National Design Handbook Prototype on Passive Solar Heating and Natural Cooling of Buildings

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United Nations Centre for Human Settlements (Habitant)
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Foreword

In line with the recommendations on energy of HABITAT: United Nations Conference on Human Settlements, the United Nations Centre for Human Settlements (Habitat) has been actively promoting energy conservation and the more efficient use of energy in human settlements over the years. The Centre has been regularly publishing reports aimed at alerting policy−makers and practitioners on the importance and implications of energy requirements and conservation in human settlements.

The process of producing electricity, which is generally the main form of energy supplied to buildings, is, unavoidably, very inefficient. The overall efficiency of electricity production, from the power station to the consumer, is little more than 20 per cent. Hence, for every unit of electrical energy that is saved in a building, up to five times that value is saved at the power station in terms of primary energy. Furthermore, by reducing energy consumption, power demand is also reduced. This reduction in power demand can lead to lowering the peak demand on the supply system. As the level of investment in expensive generating plant is in direct proportion to the peak demand, this reduction in power demands can lead to a national saving in capital investment. Passive solar heating and natural cooling of buildings, which are two ways of reducing commercial energy consumption without reducing comfort in buildings can thus lead to financial benefits, both at the consumer and at the national levels.

This publication has been prepared to act as a prototype handbook for the passive solar heating and natural cooling design of buildings. For reasons of simplicity and availability of resources, Australia has been chosen as the location for the prototype as information relevant to three distinct climatic regions, namely cool−temperate, hot−arid, and warm−humid could be presented.

Whilst the social and cultural environment in Australia is different from that in most developing countries, it was felt that for a prototype document the other factors in the thermal design process, especially available climatic data, outweigh this difficulty. Nevertheless, as a prototype this document will be relevant to many countries, especially those of the Asian and Pacific Basin and of parts of Africa. It is, therefore, hoped that this handbook will prove useful to designers in Australia, and in other countries, both developed and developing.

I wish to acknowledge the contributions of Professor John A. Ballinger in the preparation of this publication and of Mr. David Oppenheim who prepared the illustrations.

Dr. Arcot Ramachandran,
Under−Secretary General,
Executive Director.

Introduction

A. The design process

The design process is a complex. deliberate set of acts In which the designer aims to bring together, as a whole, a balance of all aspects of the problem to produce a solution. The climate, the energy use and the thermal comfort needs of the end−user are Just some of the inputs to the process. The focus of this publication is specifically on these aspects whilst still considering the other aspects of the whole such as shelter, durability, and appropriateness. The most important goal must be to aim for a balance of all these as good architecture is the product of such a balance.

The use of the sun and climate for thermal comfort and energy efficiency is as important a part of the whole design as is the structural design or indeed the design of the spaces themselves.

Some aspects of thermal design are both very simple and fundamental to a successful solution, others are more complex and require detailed calculation to fine−tune them and produce the most economically efficient result. In many instances where the building is a "one−off" design, the refinement of the building economics may be less important than, say. the method of construction for an owner−built design or the visual finishes of a prestige building. In such cases it is often not necessary to refine the thermal design thoroughly with extensive and detailed calculation.

In cases where a design is to be reused many times or the building is a prototype for further development, comprehensive design analysis is most important. The savings that will accrue from the reuse of the design work will be extremely beneficial to the community involved.

Before finalizing a design brief it is important to understand the social. cultural and climatic context of the proposed building. The first two can usually be established through careful consultation with the client(s) whilst the climatic context must be established by the designer from a knowledge and/or investigation of the site.

Most of the populated areas of Australia are located in what might be called a "summer driven climate", i.e.. warmer weather occupies the major part of the year. There are a few exceptions to this: mainly Tasmania, and the high altitude country of the Australian Alps and the Southern and Northern Tablelands along the East Coast.

Whilst designing for year−round comfort it is important to pay particular attention to the design for the more dominant season. In most of the Australian domestic sector, winter space heating consumes more energy than space cooling because a relatively small percentage of homes have full air conditioning. In some of the hotter climates, however, the situation is changing. Where the summers are hot and humidity levels are low, evaporative cooling is used extensively. These units require a ready supply of clean water, but are relatively tow energy users. In the more humid hot areas reverse−cycle air conditioning is the only choice.

Electricity marketing bodies throughout Australia are promoting the use of heat pumps for space heating because their coefficient of performance (COP) makes this form of heating competitive with natural gas. However, for a small additional cost, these units can be purchased as full reverse−cycle air−conditioning units, thus providing a readily available cooling system for the summer months. This trend will help to increase the overall energy consumption (especially in summer) and raise expectations of thermal comfort. The penalty to the consumer in the short term is increased living costs. whilst to the environment the increasing demand for electricity (generated from burning coal) will only serve to accelerate the growing problems of the global greenhouse effect.

