in terms of both improved comfort and energy consumption, if they can reduce**
  - **the risk of summer overheating and**
  - **the rate of winter night-time heat loss through windows on all facades**
- **some textured glasses should not be used in windows and doors receiving direct sunshine.**

---

[1] Bloomfield, D., 1987, IEA Task 8 - Documentation of parametric study, Building Research Establishment, Garston, Watford.

[2] Goldstone, B., 1982, Hazards from the concentration of solar radiation by textured window glass, Building Research Establishment Report, Department of Environment, HMSO, London.

Occupants and shading/insulating devices

Few households in Britain currently use external blinds or shutters. Nearly all use some form of internal covering at their windows. Where glazing is designed to exploit solar radiation, careful thought must be given to how occupants' use of window coverings will affect its energy balance.

The effectiveness of devices

There is little documented evidence available about how window shading and insulating devices are used in practice. A study of measurements made at 70 passive solar houses across the USA concluded that the usefulness of such devices is highly dependent on how frequently and how well they are used.[1] Movable window insulation, for example, has to be operated properly for at least 70% of the time if any net energy benefit is to be gained. It is suggested that this makes the viability of manually operated devices questionable. Unless consistent and appropriate use can be assured, up-grading the energy performance of the glazing itself is presented as a more efficient and cost-effective strategy.

Window coverings and privacy

Typical window coverings in Britain are translucent net curtains and/or opaque fabric ones. Both are usually employed to improve privacy. Net curtains prevent outsiders from looking in during the daytime. Opaque curtains offer the same protection at night. The latter may also be employed, on occasion, to intercept unwanted sunshine. But curtains are only thought of secondarily, if at all, as a means of reducing heat loss.

What is known about the use of shading and insulation devices in Britain comes from the monitoring of passive solar houses in Milton Keynes.[2] There the energy savings realised from south-facing glazing were, in practice, smaller than predicted because of occupants' use of window coverings. The solar absorption of windows was reduced by the presence of net curtains, half-drawn blinds and insulating shutters. A parallel investigation revealed that, given the particular layout of the Pennyland housing (where large windows to habitable rooms face on to public

---

[1] Swisher, J., Bishop, R. and Frey, D., 1983, Effectiveness of movable window insulation in passive solar homes, Report by the National Association of Home Builders Research Foundation to the US Department of Energy, Rockville, Maryland.

[2] Everett, R., Horton, A., Doggart, J. and Willoughby, J., 1985, Linford low energy houses, Report by the Open University Energy Research Group to the Energy Technology Support Unit, Report No. ETSU-S-1025, Harwell, Oxon.

circulation areas), residents chose the increased privacy offered by nets and curtains rather than the reduced fuel bills offered by uncluttered windows.[1]

A Dutch study of occupants' reactions to roller shutters found an unwillingness to accept them as a valid substitute for traditional window coverings such as nets or curtains.[2] Roller shutters were disliked for a range of functional, aesthetic and social reasons beyond simple expense. And these are findings which would probably be repeated in a UK study.

Designers who specify shading or insulation devices that require the intervention of occupants need to think about their design *and* use. Proper attention needs to be paid to:

- the layout of sites and the internal arrangement of houses to avoid problems of privacy in rooms or conservatories where glazing is intended to trap solar gain
- occupants' own needs and priorities (which may place less emphasis on reduced energy consumption than other aspects of their domestic lives such as avoidance of overlooking)
- occupants' understanding of how to operate devices, especially since (even if they have encountered them before) they are unlikely to have thought of them specifically as mechanisms for improving the energy balance of windows.

---

1 Miekle, S. (ed.), 1984, Social survey: Pennyland residents, Milton Keynes Development Corporation, Saxon House, Milton Keynes.

2 Dubbled, M. (ed.), 1984, Energy saving by using roller shutters, Commission of the European Communities, Brussels.

An occupants' manual

To provide occupants with information on:

- how to use shading and insulation devices and
- how to operate their heating systems without incurring energy penalties,

designers can provide them with an instruction manual.[1]

This would:

- describe the design of their home
- explain how it is meant to perform in terms of environmental conditions delivered and energy consumed
- offer advice on servicing and maintenance and
- give guidance on what to do in the case of malfunctions and repairs.

Points to remember

- **movable insulation may be less efficient and cost effective than up-grading the energy performance of glazing itself**
- **automatic or motorised shading or insulation devices are likely to be more effective than manual ones but only specify them if the system is very simple, reliable and the cost is reasonable**
- **before installing or recommending manual devices, give careful consideration to whether occupants are likely to operate them in ways compatible with reduced energy consumption**
- **if manual or motorised devices are installed, make sure that they are as convenient to use as possible**
- **provide simple and clear instructions to occupants about the operation of any movable shading or insulation devices (automatic, motorised or manual), stressing the need for appropriate daily operation if insulation is to provide an energy benefit.**

---

[1] Building Research Establishment, 1987, Pre-design and post-construction issues, Design Information Booklet 8, Passive and Hybrid Solar Low Energy Buildings, International Energy Agency, BRE, Garston, Watford

External shading devices

Shading devices can be used to exclude unwanted solar radiation. They are more effective if they are installed outside rather than inside glazing.

General requirements

The diurnal energy balance of glazing in the summer, especially daytime heat gains (as opposed to night-time losses), can be important to occupants' comfort. Excessive heat gains can be avoid by installing a shading device. The effectiveness of these depends principally on their:

- position
  and
- shading coefficient

although other factors such as orientation, exposure and the temperature difference across the window are also important.

Shading devices are most effective when they are located outside glazing since unwanted solar radiation is best intercepted and excluded before it reaches the glass.

The shading coefficient of a device is a relative measure of the amount of solar energy falling on it which is transferred to a building's interior, see page 40. So a device with a shading coefficient of 0.2, for example, means that it permits 20% of the solar radiation incident on it to pass through.

External shading devices can be:

- part of the roof
- part of the wall in which a window stands
- part of the window system itself.

For example, shading from solar radiation can be achieved using:

- roof overhangs
- sun screens or louvres
- awnings or blinds
- shutters.

The further south a building is located (in the northern hemisphere), the more important shading east and west windows becomes while the need for south-facing shading grows less so. This is because the high altitude of the summer sun in southern latitudes which results in less direct solar radiation falling on south-facing windows, see Figure 16.

Roof overhangs

South-facing windows are most effectively shaded from summer solar gains by horizontal projections, such as roof overhangs, which shade the surface of a window from direct radiation. During the winter, they allow winter sun to reach windows when solar gain is needed.

The effect of a projection depends upon its geometry. Figure 72 illustrates this for a simple overhang above a south-facing window for the winter and summer solistices. Because the sun's movement is symmetrical around June 21, south-facing horizontal projections which shade glazing in the summer will also partly shade it in cooler months (March and April) when the sun might be welcome. So, unless carefully planned to suit their specific orientation and latitude, fixed horizontal projections cut off potentially useful solar radiation in the autumn and spring.

A graphical method for establishing the depth of roof overhang required for specific roof pitches at particular latitudes can be found in the **Solar angle reference manual**.[1]

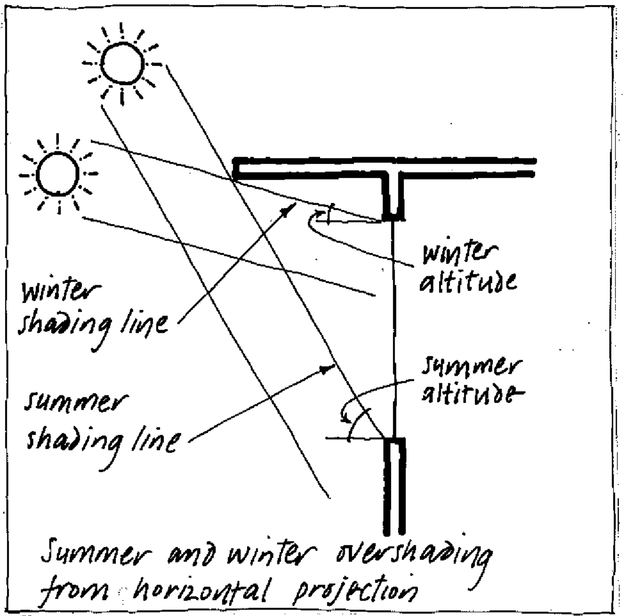


Figure 72

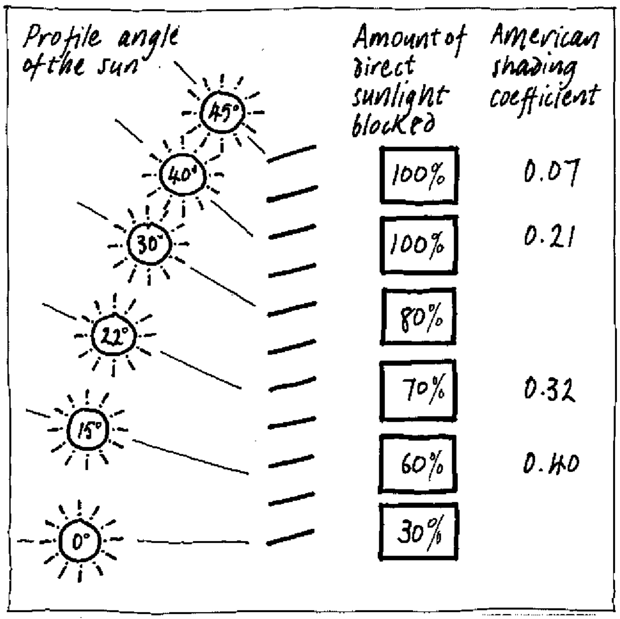


Figure 73

External louvres

The effectiveness of horizontal louvres in shading a window also depends upon their geometry. But the reflectivity of their material is important as well. Their geometry determines how high the sun must be above the horizon before the louvres block all the direct sunlight. Their reflectivity determines how much light penetrates indirectly by being reflected off the surface of the louvres, see Figure 73.

East and west-facing windows are more effectively shaded from solar gains when the sun is low in the sky by vertical projections, such as fixed or movable louvres.

If air can circulate between a shading device and the glazing, and if the latter is completely shaded from direct sunlight, then solar heat gain can be reduced by as much as 80%.[2]

---

[1] Sibson, R., 1983, Solar angle reference manual, John Wiley & Sons, New York.

[2] American Society of Heating, Refrigeration and Air Conditioning Engineers, 1967, ASHRAE Handbook of Fundamentals, ASHRAE, New York, p. 485.

Advantages of roof overhangs, sun screens and external louvres

- each reduces summer solar heat gain
- they all reduce glare on surfaces adjacent to windows, especially sun screens which block light reflected from the ground or adjacent buildings more effectively than overhangs or louvres
- sun screens and louvres offer shelter from winter winds with corresponding reduction in conduction heat losses at surface of glazing and reduction in infiltration
- they all, to some degree, reduce re-radiation to the winter night sky.

Disadvantages of roof overhangs, sun screens and external louvres

- they all require additional capital costs
- they all involve increased maintenance costs
- movable screens and louvres can reduce benefit from solar gain in winter if left in place
- screens and louvres may obstruct outward opening lights
- screens and louvres can obstruct vision:
  - vertical projections on either side of a window narrow the peripheral view. Sight lines are quickly cut off when viewer moves away from the centre of the window
  - closely spaced louvres dominate view and change scale of window. Their proportions become as important as those of the window in determining appearance.

External awnings

The capacity of a external awning to shade a window from the sun is dependent on how opaque its material is to both direct and diffuse radiation. The surface of an awning should be a light colour to minimise the amount of sunlight absorbed. Solar energy absorbed by the shading device raises its temperature. This heat can be transferred to the window in two ways

- by radiation
  and
- by raising the air temperature between the device and the glazing.

Light coloured materials are more effective because they stay cooler and transfer less heat to the window, see Figure 74.[1]

Type of awning	Orientation	
	South	West
	Percentage reduction in heat gain	
White canvas	64	77
Dark green canvas	55	72
dark green plastic	43	59

Effect of awnings on heat gain through single glazed window

Figure 74

---

[1] Hastings, R S & Crenshaw, R., 1977, Window designs to conserve energy, NBS Building Science Series 104, National Bureau of Standards, Washington DC.

To be effective, an awning must be designed to provide adequate coverage of the window area for its specific orientation. A south-facing window only needs a minimal horizontal projection to be completely shaded throughout the day in the summer. But the sides of the awning should be closed to prevent the sun from shining in from either end in the morning and afternoon, see Figure 75. East or west- facing windows need an awning which extends further down in order to provide protection from low angle sun, again especially early in the morning or late in the afternoon.

External blinds

The performance of a translucent material used in a shading device can be described in terms of its **solar gain factor** which is made up of:

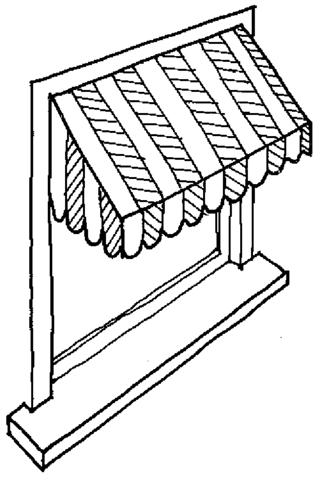
- the fraction of the solar radiation falling on a material that passes through it
  plus
- the energy absorbed by the material and then re-radiated into the building.

Solar gain factors are latitude dependent. Figure 76 gives values for the UK of various types of material.[1]

External roller blinds

These can provide shading from summer sun and reduce winter heat loss through windows. Horizontal slats on a roller can be housed at the head of a window or at the ridge of a conservatory. These can be lowered to form an opaque barrier to summer sun, blocking both direct and diffuse solar radiation. Blinds can be lowered with slats open to cut off sunlight but allow circulation of air to dissipate heat absorbed by the blind.

In the winter, they can be lowered with slats closed to trap air between the blind and the glazing to act as an additional insulating layer. At night, which is the period of greatest heat loss, closed blinds provide added insulation, decrease exposure to the cold night sky, and further reduce heat loss.



Window awning

Figure 75

Type of external shading device	Type of glazing	
	Single	Double
	Solar gain factor (typical)	
Dark green, open weave, plastic blind	0.22	0.17
Canvas roller blind	0.14	0.11
White louvred sun-breaker, blades at 45°	0.14	0.11
Dark green miniature louvre (venetian) blind	0.13	0.10

Solar gain factors for translucent materials in the UK (typical values only)

Figure 76

---

[1] Achard, , P. and Gicquel, R. (eds), 1986, European Passive Solar Handbook, Commission of the European Communities, Brussels.

External shutters

Like external blinds, external shutters have the advantage that, if occupants operate them as intended (see page 60), they can provide shade in the summer and reduce heat loss and infiltration in the winter. Like blinds, a shutter's *shading performance* depends upon how well heat absorbed by it is dissipated to outside air. Louvres which can be adjusted to block the sun but allow air to circulate improve shading performance. They are reported to be 30% more effective than similar internal shading devices.[1]

Winter heat loss through a window with closed shutters is reduced because the air space between shutter and glass provides additional resistance to outward heat flow. A shutter's *insulating performance* depends on the air tightness of the space between it and the glazing it covers. This conflicts with shading requirements. Pivoting louvres which can be opened and closed meet both needs. However even fixed open louvres reduce winter heat loss by

- sheltering the insulating film of air at the outer surface of the glass from the scouring action of the wind
  and
- reducing infiltration through window cracks.

Advantages of external awnings, blinds and shutters

- they are all proven, practical devices, used widely throughout the rest of Europe
- if designed effectively and used appropriately, they can reduce summer heat gain and winter night-time heat loss
- they all offer opportunities for independent control of each window to achieve appropriate levels of shading, lighting and view - including partial shading of a window or portion of a room
- blinds offer increased privacy and shutters can provide increased security as well

Disadvantages of external awnings, blinds and shutters

- they all involve increased capital costs
- they all incur maintenance costs
- closed blinds and shutters can delay egress in the event of fire
- they are all dependent on occupants for proper operation - so the consequences of possible non-use or mis-use have to be considered.
- except for automated or mechanically operated varieties, they all require external operation

---

[1] Achard, P. & Gicquel, R. (eds), 1986, European Passive Solar Handbook, Commission of the European Communities, Brussels.

Internal shading and insulation devices

Traditional window coverings, such as curtains and blinds, are not an effective way of excluding unwanted solar gain. But they can help reduce night time heat loss.

Internal shading devices

External shading devices are more effective than internal ones. When the sun shines on a shading device inside glazing, a proportion of its energy is transmitted or absorbed and then re-radiated to other room surfaces. While the uncomfortable experience of direct sunshine may be avoided, unwanted heat gain within the room still occurs.

The effectiveness of an internal device is mainly determined by the solar energy which is:

- reflected
- absorbed
  and
- transmitted.

A increased proportion of unwanted solar radiation can be rejected by an internal shading device if its surface facing the glazing has a low emissivity. This will then reflect near infrared radiation which the glazing will re-transmit to the outside.

During the heating season, shading or insulation devices should be opened when glazing is sunlit to allow solar radiation into the interior. Where devices are left closed, they will absorb the heat, much of which is then re-radiated straight back to the glass.