The integration of good thermal design into the whole design process is only possible if it is started at the beginning of the design process. Like the integration of structure into a design, it is rarely successful if applied after the event. At each stage of the design process there are appropriate considerations that must be taken and tests applied.

B. Site investigation

The first stage of the design process should be an analysis of the site in terms of the environmental, physical and legal considerations. The micro climate of the site, its access to sunlight and access to views are three major environmental considerations of an investigation of the site. Generally the temperature patterns on the site will be similar to those recorded in the district by the weather bureau, but the micro− wind patterns may vary somewhat according to surrounding obstructions such as buildings. trees and general topography. The summer afternoon breezes in a particular district might be from the northeast according to published data but on a particular site the direction might be changed by a small hill or grove of trees. The street pattern might deflect the wind and funnel it in another direction. A clear picture can only be obtained by visual inspection of the site. occupants can often be a useful source of information.

Before visiting the site, however, the designer should be familiar with the general climate of the district and have some idea of the appropriate design strategies for that climate, year−round. This is less of a problem where the designer lives in the district and has a first−hand knowledge of the climate of the area. The process known as "bioclimatic analysis" is especially useful where the designer is not totally familiar with the area (see chapter VI).

C. Relating the brief to the site

When establishing the brief with the clients, the designer should determine the thermal comfort needs of the intended users' building in terms of building use and occupants' activities. A building designed as a gymnasium, for example, should have a cooler Interior and perhaps better ventilation than an office space where the occupants are sedentary. Likewise a home for older people or a hospital environment should provide a more stable temperature environment, perhaps generally warmer in winter than the usual domestic environment. A custom−designed house provides an opportunity for the designer to match the thermal environment to the specific desires of the client.

D. Schematic design stage

Once the clients' brief is defined and the opportunities of the site are incorporated into that brief, drafting the schematic design can begin. First, specific zones or spaces in the building should be considered, with regard to their use, any view opportunities, inside/outside connections (both visual and physical) and winter sunlight utilization.

Then ventilation strategies for summer cooling as part of the building design are established. A clear cross−flow of cooling breezes is most important in areas where summers tend to be humid.

After this, windows are located and overall size criteria for view, daylight etc. are established. Rules of thumb are used to establish approximate sizes relative to room size and extent of thermal mass as discussed later.

The schematic design is then completed and a provisional selection of construction materials made. The schematic design should be tested using simplified methods such as graphs, nomograms or user−friendly computer models.

E. Detailed design stage

In the detailed design stage the designer is able to test all of the various elements of the building with a reasonable degree of precision. As the overall design is refined, so too should be the thermal design details such as insulation details, shading design and window design.

The external fabric design is tested for reduction of solar gains in summer and for control of conductive heat loss in winter.

External shading of openings is refined to control solar gains. Sunlight should be excluded from entering the building during certain times in order to minimize summer overheating. This is the time to determine the controlling factors in the design of shading devices (shadow cut−off angles, horizontal projections and heights above sills etc.), so that they provide the desired shade in summer and sun penetration In winter.

A final check of the north−glass area to the mass−area ratio can be made at this time using the evaluation techniques referred to above.

Construction details are developed for appropriate control of infiltration during winter and to prepare specification notes about construction quality control.

The final detailed design is tested using a suitable PC− computer−based thermal performance model such as CHEETAH, TEMPAL or ARCHIPAK.

F. An outline to this publication

The first five chapters of this publication take the reader through the basic design issues and establish the simple principles that are fundamental to good thermal design. Also included are appropriate "rule−of−thumb" guidelines for more specific use in the initial design.

The next chapter shows the designer how to evaluate the particular climate using the concept of "bio−climatic design". and thus how to choose between some of the basic design options discussed in the first chapter. This chapter addresses the problems of providing thermal comfort and improved lifestyle which, in many circumstances, is as important as the concepts of improved energy efficiency, especially where the basic energy consumption is low. Throughout history it has been found that improved thermal comfort and the entry of sunlight into northerly facing living spaces has a significant impact on the hearth general well−being of the occupants. This Is particularly so in cold winter climates where sunlit rooms are much more attractive than south−facing non−sunlit spaces.

Chapter VII investigates the detailed design using various tools and calculation procedures. It is in this section that the designer learns to refine the basic designs developed earlier. The calculation of detailed aspects such as shading for windows, energy−conservation measures and ventilation effects will be most important for prototype designs.

Evaluation and testing of a solution is important not only from the point of view of educational value but also simply to test the fitness of the design. With experience the designer will need to test design solutions less often as an intuitive design sense evolves.

Chapter VIII develops ways in which the proposed building's performance can be assessed.

Case studies have always been a valuable mechanism to bring a sense of reality to a design process. It is helpful to be able to study examples of buildings that are known to perform well and to see how and why they do so. It is also helpful to be able to see where certain strategies will produce limitations to the design in other ways. An example, perhaps, is the use of a thermal storage wall which, whilst energy−efficient and capable of producing a high level of comfort, might be too restrictive in terms of views to the north or visual connection to the outdoor spaces. In another situation or even another culture it might be ideal. The case studies included, as the final chapter of the handbook, strive to show these issues.

The annexes collect together a range of data appropriate to the Australian building designer. These should, by no means, be seen as exhaustive since the full range of useful data would require many volumes.

I. Principles of passive solar architecture

Passive solar architecture can be described as the utilization of the sun's energy together with the characteristics of a local climate to maintain thermally comfortable conditions in buildings directly. There are many houses and buildings in Australia that have been designed to optimize the pleasant aspects of the climate, and minimize the unpleasant ones. Some were designed that way intentionally, whilst others achieved this purely accidentally. On the whole, modern designers or builders have lost touch with the local environment and so design in spite of the climate, and of the sun in particular.

The principles are certainly not new; however, much of the detailed performance Is not clearly understood. The research work currently being undertaken, involves continuing investigation, analysis and definition of the many complex thermal processes that take place in a building structure. There is still much to be done and many theories to be shown to false. For example, the traditional wide verandah farm house was considered by many to be the ultimate Australian dwelling; in fact, to many it still is. What is overlooked or not fully realized is that it was designed in an era when heating was easy and cooling was Impossible, with the technology available. As a result, such houses tend to be cool in summer, but bitterly cold in winter, because the wide verandahs exclude both the summer and the winter sun.

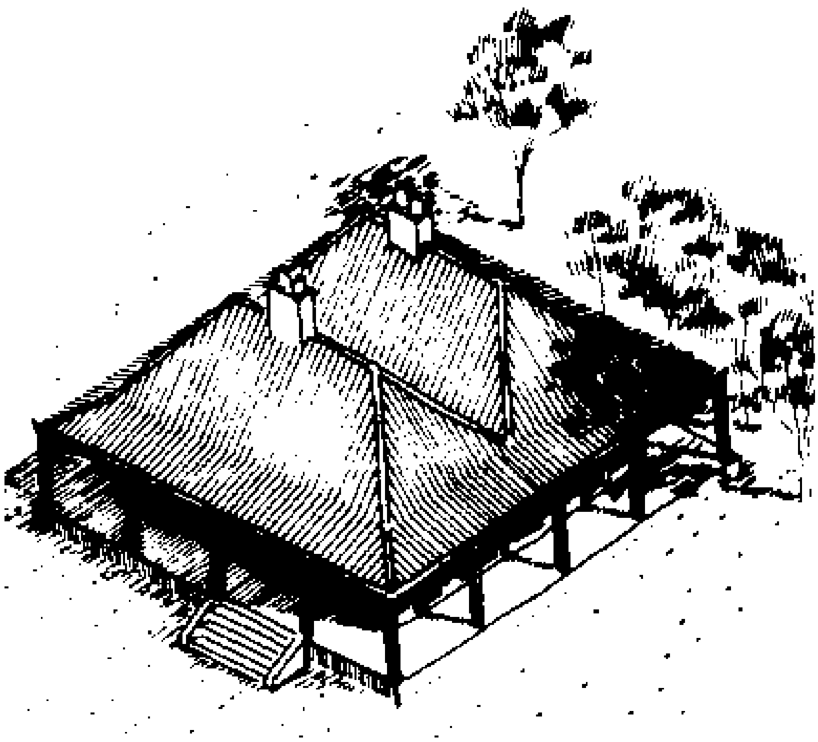


Figure 1. The traditional Australian house with wide verandahs on all sides

The history of passive solar architecture, or "design with sun and climate" goes back a long way. One of the earliest records of designing to use the sun is recorded in writings about Socrates by Xenophon approximately 400 B.C. Socrates advocated orientation of openings for exposure to the low winter sun and roof shade from the high summer sun. He also advocated the use of store rooms on the cold side as buffers for insulation against winter winds; Insulation was not available in the forms known today. Laundries and bathrooms would be good as buffers too.

When the first European settlers to Australia arrived in their new world they brought with them one survival technology in common; that of fire for heating and cooking. Their first Impressions of Australia when compared with Europe were of very hot summers and cool winters. The first houses that they built were intended to ward off the summers. The designs of wide−roofed verandahs may have come from the British experience in India. The early communications and trading between the new colony and the British traders in India is well documented in books on early Sydney.