During daylight hours in the heating season, shading or insulating devices should be stored clear of the window area so that penetration of solar radiation is not impeded. Even curtains (whose primary purpose is not to alter a window's energy balance but to provide privacy) are best fitted to a track which allows them to be opened clear of the window in order to allow all available sunlight into the room if and when it is wanted.

Internal insulation devices

Although inefficient at preventing undesired solar gain, movable window insulation can be a cheap and effective method of reducing heat lost through glazing by:

- conduction
  and
- air infiltration.

Movable insulation reduces conductive losses by trapping a volume of air which is a poor conductor of heat, see Figure 77. However, unless cracks around glazing are tightly sealed, heat is also carried to the outside by air escaping around the frame.

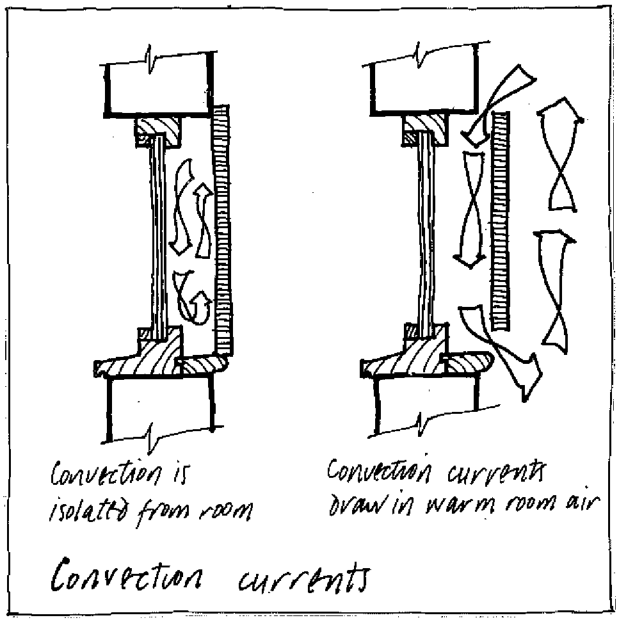


Figure 77

Infiltration losses can be considerable. For example, it has been estimated that a poorly fitting single glazed window can lose twice as much heat by infiltration as through its glazed area by conduction.[1]

The amount of heat lost by such air leakage depends on

- the size of the cracks around the frame
  and
- external wind speed and direction.

Computer simulation suggests that, in a typical house in the UK, 40% of all infiltration losses are due to leakage around closed windows.[1]

Weatherstripping is an effective method of reducing infiltration, see page 38. Movable insulation which has well sealed edges can also reduce infiltration losses if it fits tightly between window reveals. The effect of a trapped volume of air is increased if the edges of a device are sealed since this prevents convection currents inside the room from circulating across the window. Such insulation should be put in place in the evenings and throughout the night since these are significant periods of heat loss. If left open, insulating devices may cause part of the wall they cover to remain cool and result in condensation.

Nets, lightweight and insulating curtains

Little is known about the effect of the use of curtains in occupied houses on comfort conditions or energy consumption. But their performance in a test-cell has been investigated in Britain.[1] This

---

[1] Ruyssevelt, P. & Littler, J., 1985, Movable window insulation, School of Building, Polytechnic of Central London, Final Report to the Commission of European Communities, EUR 9996 EN, Brussels.

study found that, when closed, lightweight curtains are ineffective for shading purposes - almost half the solar radiation falling on glazing is transmitted into the room since the curtain operates as a solar collector, see Figure 78.

Nor are net curtains an effective means of reducing heat loss. The material in them typically fills less than 30% of the window area which they cover. As a result, they reduce heat loss through a window by radiative transfer by less than 10%, see Figure 79.

These test cell measurements suggest that drawing curtains at night can have a very significant effect on window heat loss. They show that lightweight curtains can reduce it by nearly 20%, while heavyweight ones (with a thermal lining) can do so by 40%. However, North American studies suggest that, when closed, both insulated and un-insulated curtains have similar effects on a window's rate of heat loss *if their edges are not sealed*. Figure 80 shows measured results from a North American test-cell study of the 'winter effectiveness' - ie. the percentage reduction in heating costs - of three types of curtains, including one foam-backed variety sold as 'energy saving'.[2]

Results for each type of curtain were similarly poor, ie. only marginally better than a bare window. With double glazing their 'winter effectiveness' was even less. It was concluded that, because curtains hang so loosely in front of a window, cold and heated air can easily move around them. A heat- shrunk plastic vinyl film (0.15 mm thick) was much more effective since it sealed more efficiently. Similar results have since been found in another North American study where measurements were made in an unoccupied room of a house.[3]

Type of curtain	Shading coefficient
Net curtain (fine weave)	0.76
Net curtain (wide weave)	0.85
Lightweight curtain (permanently open)	0.99
Lightweight curtain (open 10 00 - 18 00)	0.63
Lightweight curtain (permanently closed)	0.49

Measured shading coefficients of curtains: (values given for single glazed window, room with white interior)

Figure 78

Type of curtain	Percentage reduction
Net curtain (fine weave)	2
Net curtain (wide weave)	2
Night curtain (lightweight)	17
Night curtain (heavyweight)	41

Percentage reduction in heat loss through window with different types of curtain, (expressed as percentage of heat loss through uncovered single glazed window)

Figure 79

Type of curtain	Percentage reduction in heating costs
100% rayon sheer curtain	1 to 5
67% rayon / 33% acetate curtain	1 to 5
64% cotton / 36% poly (foam backed) curtain	1 to 5
Sealed 0.15mm vinyl film	37 to 43

Winter effectiveness of different types of curtain, (refrigerated cold room used to simulate winter conditions, curtains covering single glazed window)

Figure 80

1 Energy Monitoring Company Ltd, 1987, Studies in passive solar test cells, Test cell studies 1: window coverings, report to Energy Technology Support Unit, reference ETSU-S-1162.

2 Tomany, R., 1982, The measurement of window treatment effectiveness in reducing residential heating and cooling costs. ASHRAE Trans, 88 (2): 235-248.

3 Nicol, K., 1986, The thermal effectiveness of various types of window covering, Energy and Buildings, 9:231-237.

Advantages of nets and curtains

- widely accepted and conform to existing cultural expectations about window coverings and their use
- increased privacy through reduced over-looking
- (relative but disputed) improvements in summer and winter comfort conditions possible when opaque curtains closed
- improved control of glare

Disadvantages of nets and curtains

- common desire for permanent presence of airy, open weave covering at window conflicts with the thermal effectiveness of curtains in both summer shading and winter insulation
  - nets and opaque curtains across window area during sunlit periods reduce absorption of solar radiation yet are ineffectual in preventing summer overheating or winter heat loss
    and
  - the insulating capacity of curtains without sealed edges is disputed.

Internal blinds

Sunlight absorbed by a blind raises its temperature and this heat is then dissipated into the room by:

- radiation to room surfaces
  and
- convection of room air in contact with the warm surface of the blind.

The colour of a blind and and its degree of opaqueness affect its performance, see Figure 81.[1]

The effectiveness of roller blinds, measured in terms of their shading coefficients when used in conjuction with different types of glazing is shown in Figure 82.[1]

Blind characteristics	Percentage of radiation		
	transmitted	reflected	absorbed
Translucent, light colour	25	60	15
Opaque, white	0	80	20
Opaque, dark	0	12	88

The shading performance of internal blinds

Figure 81

Glass type	Blind characteristics		
	Translucent, light colour	Opaque, white	Opaque, dark
	Shading coefficient		
Single clear	0.39	0.25	0.59
Double clear	0.37	0.25	0.60
Double, heat-absorbing	0.30	0.22	0.40

American shading coefficients of roller blinds

Figure 82

---

[1] Hastings, S R & Crenshaw, R., 1977, Window design strategies to conserve energy, NBS Building Science Series 104, National Bureau of Standards, Washington DC.

Venetian blinds

Venetian blinds can be used for three purposes

- to reflect summer sun back out through a window
- to reflect daylight on to a ceiling to provide deeper light penetration into a room
- to prevent overlooking.

These uses are not necessarily compatible. For each, the slats of the blind may need to be set at a different angle.

The extent to which venetian blinds act as sun-shades also depends on their colour. Figure 83 shows the performance of two different coloured blinds with their slats set at 45° when the sun is at right angles to the slats.[1]

North American figures for the effectiveness of venetian blinds, measured in terms of their shading coefficients when used in conjunction with different types of glazing, are shown in Figure 84.[1]

These differ from figures for the performance of venetian blinds as measured in a British test-cell study, see Figure 85.[2]

Despite their differences, both the North American and British figures suggest that venetian blinds are not particularly effective as sun-shades, especially when closed. In this position, they act as a solar collector. Air trapped between the blind and the window is heated, rises and then flows into the room. Nor are venetian blinds more effective at reducing heat loss. Their performance here is on a par with net curtains, reducing heat loss by about 10% even when closed.[2]

	Percentage of radiation		
	transmitted	reflected	absorbed
Light coloured (horizontal)	5	55	40
Medium coloured (horizontal)	5	35	60

The shading performance of venetian blinds

Figure 83

Glass type	Blind characteristics	
	Light, horizontal	Medium horizontal
	Shading coefficient	
Single clear	0.55	0.64
Double clear	0.51	0.57
Double heat-absorbing	0.36	0.39

American shading coefficients of venetian blinds

Figure 84

Type of blind	Shading coefficient
Venetian blind (open)	0.83
Venetian blind (closed)	0.56

British measured shading coefficients of venetian blinds (values given for single glazed window, room with white interior, colour of blind unspecified)

Figure 85

---

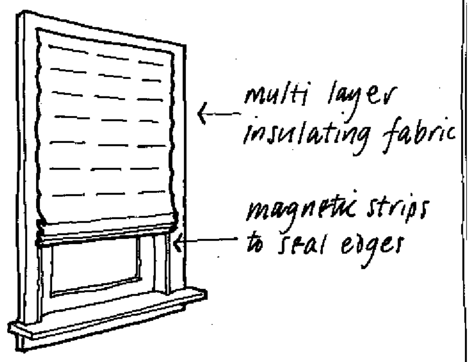
1 Hastings, S R & Crenshaw, R., 1977, Window design strategies to conserve energy, NBS Building Science Series 104, National Bureau of Standards, Washington DC.

2 Energy Monitoring Company Ltd, 1987, Studies in passive solar test cells, Test cell studies 1: Solar distribution, solar lost and window coverings, report to Energy Technology Support Unit, reference ETSU-S-1162.

Insulating blinds

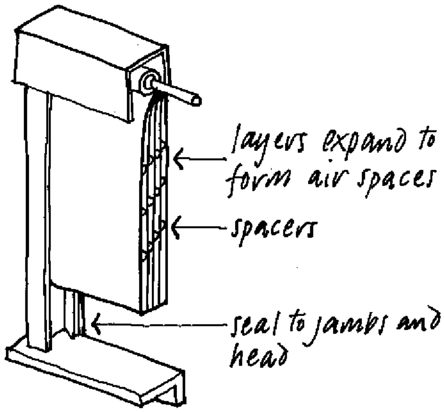
Many versions of this type of blind are marketed in the USA but few products are currently available in the UK. The Roman blind, see Figure 86, has magnetic strips to seal the edge of the blind. Where this is done, a U-value of 0.8 has been claimed when used in conjunction with single glazing.[1] Multi-layer blinds are also available, often with low emissivity surfaces, which require greater storage space when not in use, see Figure 87. Where such systems have sealed edges, a U-value of 0.4 with single glazing has been claimed.[1] Do-it-yourself quilted roller blinds, with an aluminised layer in the centre of the material, require a large storage area at the window head. These blinds use a crude sealing system of timber battens or sprung hinges.[1]

Computer simulations suggest that a double layered blind, incorporating two low emissivity surfaces and effective edge sealing, is most effective in reducing energy consumption in the UK.[1] These simulations also showed that it is difficult to achieve energy savings with window insulation devices that do not offer a means of edge sealing.



Roman blind

Figure 86



Expanding multi-layer blind

Figure 87

---

[1] Ruyssevelt, P. & Littler, J., 1985, Movable window insulation, School of Building, Polytechnic of Central London, Final Report to the Commission of European Communities, EUR 9996 EN, Brussels, p. 14.

Advantages of internal roller, venetian and insulating blinds

- most are simple, unobtrusive devices which do not complicate the appearance of a window
- they increase protection from daytime overlooking; night- time privacy is dependent on opaqueness of blind material because of interior lighting
- depending on type specified, they need minimal space for storage with minimal obstruction of window area
- they can be partially lowered to eliminate sunshine from only one portion of a room
- venetian blinds are good for interception of direct sunlight and glare and offer variable control of daylight.

Disadvantages of internal roller, venetian and insulating blinds

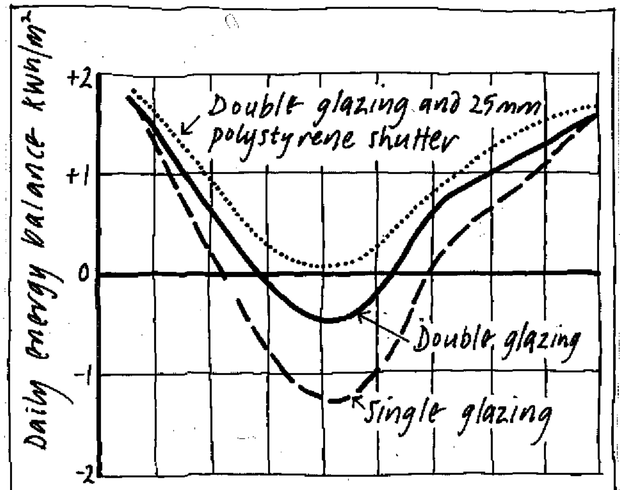
- simultaneous view out and shading/insulation is not possible, except with venetian blinds
- impeded ventilation possible with blinds lowered
- impeded access to window catches with blinds lowered
- cleaning can be tedious, especially with venetian blinds
- maintenance required for operating mechanisms

Internal shutters

An internal insulating shutter can have a significant effect on the energy balance of a window. Figure 88 shows a computer prediction of the effect of a 25mm polystrene shutter, closed during the hours of darkness. With such a shutter fitted, a south-facing double glazed window becomes a source of net energy gain throughout every month of the year. Similarly shuttered, a single glazed window has an energy balance which equals that of unshuttered double glazing.[1]

However, while the principle behind shutters is simple and their operation is technically sound, their success in use depends upon the willing and appropriate efforts of occupants, see page 60.

There is little monitored evidence of the effect of internal shutters in occupied houses. Figures are available from tests conducted on an unoccupied house in Canada where a set of shutters cut from 25mm polystrene and without any special edge sealing were placed in position at 18.00 each night and removed at 08.30 each morning for 18 days.[2] When the outside temperature was 0°C, the shutters reduced the energy consumed to heat the house by 12%.



Energy balance through unobstructed south facing glazing, at Bracknell, showing effect of closing shutters at night

Figure 88

---

[1] Everett, R., 1980, Passive solar in Milton Keynes, Energy Research Group, Report ERG 031, Open University, Milton Keynes, page 25.

[2] Nicol, K., 1986, The thermal effectiveness of various types of window covering, Energy and Buildings, 9:231-237.

Although internal shutters hold out the promise of improved comfort and reduced fuel consumption, in practice, their use is problematic.

Internal shutters come in three forms:

- push-in
- bi-fold
- roller.

Push-in shutters are the simplest, cheapest, have to be tailor-made, and are inconvenient to store when not in use, see Figure 89. A polyisocynurate insulating board with a compressable edge seal has been developed in Denmark[1] where the building regulations require a high degree of thermal integrity for the building envelope.

Bi-fold shutters fold away, concertina fashion, see Figure 90. While easier to store, it is more difficult to achieve an effective seal for each panel of the blinds when placed against the window.

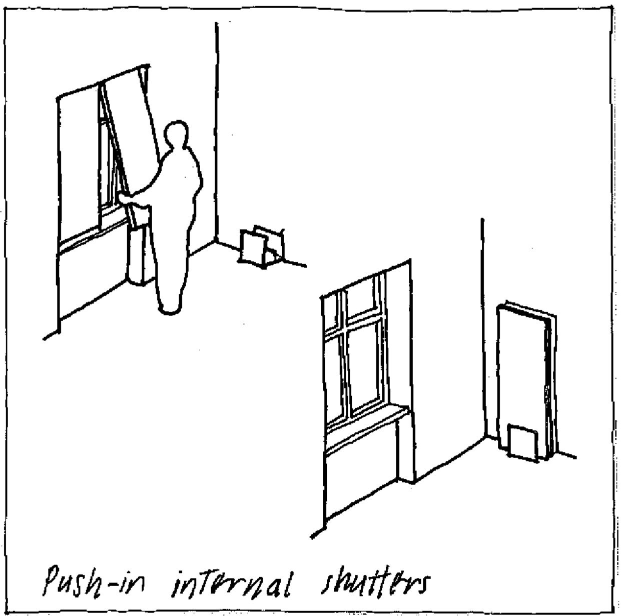


Figure 89

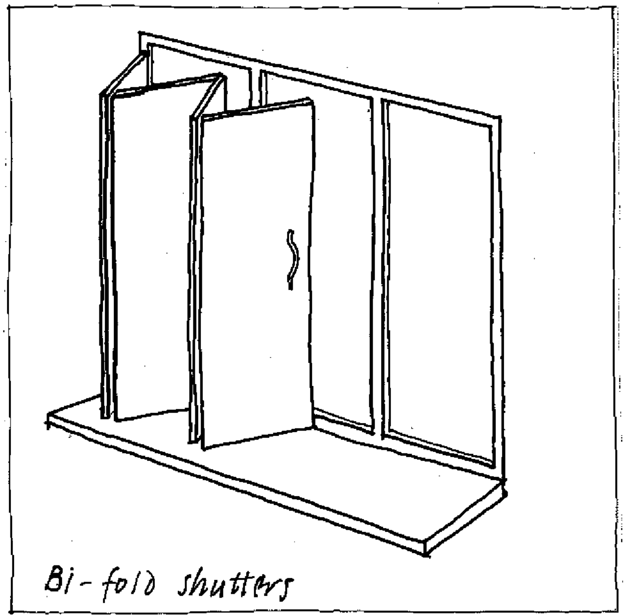


Figure 90

---

[1] Byberg, M. et al, 1985, Insulated shutters, Commission of the European Communities, Brussels.