It seems that this attitude of fighting hot summers whilst ignoring the fact that winters do get cold (especially away from the coast) prevailed until the beginning of the twentieth century. About the turn of the century houses took on a "new look". There was a growing awareness of the qualities and benefits of the sun. The health and fresh−air movement began about then too.

At that time the sleeping−out verandah and the "sun room" came into vogue. Unfortunately, such sun rooms were too often poorly orientated and received little sun. It was at that time that Walter Butler" wrote on the advantages of solar architecture and how to build "healthy buildings". In the 1930s Walter gunning, a notable architect, produced sun−orientated designs which would still be a cause for pride today − both modern and thermally effective. All this work, however, was designed intuitively and without detailed scientific knowledge.

In the years immediately following the Second World War, the Experimental Building Station was formed and people such as J.W. Drysdale and R.O. Phillips began work on the long task of quantifying many of these ideas. In CSIRO there were Muncey, Spencer and Ballantyne to name only a few. During this time, there were many others in overseas establishments undertaking similar work.

Most of this early work occurred at a time when energy was cheap and building materials expensive and scarce. Energy in Australia is still cheap. It was so cheap then that it seemed better economics to build a flimsy uninsulated enclosure and install a suitably sized (or oversized) machine to modify the indoor climate, than to build appropriately for the climate. Hence the glass box office building which is still built and unfortunately the large picture window of the "American dream home'. During that period from the late 1940s to the early 1970s, energy costs were either insignificant or simply taken for granted.

Although the cost of energy has risen little in Australia relative to wages and the cost of living, people are slowly beginning to realise that saving energy can mean significant monetary savings as well as greater levels of comfort if the problem is tackled in a sensible manner. In most applications the passive use of solar energy in buildings is both cost−effective and energy−conserving. There are much more vital uses for high− grade energy sources. oil, gas and electricity, than low−grade heat situations such as hot water and space heating. Such energy sources must be reserved for appropriate uses such as transport, lighting, or chemical production, especially when solar energy can do the job or at least a substantial part of it.

There are two basic approaches to the utilization of solar energy in buildings − active systems and passive systems. Active systems are generally those that are very visible with collectors on roofs, pumps, plumbing, control systems and storage tanks. Passive systems are defined as those where the heat moves by natural means. A passive solar energy system is one which uses the building structure as a collector. storage and transfer mechanism, with a minimum amount of mechanical equipment. This definition fits most of the more simple systems where heat is stored in the basic structure: walls, ceiling or floor. There are also systems that have heat storage as a permanent element within the building structure. such as bins of rocks, or water−filled drums or bottles. These are also classified as passive solar energy systems.

By way of analogy, consider a house as being a large combined solar collector and storage unit, such as shown in figure 2.

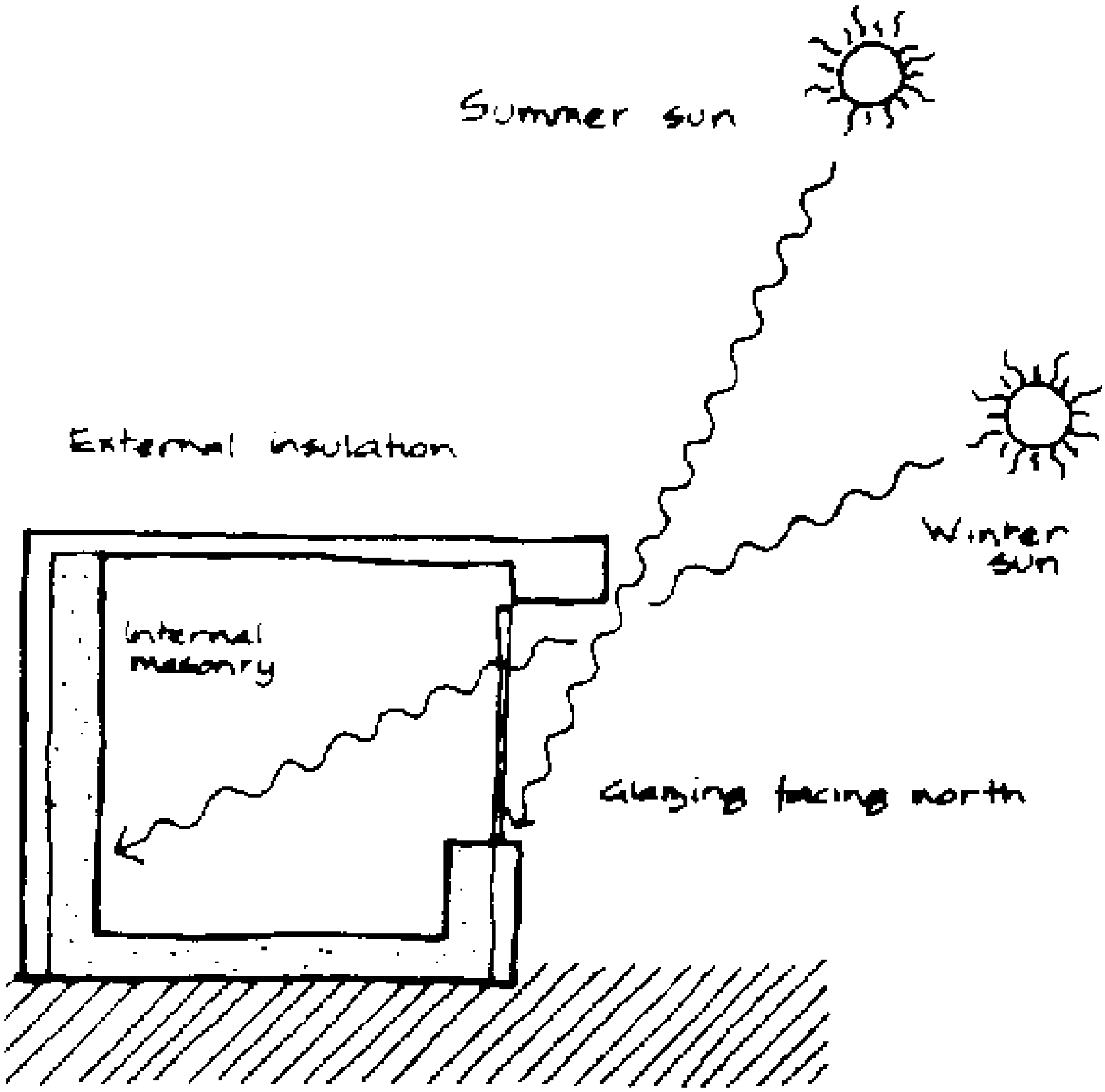


Figure 2. A building as a solar collector.

The important part of that unit are as follows:

(a) Glazed apertures exposed to the sun's path in winter but not in summer− the windows of a house if facing north will do this job admirably;

(b) A means of collecting and storing the sun's energy which enters in winter– concrete floors with quarry tiles or vinyl tiles (not cork or carpet which are insulators and stop the sun from reaching the storage material); masonry walls; or water containers or the like located in the sun's path. All of these work well to soak up the sun's heat and release it again when the temperature falls;

(c) An insulated outer skin (outside walls and roof) to restrict the flow of that energy back to the cold exterior in winter and in from the outside in summer when it is hot.

To plan a building using passive solar energy design principles a number of aspects must be considered.

The ideas that follow can be used in many types of buildings besides houses and flats. Many can be applied to small workshops or factories, to small office buildings of one or two storeys; in fact to any small–scale situation. Some ideas will apply to very large buildings too, however that is not what this discussion is all about. Not all the ideas included here are cost–effective in the short term, yet, often they are worthwhile because they make the building more comfortable for relatively little money. A study of these ideas should be made and then perhaps a check made with a quantity surveyor.

A. Site planning and orientation

If use is to be made of the sun's heat, then it has to reach buildings when it is useful. Generally, the sun should be able to reach the collection area between 9 a.m. and 3 p.m. in winter with as little and interference as possible. Trees on the site or the neighbors' site or perhaps those the householder plans to put in, might shade the vital areas of the building. This needs to be checked and the building located to minimize any such interference. During the winter, solar energy comes from approximately northeast at 9 a.m. and north–west at 3 p.m., about 90 degrees.