Roller shutters are quite common in European houses though they are usually installed to provide shading or security, not insulation. The shutter illustrated, see **Figure 91**, comes from the USA. As is clear from the illustration, it is both expensive and requires a large storage space at the head of the window.

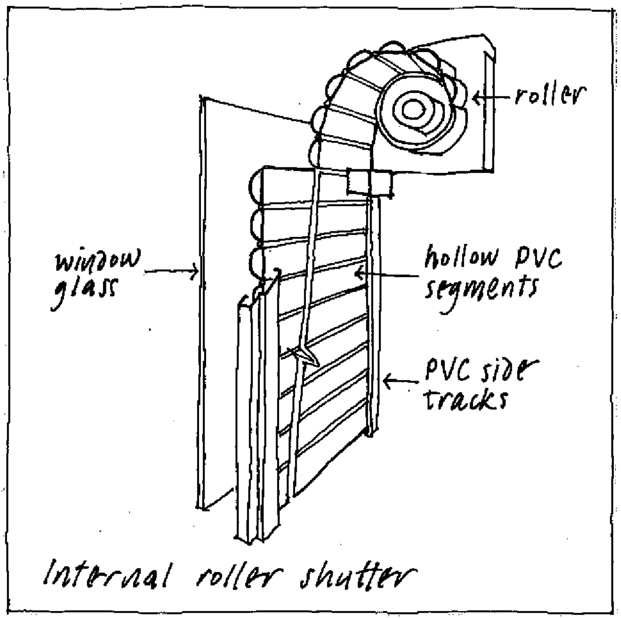


Figure 91

Advantages of internal shutters

- they do not affect the external appearance of a house
- they improve insulation and security
- shutters are protected against the weather and so can be of lightweight construction
- manual operation from the inside is possible.

Disadvantages of internal shutters

- they incur increased capital costs
- they need maintenance
- they considerably alter the internal appearance of windows
- they are dependent on occupants for effective operation
- depending on type, they potentially limit the use of:
  - furniture against the outside wall
  - the window sill
  - curtains or other more conventional window coverings
- they can cause severe condensation on window pane if the shutter is not air-tight.

Thermal mass and window design

In the past, thermal mass has often been included as a means of storing surplus energy in buildings designed to exploit solar radiation. Now it is thought more important as a means of moderating daily temperature swings.

What is thermal mass?

Thermal mass is a way of referring to the heat storing capacity of materials used in building construction. Its identifying characteristic is the ability to absorb and later release heat. Any physical material - solid, liquid or gas - has this ability to some degree. The storage capacity of a wide range of materials used in construction, expressed in terms of their specific heat (J/kg°K) and density (kg/m^3), is given in Figure 92.

The ability of a material to store the solar energy which falls on it also depends on its surface absorptance and its emissivity. The absorptance of solar radiation depends not on colour but on the molecular structure of a material's surface. Polished metals have low absorptances and low emissivities (typically between 0.1 to 0.15) in the far-infrared region of the spectrum. Most other building materials, including glass, have high emissivities and absorptances (typically 0.9 to 0.95) in the far-infrared region, regardless of colour. The solar absorptance and emissivity of a range of materials and surface finishes used in building construction are given in Figure 93.

The thickness of a material used also affects its ability to store heat. The layers of the material closest to an irradiated surface participate most in the process of heat accumulation.

The thermal response rate of materials

Lightweight materials do not store energy very well. When exposed to even a small quantity of solar energy, their temperature increases rapidly because they have a low volumetric thermal capacity. Lightweight materials then transfer heat gained from solar radiation to a room by convection from their (relatively) hot surfaces. So materials with a low thermal capacity should not be located where solar radiation will fall directly upon them or over-heating may result.

Heavier materials, with higher thermal capacities, can absorb greater amounts of solar radiation. So this type of material can safely be placed in direct sunlight without risk of over-heating occurring.

Material	Density kg/m^3	Specific heat J/kg °K
Granite	2600	900
Marble	2500	800
Concrete	2100	840
Brick	1700	800
Sand cement render	1570	1000
Gypsum plaster	1120	1000
Plasterboard	950	820
Water	1000	4186
Timber	600	1200
Lightw't conc. block	600	1000
Linoleum	1600	2000
Expanded polystyrene	15	1400

Figure 92

Material	Absorptivity
Optical flat black paint	0.98
Concrete, black	0.91
Concrete, brown	0.85
Concrete, uncoloured	0.65
Red brick	0.70
Light buff brick	0.60
Paint - black	0.90
- green	0.70
- aluminium	0.50
- white	0.30
- white gloss	0.25
- silver	0.21

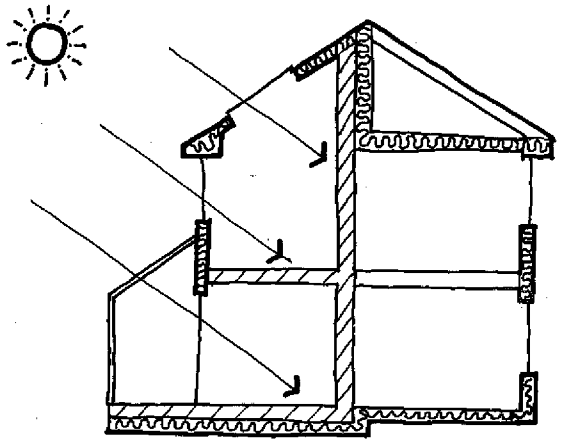
Absorptivity of solar radiation of various surfaces

Figure 93

Buildings of heavyweight construction (heavy masonry or concrete with external insulation) warm up and cool down slowly. They are said to have a slow thermal response.

Lightweight buildings (timber framed construction with insulation located within the frame or internally) have a short response time, warming up and cooling down quickly.

Neither heavyweight nor lightweight construction is necessarily the best strategy for reducing energy consumption. In most UK housing, a balance between the two would be advantageous. Lightweight materials can be used for a fast thermal response in areas which receive no solar energy or in rooms which are only intermittently used. Heavier materials are more appropriately used in positions where they can be used to absorb incoming solar radiation, see Figure 94.



Thermal mass located to receive direct solar radiation

Figure 94

The purpose of thermal mass

Thermal mass can be useful in houses for two reasons

- to moderate temperature swings which result from sudden peaks in solar or incidental gains
- to store surplus heat for periods when solar or incidental gains are reduced and auxiliary heating is required.

In the UK, where intermittent heating is common, computer simulations conducted by BRE suggest that the primary function of thermal mass is to moderate temperature swings rather than to store solar energy.[1]

Until recently, it was believed that the more thermal mass put into a house in which solar gains were to be exploited, the better its performance would be. So much of the advice offered in literature on passive solar house design over the past decade has focussed on where and how to include more thermal mass than is found in conventional housing. In Britain, this no longer accepted as necessary or even desirable. Now, on the contrary, it is thought that inclusion of excess thermal mass can lead to increased heating bills and reduced comfort.

---

[1] Bloomfield, D., 1987, IEA Task VIII - Documentation of parametric study, Building Research Establishment, Garston, Watford.

It appears that only the surface layer of thermal mass plays a role in *diurnal* heat control in the UK. Monitoring of occupied houses at Abertrydwr revealed that only about the top 10 mm of plasterboard underwent temperature changes in a space exposed to solar radiation. Similar results were found in the monitoring conducted at Woodbridge Cottage.[1]

These findings suggest that in the UK, if conventional masonry construction and window areas are employed (see page 55), then the mass inherent in large areas of plastered internal walls is sufficient to control *diurnal* temperature swings during the heating season.

Where particularly lightweight forms of construction (such as timber frame) are employed, especially in conjunction with large areas of southerly-facing glazing, additional thermal mass will need to be provided.

Whatever the form of construction employed, however, summertime overheating is more fittingly dealt with by shading and ventilation strategies. Solar radiation is best dealt with before it penetrates the external envelope, not afterwards.

The dangers of too little and too much thermal mass

It has been estimated that, on a clear sunny day during the heating season, solar energy can enter a well-insulated building with large south-facing areas of glazing four times faster than the rate at which it is needed.[2] Some of this energy has to be stored if air temperatures are to be kept at comfortable levels. With too little thermal mass, over- heating may occur.

---

[1] Littler, J. & Ruyssevelt, P., 1986, Role of thermal mass in UK housing, in The efficient use of energy in buildings, 2nd UK-ISES Conference (C46), UK-ISES, London.

[2] Lebens, R. & Myer, A. (eds), 1983, Draft CEC Passive Solar Handbook, Commission of the European Communities, Brussels, p. 102. The text was changed in the 1986 Preliminary Edition, edited by Achard and Gicquel, to read "the solar energy gained may largely exceed the heat demand" (page 4.15).

Computer simulations also suggest that, in a well-insulated house, there are likely to be few days in the heating season when solar gains exceed the demand for heating *throughout* the dwelling.[1] Adding too much thermal mass may increase fuel consumption. Heat from the heating system will be absorbed by the thermal mass in the mornings before the sun (if it comes out) can have any effect. So too much thermal mass will also have important consequences for comfort and costs:

- the low temperature of the thermal mass during the warm-up period when the heating first comes on will give rise to low radiant temperatures in a space
- occupants will need compensatory higher than normal air temperatures to feel comfortable
- for both these reasons, running costs in the form of the annual heating bill will increase
- capital costs will be increased as well because during the warm-up period, the peak demand placed on the heating system will be greater - so a larger heating plant than necessary will have to be installed
- outside the warm-up period, the heating plant will operate at low efficiency and this too will increase running costs.

Where to locate thermal mass

The best way to get solar heat into mass is to allow the sun to shine directly on it. It gets much hotter this way than if it is merely in contact with warm air. Walls and floors are the most convenient place to locate thermal mass for storage purposes.

Walls used as thermal mass do not necessarily have to be directly sunlit since they will be heated by scattered sunlight and by warmed air in the room by convection. But they do have to be located in the space that receives radiation to perform correctly.

Where the mass in a floor is to be used for storage purposes, direct sunlight is required for proper charging.[2] This imposes limitations on the kinds of floor finishes and coverings that can be used on floors intended to act as thermal mass. Carpets, for instance, are inappropriate because they insulate the floor from solar radiation. Appropriate constructions are illustrated in Figure 95.

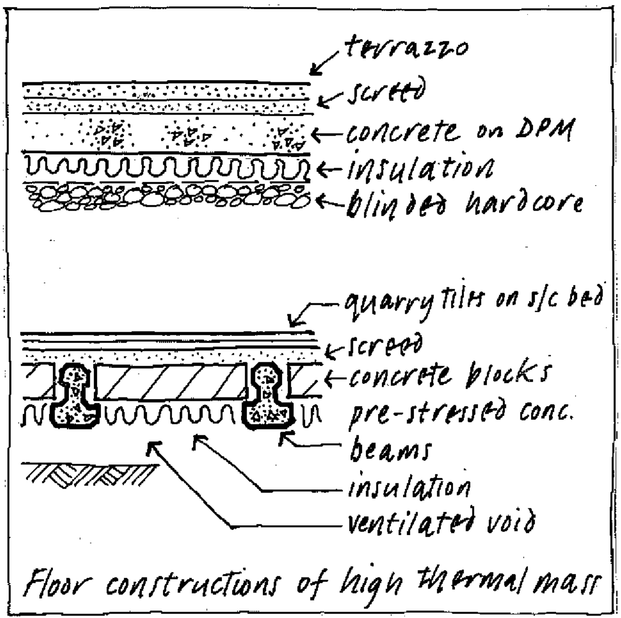


Figure 95

---

[1] Littler, J. and Ruyssevelt, P., 1986, Role of thermal mass in UK housing, in The efficient use of energy in buildings, 2nd UK-ISES Conference (C46), UK-ISES, London.

[2] Architectural Energy Corporation, 1986, Design guidelines for energy efficient passive solar homes, AEC, Boulder, Colorado.

The thermal mass provided by walls and floors can be divided into three types:

- primary, those parts of walls and floors directly sunlit
- secondary, those areas not directly sunlit but to which heat can be transferred by radiation from those that are
and
- remote, areas hidden from view of primary and secondary ones to which heat transfer occurs by convection only.

The last of these is the least effective way of providing thermal mass.

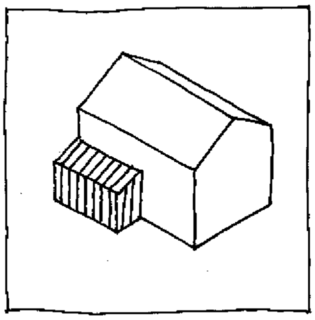
Where it is possible to spread primary thermal mass over most of the surfaces in a room, then their temperature will rise less and so fluctuations in room air temperature will be reduced.

Points to remember

- the main purpose of thermal mass in UK houses is to moderate diurnal temperature swings, not to store surplus solar energy until it is needed. The mass inherent in plastered lightweight blockwork should be sufficient for this purpose
- plasterboard on stud work (inner skin of external walls or internal partitions) may not be sufficient (in sunlit rooms with large areas of unshaded glazing) to moderate temperature swings or avoid overheating
- use of a floor as thermal mass places limits on the forms of construction and finishes which can be used without undermining its performance
- proper provision for shading and ventilation is a better way of avoiding summer-time overheating than dependence on large amounts of thermal mass
- excess thermal mass can lead to increased capital costs, poor comfort conditions, and higher than necessary energy consumption

SECTION 5

Conservatories



Conservatories in energy efficient design

Conservatories offer an opportunity to combine economical seasonal accommodation with energy savings. Achieving this combination in practice will demand careful balancing of environmental conditions with an acceptance of limitations on use.

What is a conservatory?

A conservatory is a predominantly glazed enclosure accessible directly from a dwelling but physically separated from it by some combination of door, wall and/or window.

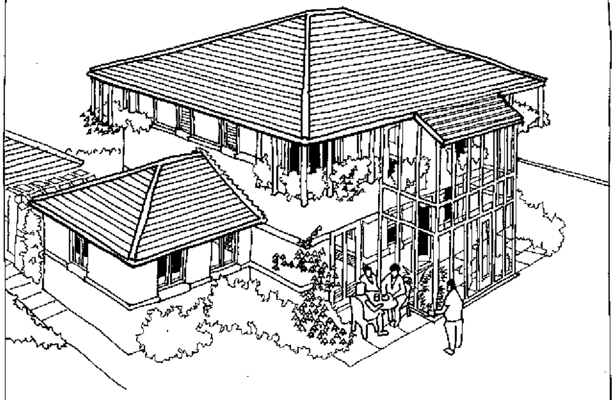
To be classified as a conservatory for the purposes of the Building Regulations, a conservatory must have a transparent or translucent roof. If it does, it may be exempt from some of the Regulations, see page 110. If instead the roof is opaque, these exemptions will no longer apply.

There are three broad ways in which conservatories can be used:

- as an attached greenhouse
- as habitable accommodation
  - for living purposes
  - for access or circulation
  - for storage
- as an energy saving feature.

These uses are not fully compatible. An unheated conservatory, which is used as habitable accommodation only when ambient environmental conditions allow, can reduce energy consumption. But it is not suitable as a greenhouse for those kinds of plants which need to be protected against low winter temperatures. If a conservatory is heated to protect plants, or so that it can be used as habitable accommodation throughout the year, then this will lead to increased fuel consumption.

So conservatories occupy an ambiguous place in energy efficient design. They are highly visible architectural features which have been incorporated in many houses that are intended to be energy efficient by exploiting solar gain to reduce auxiliary heating demand. But they are also commonly depicted as a bright and luxurious spaces, fully furnished complete with exotic plants, which can accommodate the full range of living functions. If heated, conservatories can easily become a symbol of conspicuous consumption.



The Solstice, architects Phippen Randall & Parkes

Figure 96

Figure 97

The ambiguity which surrounds the contribution of conservatories to energy saving arises because of their glazed fabric. This offers a degree of environmental control over precipitation, air movement, humidity, and temperature. But this control is less than is provided by the main fabric of the house. Glass is a poor insulant and it allows large conductive heat losses. It also leads, because of the greenhouse effect, to large solar gains. These can raise the temperature dramatically within a conservatory at times of direct sunshine. It is the thermal performance of glazing which results in both advangages and disadvantages associated with the conservatory.