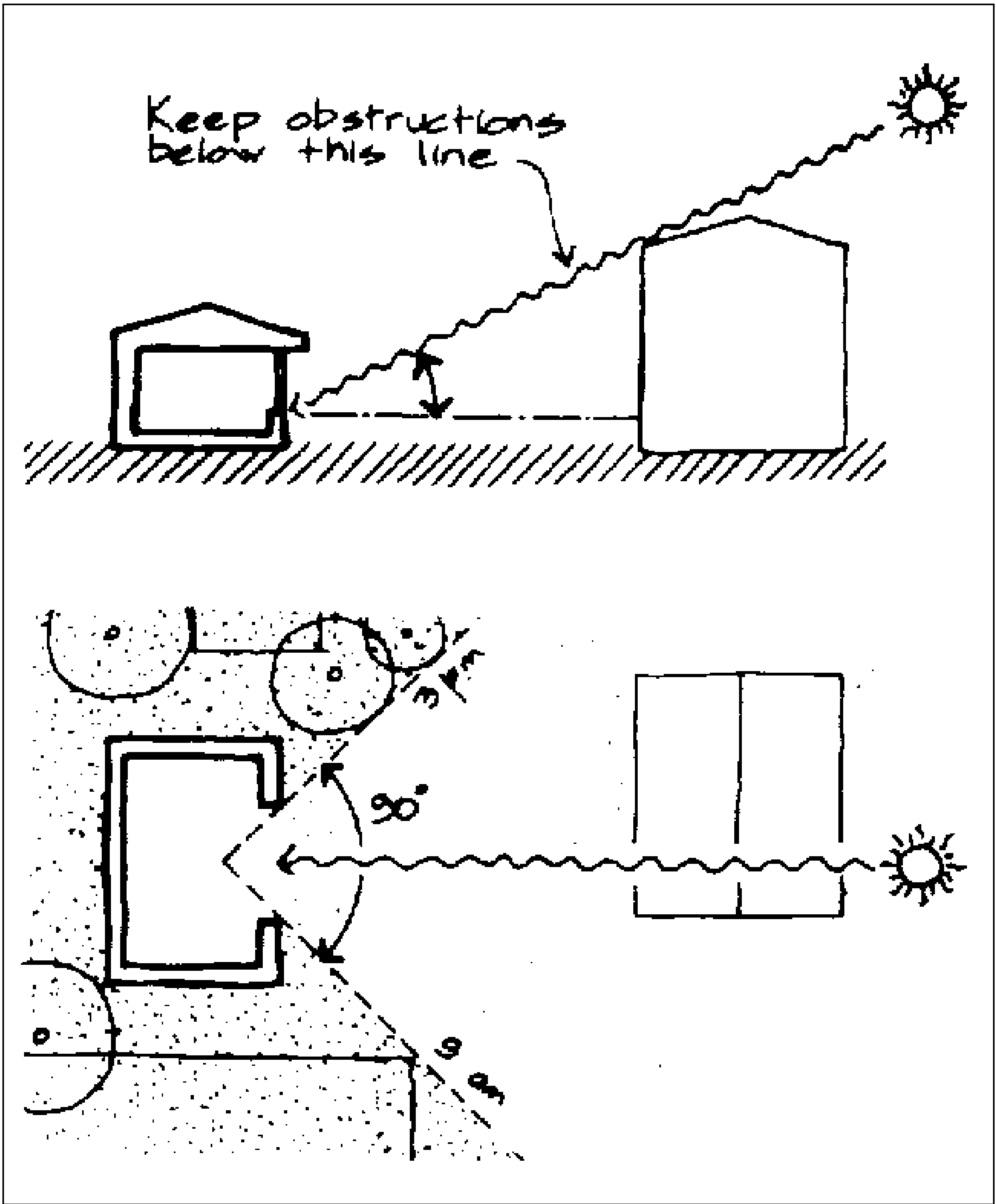


Figure 3. Sketch showing how the sun should have good access to windows that act as solar collectors.

In summer, there are often cool breezes which if directed through a building will help cool it. Weather Bureau information gives details of the direction for a particular area, but this should be checked on−site because other buildings, hills or trees might deflect those breezes to another direction. Likewise in winter, the cold winds should be deflected away from a building. They tend to come from the south, the south−west and the west. With simple local information about a site, it is possible to plan to optimize winter sun and summer breezes and to block winter winds by careful placement of obstructions such as trees, fences, hedges or a garage. If a client has not yet bought a site, then one with the right aspect should be sought. It is most Important to remember to let the sun in from the north.

The most straightforward way to use the sun's energy to warm a house is called the "direct−gain system". Here the sun is simply let into the building through correctly positioned and carefully sized windows. When describing the way buildings must face reference is being made to the direction that the main windows face. The windows of living rooms and, if possible, bedrooms should face towards the north. There is some latitude and so anywhere between 30 degrees east or west of north is acceptable. If there is a preference. then about 10 degrees east of north is best, to let some sun in for an early warming.

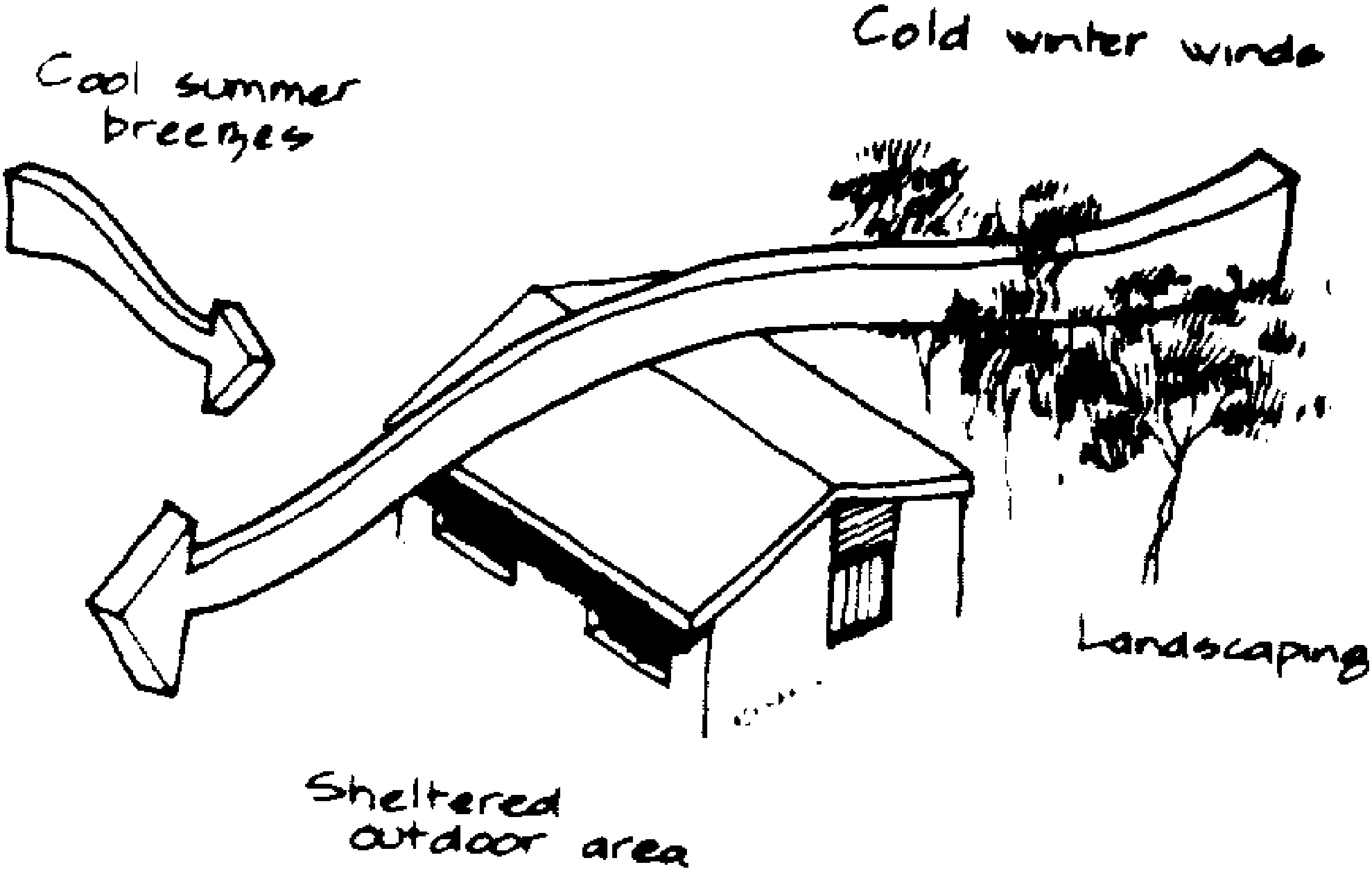


Figure 4. Use of landscaping and the building bulk deflect the cold winter winds to accept cool summer breezes.

It is important to try to avoid windows on the east or west sides, because these sides of a building receive more of the sun's heat in summer than they do in winter. The north side is quite different. It receives more heat in winter than summer, because the sun is high in the sky In summer and low in winter. Therefore, east- and west-facing windows can cause a building to overheat in summer much more so than north- or south-facing windows.