Advantages of a conservatory

- an attractive architectural feature with a wide range of potential configurations and purposes
- can be quick and cheap to erect, providing relatively inexpensive additional accommodation
- possible energy saving through reduced fabric and ventilation losses, and solar gaines.

Disadvantages of a conservatory

- internal temperatures vary widely both diurnally and seasonally
- if unheated, will not be habitable during the winter months and may not be suitable for nurturing plants
- heating to achieve comfort conditions in the winter, for people or plants, carries a heavy energy penalty
- cooling, to achieving comfort conditions in the summer, for people or plants, requires the use of shading devices and ventilation control to avoid overheating
- condensation may be a problem.

Conservatories as attached greenhouses

Many people will use their conservatories for growing plants. If they are to do so successfully, this will affect both the environmental conditions they need to maintain in the conservatory and their home's fuel consumption.

Environmental conditions in greenhouses

Historically, conservatories were devised as spaces for nurturing plants, not for housing people.[1] So the environmental conditions in them are like those which occur in greenhouses. These are typically used:

- to enable controlled propagation of seeds
- to extend the growing season
- to preserve valuable plants through the winter months
- to provide a protected environment for non-native or exotic plants and flowers.

Conservatories have an energy and temperature advantage over a detached greenhouse. They benefit from heat losses from the house which keep them warm. This marginally increases their potential for plant conservation. But for more extensive use as a greenhouse, a conservatory has to be heated.

The environmental conditions that can be maintained in greenhouses fall into four types:

- **the alpine house - unheated**
- **the cool greenhouse - minimum temperature about 6°C**
- **the intermediate greenhouse - minimum about 10°C**
- **the warm greenhouse - minimum about 15°C.**

---

[1] Huxley, A., 1983, An illustrated history of gardening, Macmillan, London.

Energy consumption in attached greenhouses

Figure 98 shows the temperature requirements of each type and the kinds of plants that can be grown in them. The energy consumption associated with these requirements has been predicted by computer simulation for a 13.5m^2 conservatory attached to standard semi-detached house.[2] The results show that the cost of heating the conservatory to 15°C is half as much as heating the main house. It is clear that using heating appliances in a conservatory, or allowing warm air from the house to leak into it through an open door or window, carries a very heavy energy penalty.

Type of greenhouse	Alpine house	Cool, half hardy	Intermediate	Warm
Suitable plant types	alpine plants	tender plants some tropical plants	most house plants	tropical plants
Minimum temperature	unheated (1)	about 6°C	about 10°C	about 15°C
Maximum temperature	— (2)	15 - 30°C (2)	16 - 27°C (2)	— (2)
Length of heating season	none	Dec. to Feb.	Oct. to April	Sept. to May
Auxiliary conservatory heating for example in Fig. 104	nil	311 kWh	1220 kWh	4752 kWh
Auxiliary house heating for example in Figure 104	9660 kWh	9480 kWh	9364 kWh	9187 kWh

Notes 1. It is generally thought that the temperature in an attached conservatory will not fall below freezing, despite outside temperatures down to -5°C.
2. In all types of greenhouse it is essential to control maximum summer temps.

Figure 98

Points to remember

- the minimum temperatures required by many plant types cannot be achieved without heating the conservatory
- the maximum temperatures tolerated by plants can mean ventilation has to be introduced in conservatories at temperatures lower than is compatible with optimising solar gains
- water for plants and associated high levels of humidity reduce the desirability of extracting air from the conservatory into the rest of the house, owing to the risk of condensation
- plants reduce the solar gain of a conservatory by blocking sunlight that would be absorbed as heat on striking the floor or dividing wall. They also transpire, causing heat in the conservatory to be used for moisture evaporation - this may be a useful cooling mechanism in the summer.

---

[2] Penz, F., 1986, The energy implications of keeping plants in conservatories, Eclipse Research Consultants, Cambridge.

Conservatories as living space

Many people will want to use their conservatories as extensions to their living space. Depending on the times of year at which they do so, this use will affect both the environmental conditions they need to maintain in the conservatory and their home's fuel consumption.

Environmental conditions in conservatories

Certain factors will influence the extent to which conservatories can be used as habitable accommodation:

- large diurnal temperature swings
- large seasonal temperature range
- direct sunlight and risk of glare
- condensation risks
- high infiltration rates - air leakage
- watertightness - especially in driving rain.

Other factors also need to be taken into account:

- security
- privacy
- safety of glass, glass fixings, and frame
- maintenance and cleaning.

Awareness of these factors at the design stage is vital. If they are understood then either

- users can be advised of the environmental conditions that are likely to occur at various times of the day and year
  or
- designers can tailor the conservatory to deliver those environmental conditions particularly suited to intended uses.

Conservatories as storage or circulation areas

Items stored in conservatories must be able to withstand the range of expected environmental conditions described below.

For some occupants, temperatures outside the normal comfort range may be acceptable in access or circulation areas, such as entrance lobbies. For others, especially the elderly or infirm, they will not. Designers need to give careful consideration to the kinds of people who are likely to live in their schemes before deciding to use conservatories for storage or circulation. In all cases, privacy and security need to be maintained.

Comfort conditions in conservatories

In a conservatory which is used primarily as living space, habitable for as much of the year as possible, the emphasis should be on achieving acceptable internal comfort conditions. These will determine the practical uses to which a conservatory can be put and its amenity value as living space.

Internal conditions: measured results

Very little data has been collected on comfort conditions in conservatories. In a monitoring exercise conducted by the Royal College of Art, a single glazed conservatory attached to a refurbished terraced house in Milton Keynes was investigated.[1] Temperatures in the conservatory were recorded over the period from October 1980 to December 1981. Figure 99 shows the house and conservatory. Figure 100 records the monthly average air temperatures. The conservatory temperature remained above ambient but below living room temperature. Figure 101 records temperatures over a period of four days in April 1981. It illustrates the extremely high temperatures that can be reached in conservatories during periods with high levels of insolation. It also reveals the wide diurnal swing in temperature from 40°C *maximum* to 10°C *minimum*.

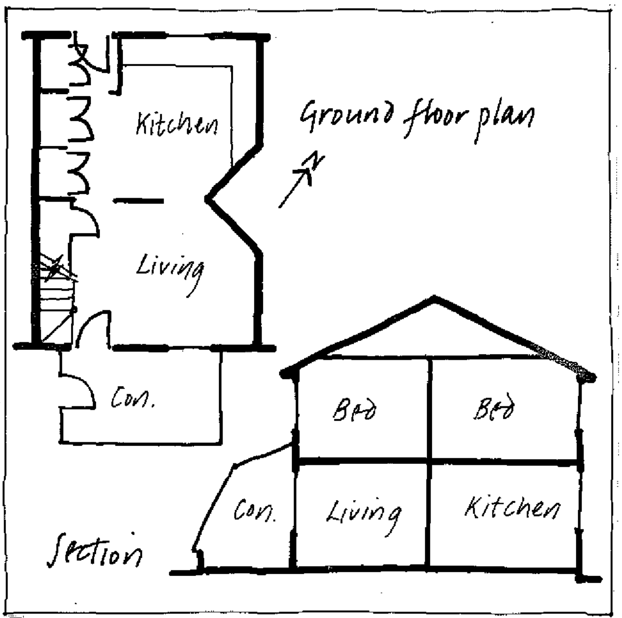
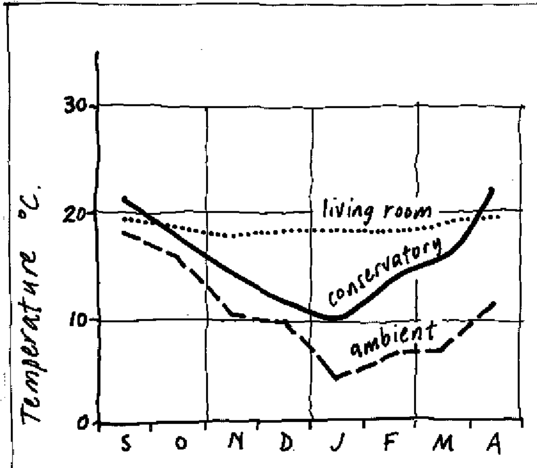
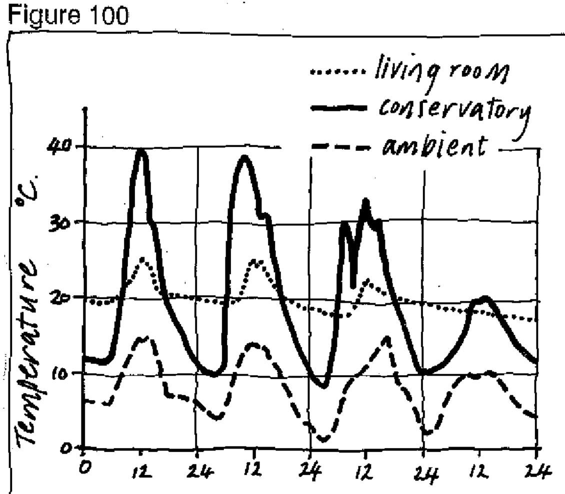


Figure 99



Monthly mean air temperature 1979-80

Figure 100



Temperatures recorded during the period 16 to 19 April 1981

Figure 101

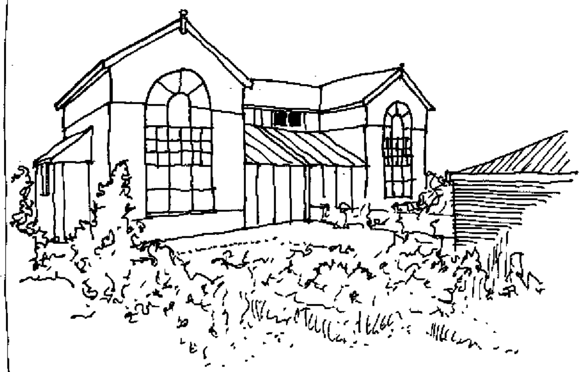
---

[1] Ford, B, 1983, Thermal performance monitoring of a terrace house with conservatory, New Bradwell, Milton Keynes, Report by the Department of Design Research, Royal College of Art, to the Energy Technology Support

Internal conditions: computer simulations

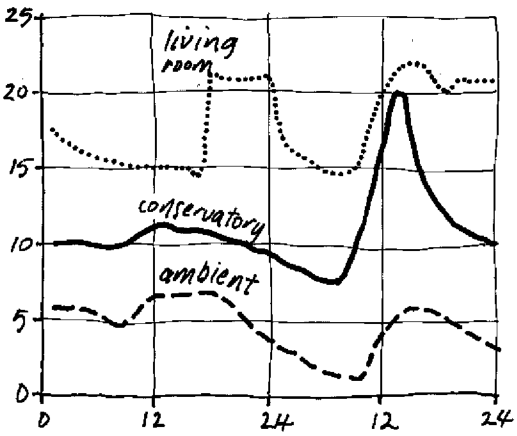
Similar trends have been predicted by simulation, such as those performed by CAP Scientific for ETSU using the thermal simulation model SERI-RES, to simulate conditions in the house with conservatory shown in Figure 102. The plan of the house is shown in Figure 124. Figure 103 shows the results for a 48 hour period in February.

For the whole of this period the conservatory temperature was at least 4°K above ambient temperature. During the first day, which was overcast, the conservatory temperature even during the daytime remained at about 4°K above ambient. During the second, sunny, day the conservatory temperature rose to reach 20°C for a short period in the early afternoon.



Semi-detached house with conservatory used in simulations: plan of house is shown in Figure 124

Figure 102



Temperatures during the period 11 to 12 February, as simulated

Figure 103

---

1 James, R and Dalrymple, G., 1985, Modelling of conservatory performance, in Norton, B (ed), Greenhouses and conservatories, UK-ISES Conference Proceedings, UK-ISES, London.

Simulations performed by Penz at the University of Cambridge produced the predicted performance shown in Figure 105.[1] Maximum temperatures for December, January and February were in the region of 19-22°C with minima about 2-4°C, giving a range of 20°K. Maximum temperatures from April to October exceed 30°C and they exceed 25°C from March to November.

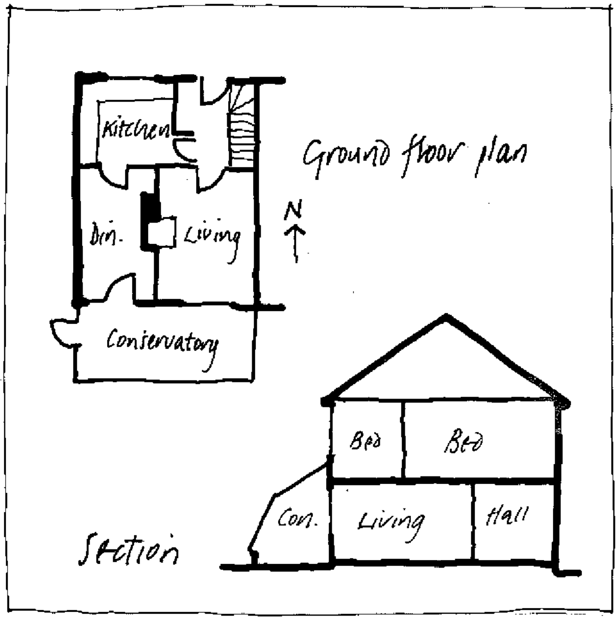
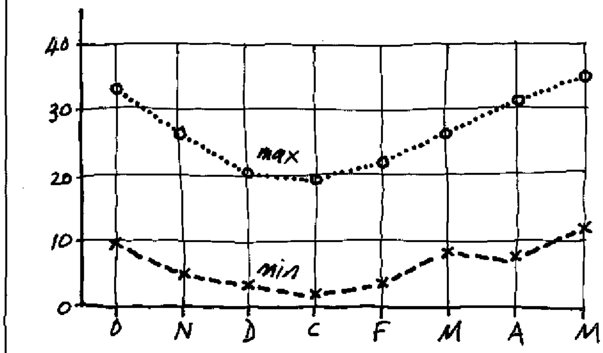


Figure 104



Maximum and minimum average monthly temperatures in the conservatory illustrated in Figure 104

Figure 105

---

[1] Penz, F., 1983, Passive solar heating in existing dwellings, unpublished PhD thesis, University of Cambridge.

A series of computer simulations were conducted at the University of Louvain of an unheated attached conservatory in the Belgian climate at a latitude similar to the south coast of England.[1] The effects on internal temperatures of the conservatory resulting from changes to its glazing and to the elements dividing it from the house were investigated, see Figure 106. This study suggests that double glazing a conservatory with clear glass or with coated glass raised its minimum internal temperature in the winter by about 3 to 4°K. But this measure also raises its maximum temperature in the summer, thereby increasing the risk of overheating and the need for shading and ventilation.

Figure 107 shows the effects of changing the orientation of this conservatory between East and West. One conclusion that may be drawn from these simulations is that minimum temperatures vary only slightly (by about 2°K) with the changes in orientation, while maximum temperatures vary much more. The maximum for an east facing conservatory is 21°C, compared with 23°C for a west facing one, and 30°C for one facing south.

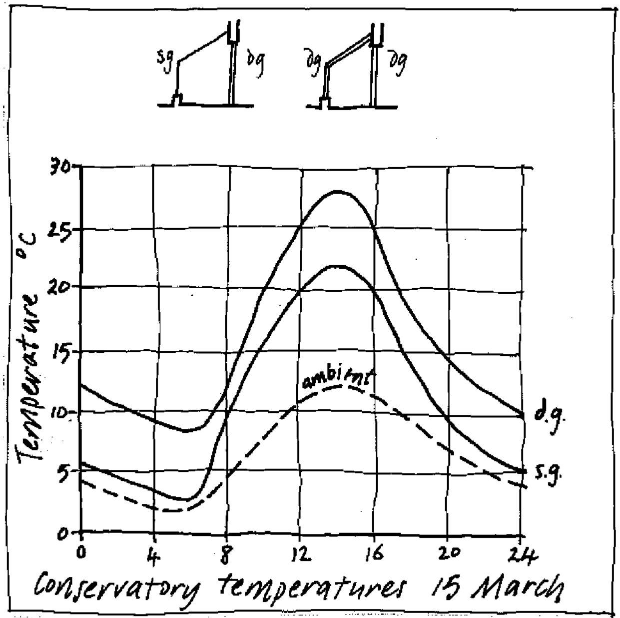


Figure 106

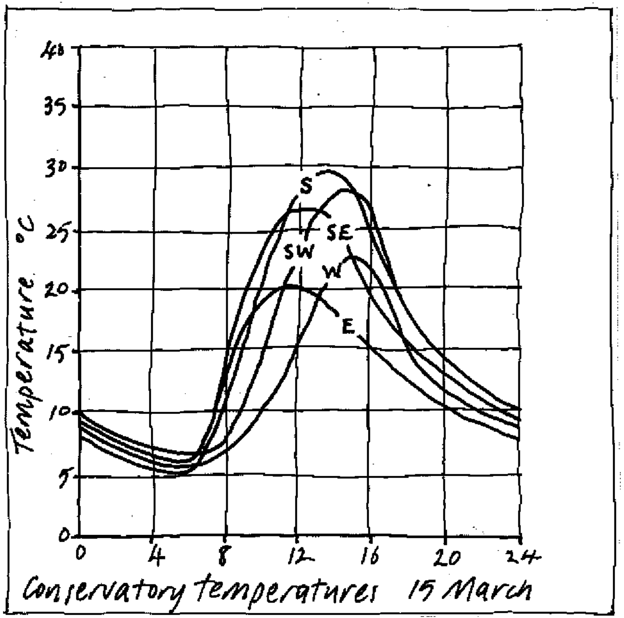


Figure 107

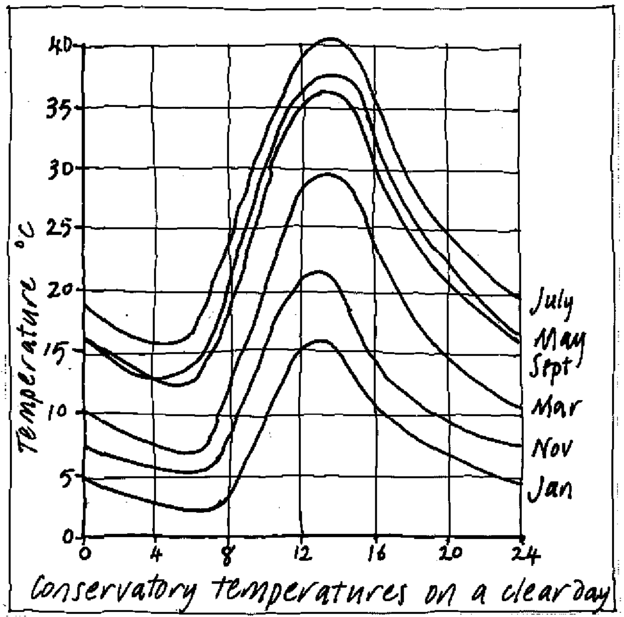
---

[1] le Paige, M., Gratia, E. and de Herde, A., 1986, Architecture et climate: guide d'aide a la conception bioclimatique, Services de Programmation de la Politique Scientifique, Bruxelles.

Figure 108 shows some of the maximum and minimum temperatures achieved in this conservatory in Belgium during the day in various months of the year:

- maximum temperatures from May to September reached 36 to 40°C
- minimum temperatures were about 2°C in January
- for about three months of the year, the conservatory is unlikely to reach a habitable temperature of 20°C except for a possible short period between midday and early afternoon on sunny days
- at the beginning and end of the heating season the conservatory will be above 20°C for up to 8 hours on sunny days.

The monitored results presented in Figure 100 confirm the same trend for the UK climate as these simulations. Overall, conservatories appear to be capable of achieving a phenomenon known as the **seasonal shift**: the internal temperature in a conservatory in March is likely to be equivalent to the ambient air temperature about six weeks later.



Conservatory temperatures on a clear day

Figure 108

Conservatory form and performance

Internal temperatures in conservatories arise from decisions about their form and fabric. Comprehensive information about the inter-relationship between all the design variables involved is not available. It is possible, however, to give preliminary advice about most of them.

Orientation

South facing conservatories will achieve

- higher maximum temperatures
  and
- higher minimum temperatures in both winter and summer than those orientated in other directions.

Form

Attached conservatories achieve

- higher maximum temperatures from solar gain because of their large areas of glazing
  and
- lower minimum temperatures because of the large conduction losses from the conservatory and because of the smaller amount of heat conducted through the more limited area of external elements of the house that are covered.

Recessed conservatories achieve

- lower maximum temperatures because of their smaller glazed area
  and
- higher minimum temperatures because of their reduced conduction losses from the conservatory, and the larger amount of heat conducted through the increased area of external elements of the houses they cover.

Ratio of glazing to solid elements

Large areas of glass cause

- higher maximum temperatures because of solar gain
- lower minimum temperatures because of increased conduction losses.

Glazed roofs in particular cause the greatest overheating problems in the summer.

Insulation values of wall covered by conservatory

If a conservatory covers mainly windows or doors, more heat will escape into the conservatory from the house so raising its minimum temperature. However, these same windows and doors will provide less thermal mass in the conservatory so its maximum temperature will also be raised during sunny conditions.

Glazing and frame types

Specification of double glazing and/or coated glass will achieve

- higher minimum temperatures
  and
- higher maximum temperatures.

Timber frames or metal frames with thermal breaks will also achieve

- higher minimum temperatures
  and
- higher maximum temperatures.

All conservatories with direct access from the house, whether intended to be used as accommodation or not, should be glazed in accordance with BS 6262: 1982 **Glazing for buildings** . Also many cheap prefabricated conservatories have very crude fixings for attaching glazing to their frames. These may be a safety hazard if the conservatory is used as living space.

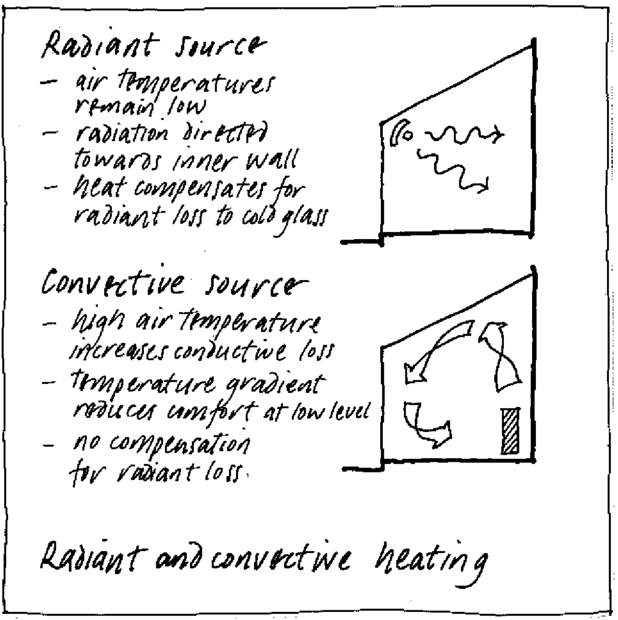


Figure 109

Points to remember

Unheated conservatories

If an unheated conservatory is intended to be used as living space for as much of the year as possible, then the emphasis should be on:

- **a southerly orientation**
- **a recessed or semi-recessed plan. If, however, an attached conservatory is chosen, opaque and insulated side walls should be specified**
- **high admittance surfaces in the floor and in the part of the external wall covered by the conservatoy to absorb excess solar gain**
- **double glazing or better to reduce heat loss**
- **an insulated opaque roof for solar control or, at the very least, roof shading devices (although the former will mean that the accommodation provided will not be considered as a conservatory for the purposes of the 1985 Building Regulations)**
- **finely adjustable controls over ventilation**
- **possibly movable insulation to glazing.**

Heated conservatories

If conservatories are heated, either by means of a heat emitter in the conservatory or by heat admitted through doors or windows from the rest of the house:

- **they will be a substantial energy penalty because of their poor insulation values**
- **their comfort conditions are likely to be poor because glass has a poor thermal performance - internal shutters or thermal blinds could be specified to lessen this effect, see pages 70-78.**

If intermittent local heating is required, then:

- **it should be of the highly radiant kind so that thermal comfort can be attained without raising the air temperature in the conservatory (which would increase conductive loss through the glazing)**
- **heat emitters such as radiators should be located on the outside perimeter of the conservatory and be backed by insulated panels to reduce heat lost directly through the glazing**
- **heating should be directed away from the glazing so that radiant losses to the cold glass surface will be minimised and only internal surfaces will be warmed by the absorbed radiation, Figure 109.**

Conservatories and energy performance

Conservatories act in a number of related ways to modify the energy balance of houses to which they are attached. These need to be understood if designers are to exploit the potential conservatories possess for reducing energy consumption. This section only deals with how unheated conservatories do this.

The energy balance of conservatories

Conservatories can modify the energy balance of houses to which they are attached in three different ways:

conservatory as buffer zone

- providing an extra layer of building fabric and of trapped air, so reducing the rate of heat loss from the house

conservatory as high temperature solar collector

- because of the greenhouse effect, conservatories can be used to capture and store solar radiation

conservatory for pre-heating ventilation air

- by raising the temperature of in-coming air, drawn through the conservatory before distribution about the house for ventilation purposes.

Any one of these three types of conservatory can contribute to reducing total energy consumption if:

- there are no heating appliances in it and/or
- its internal temperature is not raised by occupants' allowing heat from the rest of the house to warm it.

A conservatory which is heated, by either of these methods, will increase total consumption, see page 88.

Conservatories as buffer zones

Buffer zones are parts of a building which, during the heating season, are at temperatures between the warmed interior and the cold outside air. They can reduce the rate of heat loss by decreasing the temperature difference across that portion of the fabric of the heated accommodation which they cover.

The buffer effects

In a conservatory, these result from:

- **the additional layer of building fabric**
  Whatever materials the conservatory is made of, whether transparent or opaque, it:
  – provides an extra layer of building fabric
  – keeps the enclosed surface of the main fabric dry
  – reduces wind velocity at the surface of the main fabric
  and
  – traps a volume of air.

  In effect, it increases the insulation value of the external wall elements that it covers to give an improved resistance to outward heat flow.
- **solar gain in the buffer space**
  Where a conservatory is mainly transparent, the fabric effect is enhanced by collecting solar radiation within it (described in more detail later). This gain raises the temperature in the conservatory and so further reduces the temperature differential across the external fabric of the building.
- **the draught lobby effect**
  By reducing the wind speed and wind pressure on the windows and other gaps in the external wall which it covers, a conservatory reduces infiltration losses through these elements.

Although the direction of the prevailing wind must be taken into account, the additional fabric and the draught lobby effects operate under most conditions and are both independent of orientation. But both effects are reduced in influence

- as the insulation values of the walls and windows are improved
  and
- as the building becomes more airtight.

In a double glazed, well-insulated and well-sealed building, heat loss through the fabric is comparatively low. In these circumstances, the addition of a conservatory makes only a small improvement to reducing fabric and infiltration losses.

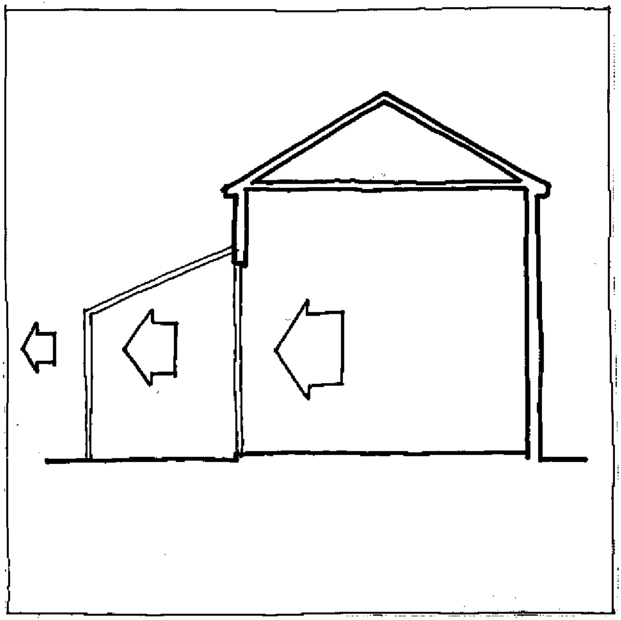


Figure 110

Points to remember

If it is desired to maximise a conservatory's buffer effects, it should:

- **cover the maximum number of openings and the largest area of wall possible**
- **have a southerly orientation.**

Conservatories as high temperature solar collectors

Solar radiation which enters a conservatory raises the temperature of the air trapped inside by means of the greenhouse effect. In the UK, direct use of this solar gain for space heating purposes is limited.

The greenhouse effect

The principles behind this form of solar gain are similar to those described for windows. **Short wave solar radiation** enters a conservatory through the glass, see Figure 111. It is then absorbed by the surfaces of the wall and floor and converted into heat. This is then transferred by three means:

- by convection to the air in the conservatory
- by radiation to colder surfaces in the conservatory (for example the glass)
- by conduction into the materials of the walls and floor.

In this way, solar gains raise the temperature of both the air and the surfaces in the conservatory. The heat is stored partly in the fabric of the enclosed wall of the house and partly in the floor of the conservatory. These solar gains and their storage result in conservatory temperatures which are almost always above external air temperatures.

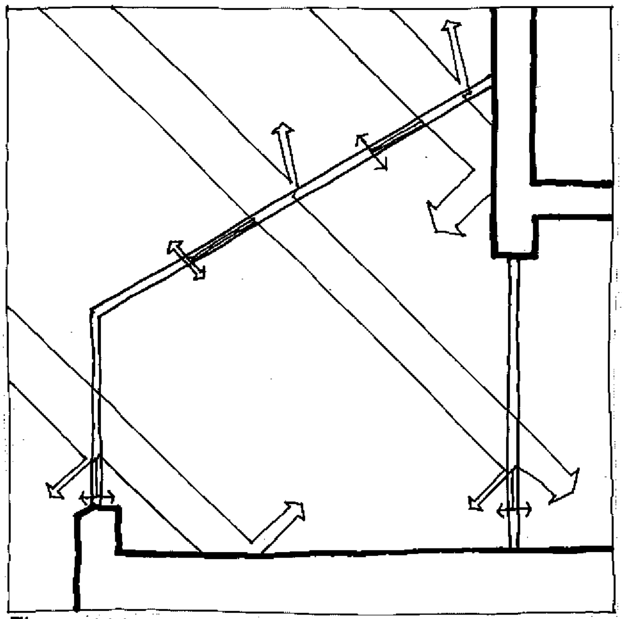


Figure 111

Optimum climate for solar collection

In climates where there is a combination of:

- low air temperatures
  and
- high solar radiation,

air temperatures in a conservatory are likely to be above the demand temperature of the house for substantial periods of time. Under these conditions, which do not occur in the UK very frequently, solar heated air can be transferred to the rest of the house, Figure 112. Opening doors and windows between the house and the conservatory will cause air to circulate between the two spaces, resulting in a net heat gain by natural convection into the house. The openings must be closed when the air temperature in the conservatory falls below the house temperature or else there will be a net heat loss from the house as reverse flow takes place.

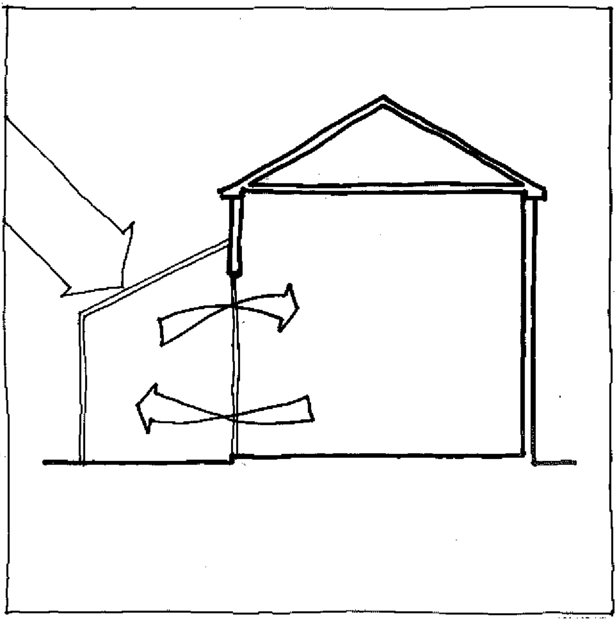


Figure 112

UK climate and solar collection

In the UK climate, both monitoring and simulation studies suggest that, while air temperatures in conservatories will normally remain above ambient temperature, there are problems in designing a conservatory that will operate as a warm air exporter:

- the air temperature in the conservatory will only rarely be above the demand temperature of the house during the heating season, see Figure 100, and very rarely sufficiently above it for moving the warmed air into the house to be worthwhile
- warm air itself is a very poor medium for transferring significant amounts of heat.

Transferring solar-heated air to the house

If climatic conditions do allow a conservatory to be designed as a high temperature solar collector, solar-heated air can be transferred from a conservatory by two means:

- **manually** by opening linking doors and windows whenever the conservatory temperature is above the demand temperature of the main house. This will achieve convective exchange of air between the house and conservatory. These openings must be closed again when the conservatory temperature drops below demand temperature
- **mechanically** by the use of a thermostatically controlled fan and ductwork linking the conservatory with the house. The fan needs to be controlled by thermostats which detect temperatures in both the main house and the conservatory. When the temperature in the conservatory is above the demand temperature required for the house (and provided the temperature of the house is not already above demand temperature), then the fan is switched on and pumps warm air from the top of the conservatory into the house. The heating system for the house must be designed to be able to respond to this imported warm air.

Limitations on the direct use of solar gain

Besides the questionable ability of the UK climate to support high temperature solar collection, there are other factors associated with trying to optimise conservatory as a solar collector:

- comfort conditions in such a conservatory will be affected detrimentally. Because of solar gain, temperatures will vary greatly both daily and across the seasons. This may make a conservatory less suitable as living space or for growing plants and reduces its amenity value.
- solar control measures in the form of shading and ventilation will be essential to prevent overheating in summer
- if the conservatory is also used as for cultivating plants, its air may be at a high relative humidity. When this is transferred to the house interior, it may cause condensation on cool surfaces.

Where there is a limited budget for measures to reduce energy consumption, it is more worthwhile to insulate and draughtproof the rest of the house before trying to improve the performance of a conservatory as a solar collector.[1]

Points to remember

If a conservatory is to be used as a high temperature solar collector, emphasis should be placed on raising its air temperature as much as possible. This can be achieved by:

* **an attached conservatory with as much glazed area facing south as possible**
* **a high ratio of glazed conservatory area to house wall area covered**
* **lightweight surfaces within the conservatory to reduce absorption of heat**
* **double glazing (or better) to reduce heat loss**
* **movable insulation to the roof and walls.**

If benefit is to be gained from exporting solar heated from the conservatory to the house,

* **the conservatory must to be warmer than the heated part of the house**

  and
* **an efficient manual or mechanical route for transferring the warmed air has to be provided.**

---

[1] James, R and Dalrymple, G., 1985, Modelling of conservatory performance, in Norton, B. (ed), Greenhouses and conservatories, UK-ISES Conference Proceedings C39, UK-ISES, London.

Conservatories for pre-heating ventilation air

Solar gain and storage, and conductive losses from a house to its conservatory, raise the conservatory's air temperature above ambient temperatures, even in the UK climate. With controlled ventilation, this can be used to pre-heat incoming air before it is brought up to internal comfort levels by the heating system.

Ventilation pre-heat

If ventilation in a house can be controlled so that a high proportion of incoming air enters via the conservatory, then pre-heating this air can reduce auxiliary heating demand. There will be no threshold above which the conservatory temperature has to rise before solar gain can be used. Any increase in temperature represents a useful heat gain.

Consider as an example a conservatory attached to a well insulated house. The day-time air temperature in the conservatory on a cloudy winter day might be say 9°C, while the external temperature could be 4°C. Any ventilation air drawn from the conservatory will thus have to be heated through only 10°K to reach a demand temperature of 19°C, rather than through 15°K. If all the house ventilation air could be pre-heated in this way, the heating load due to ventilation could be reduced by a third.

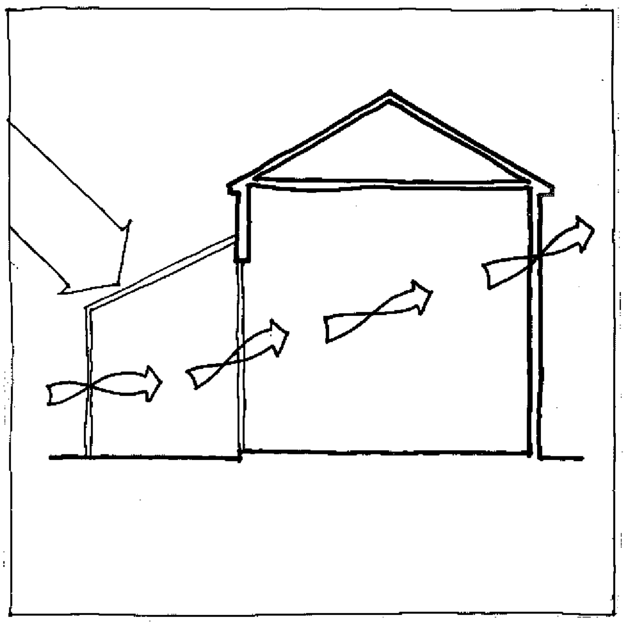


Figure 113

In the case of very well insulated houses, where fabric losses have been reduced to low levels, there is still a need for ventilation of at least 0.5 air changes per hour. And, in such a house, the ventilation load may be similar in magnitude to its conductive loss. Pre-heating of the ventilation air can then begin to make a major contribution to reducing the auxiliary heating load.

Natural ventilation and solar pre-heat

In practice, controlling the flow of air from the conservatory to the rest of the house and extracting contaminated air to the outside by natural means demands

- investigation of the site micro-climate
- knowledge of the principles of wind pressure and stack effect on air movement
- control over the permeability of the building fabric

These issues are beyond the scope of this handbook. A detailed discussion of them can be found elsewhere.[1]

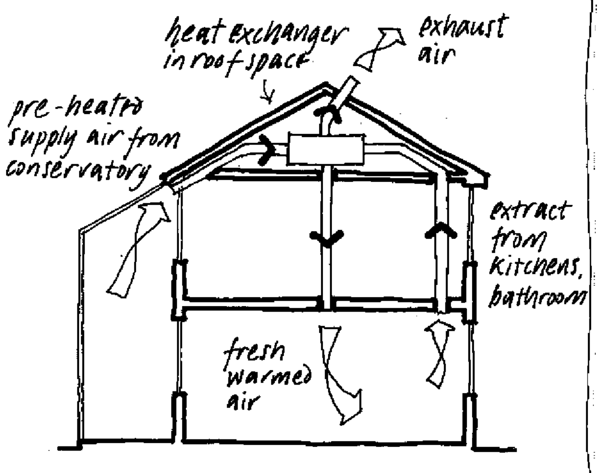
---

[1] Baker, N., 1985, The use of passive solar gains for the pre-heating of ventilation air in houses, Report by ECD Partnership to the Energy Technology Support Unit, Report No. ETSU-S-1142.

Mechanical ventilation and solar pre-heat

An alternative to a reliance on natural means of air intake, distribution and extract is to introduce a mechanical ventilation system. This can be linked to a conservatory to achieve both ventilation pre-heat and control over airflow within the building. Although there are likely to be cost implications, there will be fewer uncertainties about the final performance than may be experienced if attempts are made to use natural means.

Several of these mechanical ventilation systems linked to conservatories were constructed in houses at the Milton Keynes Energy World exhibition in 1986. Generally they operate by the warm air being ducted from the conservatory up to the roofspace, which is used as a warm fresh air store. Air handling plant in the roof space heats the air further. It is then ducted around the house for delivery as required. Air extracts in particular rooms may lead either directly to outside or to heat exchangers in the roofspace. For summer use, there are large ridge ventilators on the main house to let the warm air straight out by stack effect.



Mechanical ventilation system using pre-heated air from conservatory

Figure 114

Points to remember

- In a well-insulated house, pre-heating ventilation air can make a significant contribution to cutting fuel bills
- Where a conservatory is to be used for this purpose, a high proportion of this incoming ventilation has to be admitted via the conservatory
- Such control can be accomplished either naturally or by a mechanical system. The latter is easier to regulate but more costly.
- Once air admitted for ventilation is under control, any increase in conservatory air temperature can help to offset energy consumption
- Employing a conservatory for pre-heating purposes does not incur the limitations on its use or amenity value associated with direct exploitation of solar gain.

Conservatories and energy savings

Some occupants will want to use their conservatories to help reduce their fuel bills. At present, there is very little evidence available to show how effective conservatories are as a means of doing this.

Evidence on energy savings

Under certain circumstances, conservatories can reduce fuel bills. But there is little documented evidence about what actually happens in practice. Work that has been undertaken falls into two types: measured and simulated results.

Measured results

The thermal performance of an attached conservatory at Milton Keynes, has been monitored, see Figure 99.[1] From measurements taken, calculations were made to estimate the savings due the conservatory as follows:

- **the buffer effect**
  (due solely to the additional insulation provided by the conservatory) was calculated to be worth 120kWh/year. This could be estimated for any design by a simple U-value calculation.
- **solar gains**
  these, transferred to the house from the conservatory principally by conduction, were estimated at 270kWh/year
- **ventilation pre-heating**
  because the house was in a terrace, the conservatory covered about one third of its external wall areas. It was assumed that half the ventilation air entered the house via the conservatory. As the air temperature in the conservatory was higher than the external ambient temperature, this pre-warmed air gave an estimated energy saving of about 270 kWh/year. The house also had a thermostatically controlled fan between the conservatory and house which drew warm air from the conservatory into the house when appropriate. This was estimated to be worth 150kWh/year.

---

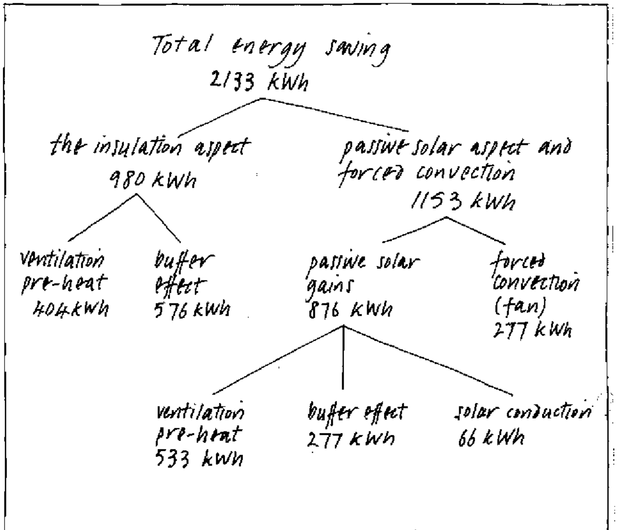
[1] Ford, B., 1983, Thermal performance monitoring of a terrace house with conservatory, New Bradwell, Milton Keynes, Report by the Department of Design Research, Royal College of Art, to the Energy Technology Support Unit, Report No. ETSU-S-1056B.

Simulated results

Computer simulations have been performed to explore the effect of attaching conservatories to existing dwellings.[1] The results for a single glazed conservatory attached to a semi- detached house, see Figure 104, suggest the energy savings shown in Figure 115.

For this poorly insulated house (the U-value of the walls was 1.36W/m^{2}K), the conservatory was predicted to save energy at the rate of 100kwh/year per square metre of house fabric covered. This reduced annual consumption by 20-25%. Savings as large as this are unlikely to be achieved, however, with a new house built to the 1985 Building Regulations standards.

Computer simulations have also been conducted for ETSU by CAP Scientific using SERI-RES for the house design study illustrated in Figure 102.[2] The modelled house was a new semi-detached with a floor area of 100 m^2, constructed to the 1982 Building Regulations standards (that is walls 0.6 W/m^{2}K, roof 0.35 W/m^{2}K) and with single glazed patio doors abutting the conservatory. If an occupancy schedule with intermittent partial heating to 21°C is assumed, the simulations suggest the figures for space heating demand shown in Figure 116.



Energy saving contribution of conservatory

Figure 115

Design without conservatory	7400
Design with conservatory	4950
Saving due to conservatory made up as follows:	2450
- saving due to buffer effect	1390
- saving due to ventilation pre-heating	1060

Space heating demand in kWh for the house shown in Figure 102

Figure 116

---

1 Penz, F., 1983, Passive solar heating in existing dwellings, unpublished PhD thesis, University of Cambridge.

2 James, R and Dalrymple, G., 1985, Modelling of conservatory performance, in Norton, B. (ed), Greenhouses and conservatories, UK-ISES Conference Proceedings C39, UK-ISES, London.

A further set of simulations on the same house were performed but with the house kept at a constant 21°C. This gave the figures for space heating demand presented in Figure 117.

Figure 118 shows a further breakdown of the sources of the savings.

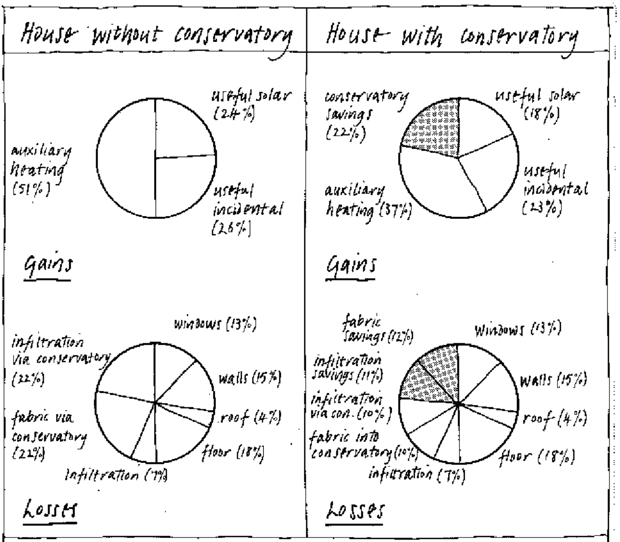
These simulations leave two important questions unanswered:

- what would the energy demand figures be for a design of equivalent floor area but with a simple square plan shape?
  and
- what are the cost implications of the additional perimeter wall that results from the L-shape plan?

Design without conservatory	25 000
Design with conservatory	19 300
Saving due to conservatory	5 700
made up as follows:	
– reduced conduction	2 900
– reduced infiltration	2 800
Reduced conduction losses made up of	
– extra fabric effect	1 800
– solar raised temperature	1 100

Space heating demand in kWh

Figure 117



The effect of the conservatory on gains + losses

Figure 118

Conservatory shading and ventilation

If people and/or plants are to be comfortable in a conservatory, adequate shading devices and means of ventilation need to be provided, particularly to avoid overheating during the summer. There are also other steps which can be taken in the design of conservatories to minimise this risk.

Summer overheating

This is a common problem with conservatories, confirmed both by monitoring and computer simulation studies. A range of methods are available to combat overheating:

- opaque elements, especially in the roof or side walls
- shading devices
- ventilation
- thermal mass.

These methods are best used in combination.

Shading devices

As with windows, the most effective position for these devices is outside the glazing. In this position, they will prevent solar gain from entering the conservatory. Although external devices are preferable, they have higher costs and maintenance requirements. Internal devices are cheaper but will be less effective in preventing overheating since they absorb solar radiation themselves before re-radiating their heat to the interior of the conservatory.

The main types of shading devices are:

- roller or blinds, fabric or sheet material
- folding blinds, fabric or card
- slats that may be rolled up, typically wooden
- venetian blinds, wood or aluminium
- matting, jute or hesslan.

For information on the performance characteristics of these devices, see pages 63-78.

Ventilation

Ventilation occurs naturally in conservatories because of the temperature difference between inside and outside. The rate of ventilation is affected by the vertical distance between the air inlet and outlet, see Figure 120. It is important to keep the distance marked as 'h' in this figure as large as possible.

On hot sunny days, 30 air changes per hour or more are necessary to bring the temperature in a conservatory close to ambient.

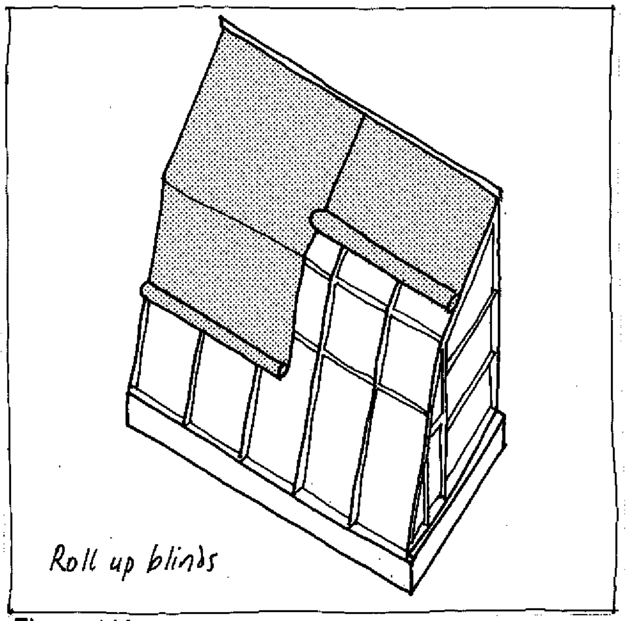


Figure 119

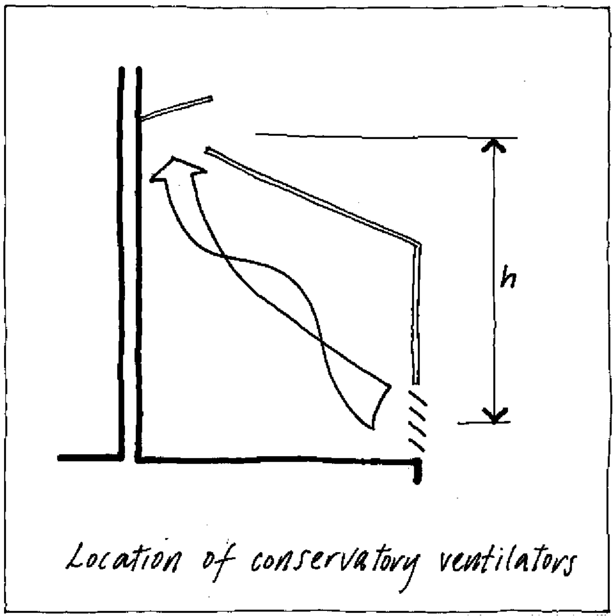
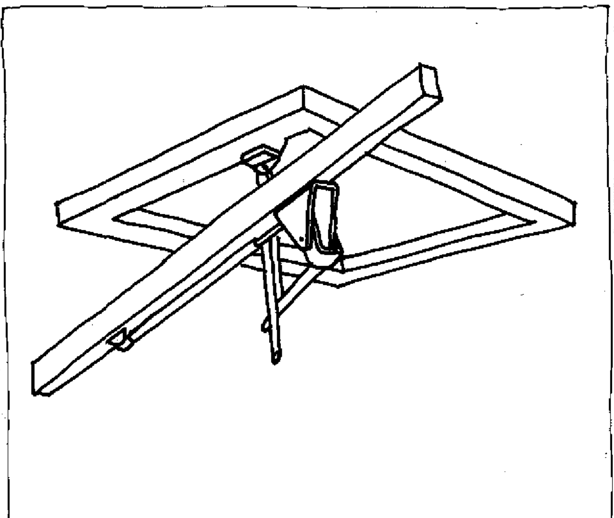


Figure 120

The size of inlet and outlet required to achieve this ventilation rate is about 20% of a conservatory's floor area.[1] For a 4.0m x 2.0m conservatory, this would mean an inlet and outlet of 1.6 m^2 each. These are comparatively large areas to accommodate in what is only a medium size conservatory.

The most common type of ventilators are:
- manually operated louvre blades at low levels and
- automatic vents for high outlets.

These are made for the commercial greenhouse market, are reliable and comparatively inexpensive. They may be preset to the required ventilating temperature, usually between 18°C and 28°C. Automatic controls are preferable, if they can be afforded, because manual ones place heavy demands on occupants if overheating is to be avoided.



Automatic vent opener

Figure 121

Thermal mass

The inclusion of materials within a conservatory which absorb and store solar radiation can also be used to combat overheating. This solar storage is most likely to be sited in the floor and the wall between the house and the conservatory. Although this thermal mass is helpful in reducing temperature swings, its rate of heat absorption is too slow for it to be relied upon to control maximum temperatures.[2] Additional mass, such as that provided by containers full of water, is also likely to be too slow in absorbing heat to prevent quick temperature rises from solar gain. Simulations by Penz suggest that if the the equivalent of four 200 litre barrels of water were stored in the 13.5m^2conservatory he modelled, the air temperature could be lower by 4 to 5°K when overheating was a risk.[3] The total volume occupied this amount of water is almost 1 m^3.

Points to remember

- adding thermal mass is not an effective way of preventing overheating in conservatories
- opaque materials used in roofs or side walls are more effective
- external shading devices are more effective than internal ones
- large air inlets and outlets are necessary to provide the rate of ventilation required to combat overheating
- inlets should be provided at low level, outlets at high level
- the rate of ventilation improves the further apart vertically the inlet and outlet are located.

---

[1] Penz, F., 1986, The energy implications of keeping plants in conservatories, Eclipse Research Consultants, Cambridge, (summarised on pages 88 to 89).

[2] Littler, J. and Ruyssevelt, P., 1986, The role of thermal mass in UK housing, in The efficient use of energy in buildings, 2nd UK-ISES Conference C46, UK-ISES, London.

[3] Penz, F., 1983, Passive solar heating in existing dwellings, unpublished PhD thesis, University of Cambridge.

Conservatories and the Building Regulations

Whether a glazed extension to a house falls within the Building Regulations' definition of a conservatory or not, it will still have to conform to requirements for ventilation, means of escape, etc.

Definition and exemptions

According to the Manual to the Building Regulations 1985 for England and Wales, a conservatory means - for the purposes of the Building Regulations - a conservatory with a transparent or translucent roof. Any glazed extension to a house that has an opaque roof is not, for the purpose of the Regulations, treated as a conservatory but as part of the rest of the house.

Under Regulation 9, the Building Regulations do not apply to any work described in Class VII of Schedule 3. This Class includes an extension to a building by the addition at ground level of a greenhouse or conservatory whose floor area does not exceed 30m^2.

While this regulation makes it clear that conservatories of over 30m^2 (whether extensions to existing buildings or constructed as part of a new dwelling) are not exempt, it remains unclear whether conservatories of less than 30m^2 are exempt when built with a new house. Advice on interpretation should be sought either from the local authority or, if necessary, from the Department of Environment.

Conservatories and house ventilation

Part F of Schedule 1 to the Building Regulations 1985 requires a means of ventilation in dwellings so that an adequate supply of air may be provided for people in the building. The Approved Document to Part F shows provisions meeting the requirement.

Where a conservatory covers a window or door which would ventilate a habitable room, the habitable room may be ventilated through the conservatory, provided that

- there is an opening (which may be closable) between the habitable room and the conservatory with an area which is equal to at least 1/20th of the combined floor areas of the room and the conservatory
  and
- there is a ventilation opening area in the room and the conservatory together, or in the conservatory alone, which area is equal to at least 1/20th of the combined floor areas of the room and the conservatory
  and
- some part at least of the ventilation opening area is at least 1.75m above the floor level.

Figure 122 shows the requirements.

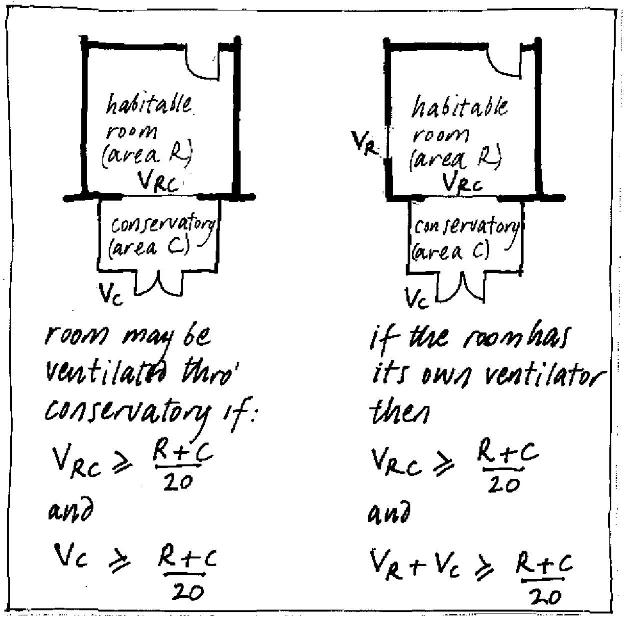


Figure 122

A ventilation opening includes any means of ventilation (whether it is permanent or closable) which opens directly to external air, such as the openable parts of a window, a louvre, or airbrick. It also includes any door which opens directly to external air, as long as the room or space also has an area of ventilation opening (equal to at least 100mm x 100mm) which can be opened without opening the door.

The required performance can also be met by following the relevant recommendations of BS 5925:1980 **Code of practice for design of buildings: ventilation principles and designing for natural ventilation** of which the relevant clauses are numbers 11 to 15.

Conservatories and the conservation of fuel and power

Part L of Schedule 1 of the Building Regulations 1985 states the requirement for the resistance to the passage of heat in dwellings and gives the maximum rate of heat loss permitted in the exposed elements of the fabric. The Approved Document shows procedures for calculating the rate of heat loss.

The Appendix to the Approved Document, which shows examples of exposed elements, contains Diagram A1 - reproduced as Figure 123. The accompanying text states that, in Diagram A1(b), the car port is open at one end to give a permanently open ventilation area in excess of 5 percent of the area of walling enclosing the car port. Section AB is therefore an exposed element. It would appear from this diagram that if the carport were a conservatory which did not not have a permanently open ventilation area in excess of 5 percent of the area of walling section AB would not be an exposed element. It would therefore not need to comply with the insulation value demanded of exposed elements.

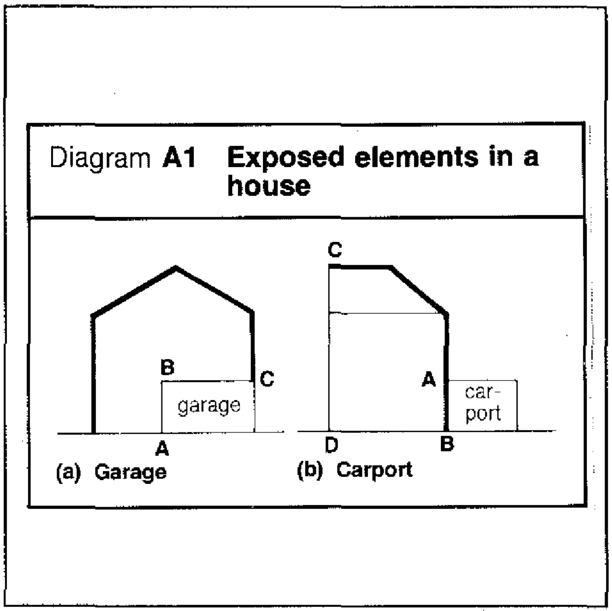


Figure 123

Despite this, in view of the expected monthly average temperatures in a conservatory (see page 91), it is desirable that any dividing wall is insulated to reduce heat loss to the conservatory. For the same reason, large areas of single glazing between a house and its conservatory, while permitted under the Regulations, will lead to excessive heat loss into the conservatory.

Conservatories and means of escape in case of fire

Part B of Schedule 1 of the Building Regulations 1985 requires means of escape in case of fire from a building to a place of safety outside the building which is capable of being safely and effectively used at all material times. This demand may only be met by complying with the relevant requirements of **The Building Regulations 1985 - Mandatory rules for means of escape in case of fire**, published by HMSO.

These state that a dwelling house shall be constructed in accordance with the recommendations in the relevant clauses of BS 5588 **Fire precautions in the design and construction of buildings, Section 1.1: 1984 Code of practice for single family dwelling houses**. These requirements apply only to to dwellings of three or more storeys.

One and two storey houses

These are excluded from the requirements of the Regulations for means of escape. But there are recommendations in BS 5588 that apply to one and two storey houses which need to be considered.

In BS 5588, a window is used for rescue or escape when a room (other than kitchen, utility room, bathroom, dressing room or wc) is an "inner" room. This is a room from which escape is possible only by passing through an "access" room. And this, in turn, is a room that is the only escape route from an inner room, as opposed to a passageway that leads to an external door. In other words, if a staircase lands within a downstairs room (such as a living or dining room), then an alternative means of escape or rescue must be provided from the windows of upstairs habitable rooms.

In the house designs illustrated in Figure 124, both of which are featured on page 91, the stairs land within downstairs rooms which are therefore defined as "access" rooms. If a fire were to start in the room containing the staircase, the alternative means of escape from the bedroom(s) on the upper floor would be via the bedroom windows. These should meet the recommendations for escape or rescue:

- the unobstructed opening should be not less than 850mm high by 500mm wide
- the bottom of the opening should be not more than 1.1m above floor level (and this will determine the height of the conservatory roof).

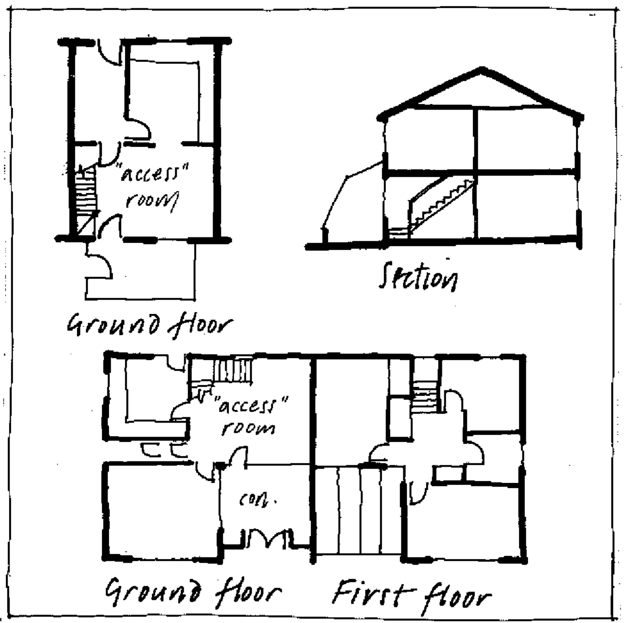


Figure 124

In the case of the south facing bedrooms, escape or rescue would be over the glazed conservatory roof. The practical implications of this escape route should be borne in mind.

Conversely, a two storey conservatory which encloses a first floor window, while perhaps aiding escape from the bedroom, might also trap smoke from the fire and cause it to penetrate the upper floor. Since BS 5588 does not refer to escape or rescue via a conservatory, it may be necessary to seek advice from the local fire authorities where this option is contemplated.

Three storey houses

The recommendations in BS 5588 become mandatory under the Building Regulations for houses of three or more storeys.

Windows in the top storey of such dwelling are not required for escape or rescue because an alternative escape route or protected stairway has to be provided. A conservatory roof could therefore be sited under a top floor bedroom window without raising difficulties about escape or rescue. Unless a protected stairway is provided to the first floor, first floor windows have the same requirements as they do in two storey houses. So the alternative means of escape given in the examples above for two storeys apply. In practice, it is unlikely that the open plan arrangement illustrated would be used in a three storey house, as a protected staircase leading directly to an outside door will be the usual method of meeting the requirement.

Four storey houses

The additional requirements here are for alternative means of escape for the upper floors other than a single protected internal stairway. Conservatories for such houses need to be designed taking these requirements into consideration.

Flats and maisonettes

BS CP3 Chapter IV, **Code of basic data for the design of buildings**, is the relevant code of practice. Here windows are not used as means of escape because protected passage ways are required. Balconies may be used as escape routes. Care should be taken that conservatories adjoining such escape routes do not obstruct them. Conservatories may be constructed on balconies that are not used as escape routes.

Conservatories and fire: internal and external fire spread

For conservatories which fall within the scope of the regulations, (ie. those over 30m^2 or that do not have a transparent or translucent roof), some of the requirements in Part B of Schedule 1 of the Building Regulations 1985 which relate to internal and and external fire spread are relevant. These requirements may influence the choice of both roof and external wall materials.

Figure 125 summarises the requirements.

Roofs: internal spread of flame

Any wall which is at an angle of less that 70° to the horizontal is classified by the Regulations as a roof. Glazed conservatory roofs are not specifically mentioned in the Approved Document except in Table B1 of Appendix B.

Where a conservatory roof is within 6m of a boundary, its internal surface should have a Class 1 surface spread of flame, see Table 1.4 of the Approved Document to Part B. Georgian wired glass and clear annealed glass achieve this rating. PVC and polycarbonate sheet can also do so. Table B1 of Appendix B of the Approved Document shows concessions for rooflights of plastics materials under certain circumstances. For conservatories of less than 40m^2, rigid PVC may be used.

Roofs: external spread of flame

Table 1.3 of the Approved Document shows the limitations placed on roof construction. Where a conservatory is less than 6m from a boundary, only roof coverings that are rated AA, AB or AC may be used. Both 6mm georgian wired glass and 3mm wired PVC can achieve this rating. Annealed glass, unwired PVC, polycarbonate or acrylic sheet cannot. However where the conservatory is less than 40m^2 in area, annealed glass or unwired PVC may be used for the roof but polycarbonate or acrylic sheet cannot.

Walls: internal spread of flame

Table 1.4 of the Approved Document states that walls should have Class 1 surface spread of flame. This would include wired glass, clear annealed glass (which being non-combustible is classified as Class 0), and may include rigid PVC and polycarbonate under some circumstances.

Walls: external cladding

The external cladding of walls that are less than 1m from the boundary should be of Class 0 combustibility. This includes glass but excludes thermoplastics materials.

	Roofs		Walls	
	internal	external	internal	external
surface spread of flame	Class 1 (< 6m from boundary)	AA, AB, or AC	Class 1	Class 0 (< 1m from boundary)
allowable materials	wired glass clear glass	wired glass wired PVC	wired glass clear glass	wired glass clear glass
concessions for conservatories $< 40\ m^2$	rigid PVC	clear glass unwired PVC	–	–

Internal and external fire spread

Figure 125

Walls: limits of unprotected areas

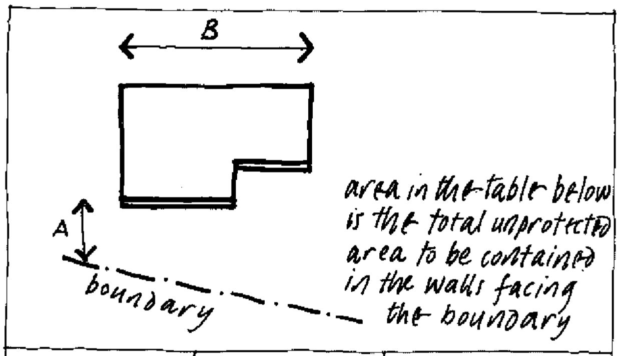
A glazed conservatory wall must comply with the requirements for an unprotected area of wall. An unprotected area of wall is one with less than the required degree of fire resistance and includes windows and doors. The danger from unprotected areas is that fire will spread by heat radiation from one building to another.

Appendix J of the Approved Document describes three alternative methods of calculating the permitted extent of unprotected areas. Method 1 applies to residential accommodation less than three storeys high and 24m in length which is not less than 1m from the relevant boundary. Unprotected areas are not permitted less than 1m from a boundary. The diagram shown as Figure 126 illustrates the permitted extent of unprotected areas according to Table J1. It can be seen that a fully glazed conservatory may be limited in size, depending on its proximity to the boundary, or that some opaque walling will be necessary near boundaries.

Junction of separating wall and roof

Adjoining conservatories in terrace and semi-detached houses are covered by the requirements for separating walls in Appendix C of the Approved Document. The requirements are to prevent the spread of fire from one dwelling to another. Either the wall should be taken up above the roof or the roof and its covering should resist fire penetration and spread.

If AA, AB or AC rated roof glazing is used (eg. wired glass, clear glass, or wired PVC), the glazing may be carried over the top of the separating wall providing it is adequately firestopped with mortar or similar material. For other types of glazing the separating wall must project 375mm above the roof covering.

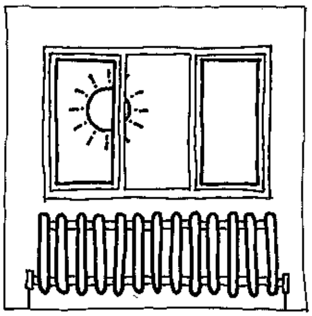


Minimum distance (A) to boundary	Maximum length of side B	Maximum total area of unprotected area
1.0 m	24 m	5.6 m²
2.5 m	24 m	15 m²
5.0 m	12 m	no limit
6.0 m	24 m	no limit

Figure 126

SECTION 6

Heating systems and solar energy



Space heating and solar gain

Solar gains are an important consideration when calculating the heat balance of a well-insulated house and influence the choice of its space heating system. Likewise the responsiveness of the system and its controls will help to determine whether solar gains that do occur are, in practice, useful.

Solar energy and space heating

Solar gains may be considered to fall into two categories:

- **useful** solar gains which reduce the need for an input from the space heating system (called auxiliary heating)
  and
- **excess** solar gains which raise room temperatures above demand temperature.

To maximise the usefulness of solar gains and reduce the likelihood of overheating, it is essential that the auxiliary heating system can respond to:

- the solar gains
  and
- the internal heat gains (from cooking, occupants and appliances)

that occur within a house.

In the past, when houses were poorly insulated, the influence of solar and internal gains was small in comparison with fabric and ventilation losses. So both barely figured in calculations of auxiliary heating demand.

In low energy houses which incorporate high levels of insulation and sophisticated glazing systems, their importance has to be recognised. Not only is heat loss through adventitious ventilation (cracks around windows and doors) reduced but the rate of heat loss through the fabric is also much lower. Thus the energy inputs required to balance heat losses are lower. In these circumstances, solar and internal gains are more significant. On their own, they can constitute a relatively large proportion of the energy inputs required to bring a house up to its demand temperature.

On an hourly or daily basis, it is possible that (even during the heating season) solar gains may exceed the space heating requirements of a house, especially if they occur at the same time as other large internal gain such as cooking. Even if they do not exceed the total requirements, solar gains (alone or with internal gains) may, on occasion, cause excessive temperatures in the rooms on the sunny side of a house.

For these reasons, solar and internal gains have to be treated as important factors when calculating the energy balance for well-insulated houses. They have to be taken into account both in the overall design of a space heating system and in the specification and location of its controls.

Heating load calculations

The overall energy balance of a house comes from the simple equation

energy input = energy output.

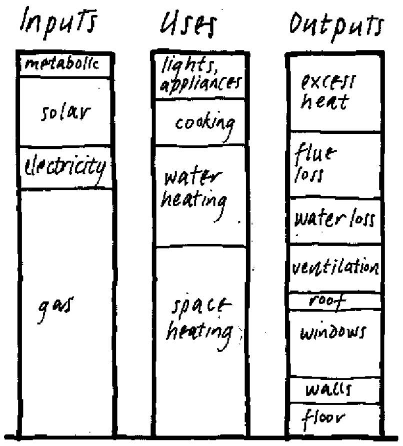
Energy inputs are made up of:
- delivered energy (the purchased fuels)
- metabolic gains from the occupants and
- solar gains.

These are put to various uses:
- space heating
- water heating
- cooking and
- lights and appliances.

Solar and metabolic inputs are usually counted as contributions to the space heating.

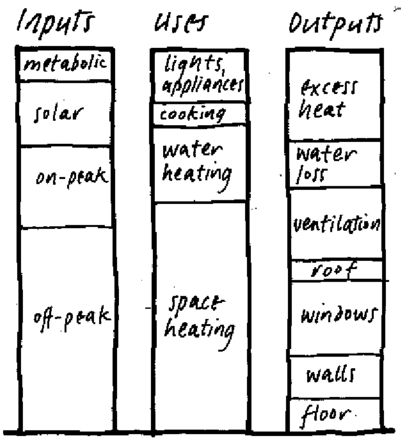
Energy outputs refer to how energy is lost:
- conduction losses through the fabric
- ventilation losses both deliberate (through opened windows) and adventitious (through cracks)
- losses from hot water that goes down the drain
- losses from flues and chimneys

Figures 127 and 128 shows examples of the results of calculations using a computer program called Energy Designer, based on the BRE Domestic Energy Model (BREDEM), to analyse the inputs, uses and outputs for a low energy house.[1]



Heat balance for a low energy house: gas example

Figure 127



Heat balance for a low energy house: electric example

Figure 128

---

[1] Milton Keynes Development Corporation, 1986, Energy World exhibition catalogue, MKDC, Milton Keynes.

In these figures the notional output term - excess energy - refers to energy surplus to requirements, ie. energy which would take a house above its demand temperature (21°C). The largest contribution to this category will come from solar and other internal gains. In practice, it is assumed that some people will take this heat as a bonus, while others will open the window to ventilate it away.

The model attempts to represent the exchanges between different categories of energy. For example, some of the energy used for water heating is lost as 'water loss'. But some of this goes into the air from:

- the hot water cylinder
- the pipes
  and
- hot water while standing in sinks etc.

This heat is lost through the fabric or by ventilation.

The total capacity of a system should be designed matched to the heat load of the house. Oversizing, though frequent in practice, reduces the efficiency of some types of heating system which operate most efficiently at maximum output.

The responsiveness of a heating system

A system should be chosen to match the construction of a house, particularly in terms of the thermal response of its fabric. Both should match the anticipated heating regime(s) of occupants. Conventional wisdom is that a lightweight building offers a quick thermal response so that, together with a warm air system, it will be well suited to two period intermittent (morning and late afternoon to evening) heating regimes or to partial house heating. A heavyweight building heats up and cools down much more slowly. It should be fitted with a system more suited to delivering continuous or one-period intermittent (early morning to evening) heating regimes and to whole house heating.

Zoning

In well-insulated houses, it may be possible to achieve adequate comfort conditions without having heat emitters in every room. Similarly the use of localised heat sources may have advantages over the installation of a central heating system.

Several options are possible where there are uneven heat requirements throughout a house:

- local control in each room, for example by thermostatic control of each heat emitter
- zoning of the system, for example, into living room and bedroom zones, or into south facing and north facing zones
- redistribution of heat may be possible with warm air systems from, for, example south facades to north facades.

Thermostats should be located to avoid positions which suffer from draughts, or receive heat from a radiator, or are in direct sunlight.

The location of heat emitters

In the past when houses were poorly insulated with leaky single glazed windows, it was essential for heat emitters to be placed beneath windows to counteract cold downdraughts caused by the cold surface of the glass. But, where window systems are used that have a higher energy performance, this may no longer be necessary. Heat emitters can be placed on internal rather than external walls, so making greater use of the heat emitted to warm the internal structure of the house rather than just its external envelope.

Boiler energy manager systems

A further level of control over the heating system may be achieved by the use of a boiler energy manager system. Electronic sensors measure both outdoor and boiler temperatures, and these measurements are used to calculate the optimal ratio of the boiler 'on' and 'off' cycles necessary to satisfy the heat demand. Such systems reduce boiler cycling and maintain boiler efficiency at at high level irrespective of heat load.

Points to remember

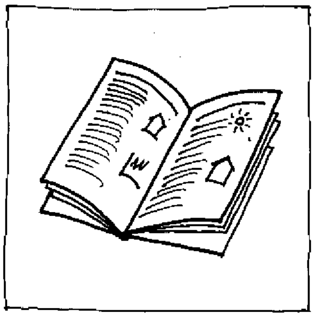
Because of the diverse nature of space heating systems and fuels available, it is impossible to give detailed advice here about how to design a system taking solar gain into account.

In general, the aims should be:

- **ensure that the construction of a house and its heating system are matched to be responsive**
- **install a heating system with sufficient capacity to provide good levels of comfort, within a reasonable time-scale, throughout the house even when no solar gains are available**
- **zone the system, and position localised controls, so that solar (and internal heat) gains can be compensated for where and when they occur. Doing this will also provide a heating system that enables occupants to find their own preferred level of heating within each space**
- **ensure that occupants are given sufficient information and instructions to operate their heating system effectively, with specific advice about what to do in spaces where solar gain is expected to occur.**

SECTION 7

References and index



Useful organisations

A full list of organisations providing professional, technical or trade advice or information about building design and the construction industry can be found in Building Design's Easibrief.[1]

Those listed below are 'government' organisations with responsibility for producing information drawn upon in this handbook.

British Standards Institution
2 Park Street
London W1A 2BS
Telephone: 01 629 9000
Telex: 266933
Fax: 01 629 0506

Building Research Advisory Service
Building Research Establishment
Garston
Watford WD2 7JR
Telephone: 0923 664664
Telex: 923220
Fax: 0923 664010

BRECSU Enquiries Bureau
Building Research Energy Conservation Unit
Building Research Establishment
Garston
Watford WD2 7JR
Telephone: 0923 894040
Telex: 923220
Fax: 0923 664010

General Enquiries
Energy Efficiency Office
Department of Energy
Thames House South
Millbank
London SW1P 4QT
Telephone: 01 211 6774 or 6811

International Energy Agency
2 rue Andre Pascal
75016 Paris
France
Telephone: 010 33 45 24 8200

Meteorological Office
London Road
Bracknell
Berkshire RG12 2SZ
Telephone: 0344 420242

Renewable Energy Publicity Office
Energy Technology Support Unit
Building 156
Harwell Laboratory
Oxon OX11 0RA
Telephone: 0235 834621 extension 3467
Telex: 83135
Fax: 0235 432923

---

[1] Haverstock, H. and Heard, H., 1987, The Building Design Easibrief: a concise reference book for building designers, Morgan-Grampian, London.

Sources of figures

The following figures have been redrawn, or the information taken, from the sources listed.

1: Hawkes, D., 1986, Modern country homes in England: the Arts and Craft architecture of Barry Parker, Cambridge University Press, Cambridge.

2: Royal Institute of British Architects, 1933, The orientation of buildings, RIBA, London.

4: Steadman, P., and Brown, F., 1987, Estimating the exposed surface area of the domestic stock, in Hawkes, D., Owers, J., Rickaby, P. and Steadman, P., Energy and urban built form, Butterworths, London.

5, 6, 8, 10, 11, 12, 20: Jones, R. W. and McFarland, R. D., 1984, The sunspace primer: a guide for passive solar heating, Van Nostrand Reinhold, New York.

7, 9, 16, 76, 92: Achard, P. and Gicquel, R., (editors), 1986, European Passive Solar Handbook, CEC, Brussels.

13, 14, 21: British Standard Draft for Development DD67:1980, Basic data for the design of buildings - sunlight, BSI, London.

15: UK-International Solar Energy Society, 1976, Solar energy: a UK assessment, UK-ISES, London.

18: Oppenheim, D., 1981, Small solar buildings in cool northern climates, Architectural Press, London.

19: Bartholomew, D., 1984, Possibilities for passive solar designs in Scotland, Energy Technology Support Unit Occasional Paper, reference ETSU L14, ETSU, Harwell.

27, 28, 29, 106, 107, 108, 111: le Paige, M., Gratia, E. and de Herde, A., 1986, Guide d'aide a la conception bioclimatique, Services de programmation de la politique scientifique, Brussels.

30: Milbank, N., 1986, The potential for passive solar energy in UK housing, PD 102/86, Building Research Establishment, Garston, Watford.

31: Holtz, M. J. and Place, W., 1979, A classification scheme for the common passive and hybrid heating and cooling systems, proceedings of the third National Passive Solar Conference, San Jose, California, USA.

32,37: NBA Tectonics, 1986, A study of passive solar housing estate layout, report to the Energy Technology Support Unit, reference ETSU-S-1186, Harwell.

33, 34, 58: Lowe, R., Chapman, J. and Everett, R., 1985, The Pennyland project, report to the Energy Technology Support Unit, reference ETSU-S-1046, Harwell.

35, 36: Tabb, P., 1984, Solar energy planning, McGraw Hill, New York.

38: House at Milton Keynes Energy World exhibition, 1986, designed by PCKO Architects, developer D. F. W. Golding (Hertford) Limited.

39: House at Milton Keynes Energy World exhibition, 1986, designed by Max Lock Easton Perlston & King, developer S & S Homes.

40, 47, 48, 55, 68: Button, D. 1982, Energy options for housing design: glazing options, Journal of the Royal Institute of British Architects, vol. 89, no. 10.

41: British Standard BS 6375 Performance of windows, Part 1: 1983 classification for weathertightness, BSI, London.

42: Green, J., Innes, W., Maby, C. and Osbaldeston, J., 1987, Heating advice handbook, London Energy and Employment Network, London.

45: Chartered Institution of Building Services Engineers, CIBS Energy Code: Part 1: Guidance towards energy conserving design of buildings and services, 1977, CIBSE, London.

46: Pilkington Environmental Advisory Service, 1988, Glass and transmission properties of windows, Pilkington Glass Ltd, St. Helens.

49, 56: Owens, P., 1984, Low emissivity coatings on glass in windows, UK-ISES Conference Proceedings (C38): Coatings for energy efficiency and solar applications, pages 11-21.

50, 51, 52, 53: Wilberforce, R., 1976, The energy balance of windows, Building Services Engineer, vol. 43, no. 12, pages 241-243.

54: Energy Technology Support Unit, 1984, Passive solar study group: windows, ETSU, Harwell.

62: Davis, Belfield & Everest Consultancy Group, 1986, Newbuild design studies: summary of quantitative data from the const analysis project, Report to the Energy Technology Support Unit, DB&E, London.

63,64,65: Cost information prepared for this handbook by Davis, Belfield & Everest Consultancy Group.

67, 71: Bloomfield, D., 1987, IEA Task VIII - Documentation of parametric study, Building Research Establishment, Garston, Watford.

69: House at Milton Keynes Energy World exhibition, 1986, designed by Feilden Clegg Design, developer Haslam Homes.

70: Greenberg, S. and Hawkes, D., 1984, Report on Wimpey passive design study, ETSU Passive Solar Programme, Greenberg & Hawkes, London.

72: Harris, N. C., 1985, Solar energy systems design, Wiley, New York.

73,74, 81, 82, 83, 84: Hastings, R. S. and Crenshaw, R., 1977, Window designs to conserve energy, NBS Building Science Series 104, National Bureau of Standards, Washington DC.

77, 86, 87, 89, 90, 91: Ruyssevelt, P. and Littler, J., 1985, Movable window insulation, Final report to the CEC, reference EUR 9996 EN, Brussels.

78, 79, 85: Energy Monitoring Company, 1987, Studies in passive solar test cells, Test cell studies 1: Solar distribution, solar lost and window coverings, report to the Energy Technology Support Unit, reference ETSU-S-1162, Harwell.

80: Tomany, R., 1982, The measurement of window treatment effectiveness in reducing residential heating and cooling costs, ASHRAE Transactions, vol.88, no. 2, pages 235-248.

88: Everett, R., 1980, Passive solar in Milton Keynes, Energy Research Group, Report ERG 031, Open University, Milton Keynes.

93: Balcomb, J. D., Jones, R. W., McFarland, R. D. and Wray, W. O., 1984, Passive solar heating analysis: a design manual, Los Alamos National Laboratory/ASHRAE.

94: Pitts, G. 1982, Energy options for housing design: building fabric, Journal of the Royal Institute of British Architects, vol. 89, no. 10.

95: Based on constructions illustrated in Kok, H. W. M., 1987, Construction issues: Design Information Booklet 5, International Energy Agency Task VIII.

96: House at Milton Keynes Energy World exhibition, 1986, designed by Phippen Randall and Parkes, developer John Mowlem.

97: Tressider, J. and Cliff, S., 1986, Living under glass, Thames and Hudson, London.

98, 120: Penz, F., 1986, The energy implications of keeping plants in conservatories, Eclipse Research Consultants, Cambridge.

99, 100, 101, 119, 121: Ford, B., 1983, Thermal performance monitoring of a terrace house with conservatory, New Bradwell, Milton Keynes, report to the Energy Technology Support Unit, reference ETSU-S-1056B, Harwell.

102, 103, 115, 116, 117, 118: James, R. and Dalrymple, G., 1985, Modelling of conservatory performance, in Norton, B., (editor), Greenhouses and conservatories, UK-ISES Conference Proceedings (C39), UK-ISES, London.

104, 105: Penz, F., 1983, Passive solar heating in existing dwellings, unpublished PhD thesis, University of Cambridge.

109: Baker, N., 1983, Sunspaces - heat transfer, modelling and auxiliary heating, in Yannas, S. and McCartney, K., Sunspace Retrofit Studies, unpublished report by the Architectural Association to ETSU.

114: Based on examples in the Milton Keynes Energy World Official Guide, 1986, MKDC.

122, 124: NBA Tectonics, 1985, A study of institutional constraints on passive solar design, report to the Energy Technology Support Unit, reference ETSU-S-1143, Harwell.

123: Building Regulations 1985, Approved Document to Part L: Conservation of fuel and power, HMSO, London.

126: Building Regulations 1985, Approved Document to Part B: Fire, HMSO, London.

127, 128: Milton Keynes Energy World Official Guide, 1986, MKDC.

Index