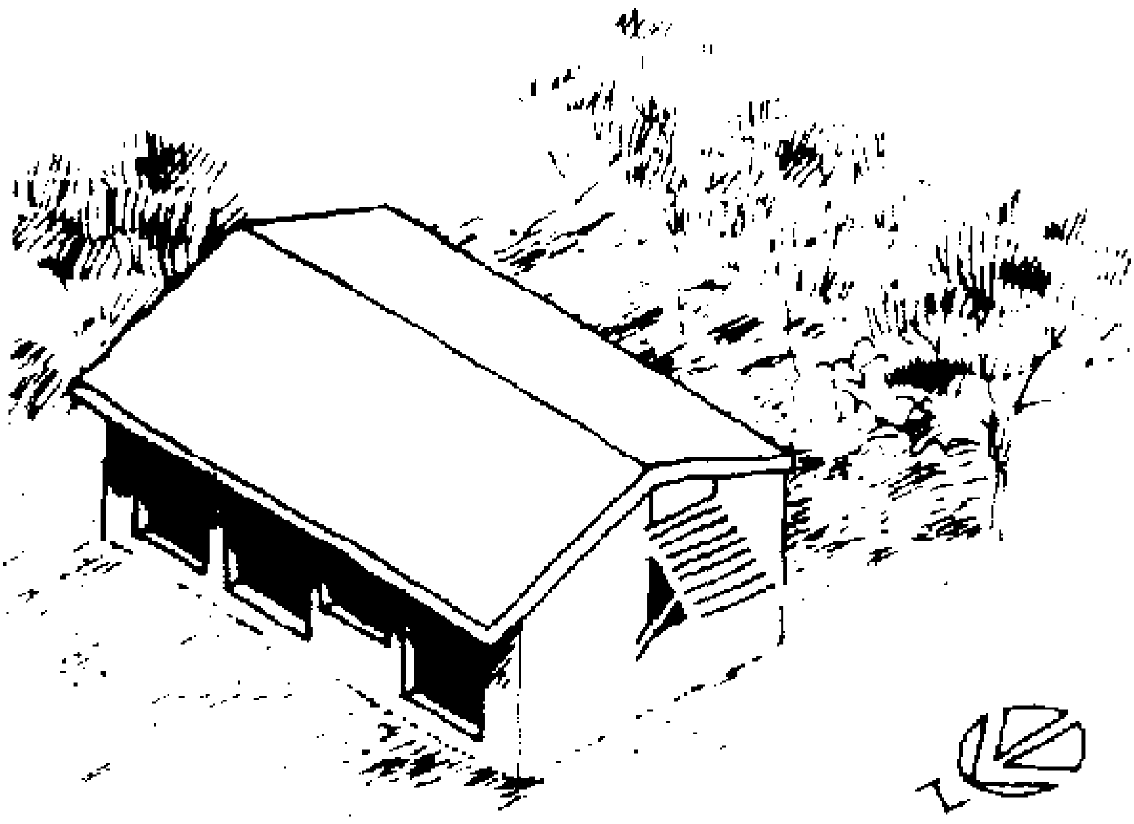


Figure 5. Example of a building having good performance and acceptable internal conditions.

Shade for north–facing windows is relatively easy with a simple overhang: this will still retain the view. East– and west–facing windows would need a full cover in summer which will restrict the view to the outside throughout most of the summer months.

Glass lets heat out in winter and in in summer by conduction approximately 10 times faster than an insulated wall, and three times faster than a brick–veneer wall. This is another reason for not having windows too large. The rate at which heat passes out through glass is fastest at night when it is very cold, so good curtains with insulating linings should be drawn across after sunset. These curtains should be close–fitting at the floor and the sides and have pelmets at the top. In an office, it may not be practical to do this, so It is necessary to accept that the rooms will be a little colder at night, when normally everyone will have left.

Sunlight through the roof using a clerestory may be practical where normal–level windows cannot be located to face north. Such a solution should be designed so that all the criteria of size and shading apply. Clerestory windows in the roof should be vertical in preference to sky domes and the like. The sun is overhead in summer and so much stronger than in winter on any surfaces near horizontal, such as roofs.

When renovating a building, consideration should be given to moving windows from the east and west sides to the north. Where this is not possible, clerestory windows should be considered. Unfortunately, terrace houses that face east or west are extremely difficult to improve in order to optimize solar energy, if not impossible.

"The sun porch" is another passive solar system which has tremendous potential for many houses, flats and units. Many buildings already have these but they lack a few details. In the 1930s they were called sun rooms and many houses were built with them. It Is important, agaun, that the glass faces north. Such a space with a large area of glass will trap a lot of heat. The space should, therefore, be connected to the rooms needing heath, with a simple exhaust fan at the top and a return ventilator at the bottom, as indicated in figure 6. The easiest place to install the fan is probably at the top of a window, but the exact position is not too important and will vary for each example. The sun porch then becomes a solar collector. There are many of these in Sydney already, and all that is needed is the fan and ventilators. At night, the temperature drops quite low in sun porches because of the large quantity of glass. Therefore, both the fan and the ventilator at the bottom should have a shutter or flap to be closed at night. Besides being a solar collector, the sun porch also serves as a useful room. This system is ideal for older–style houses where the fabrics and materials may be a delicate colour and would otherwise be damaged by lots of bright sunshine coming in all day during the winter.

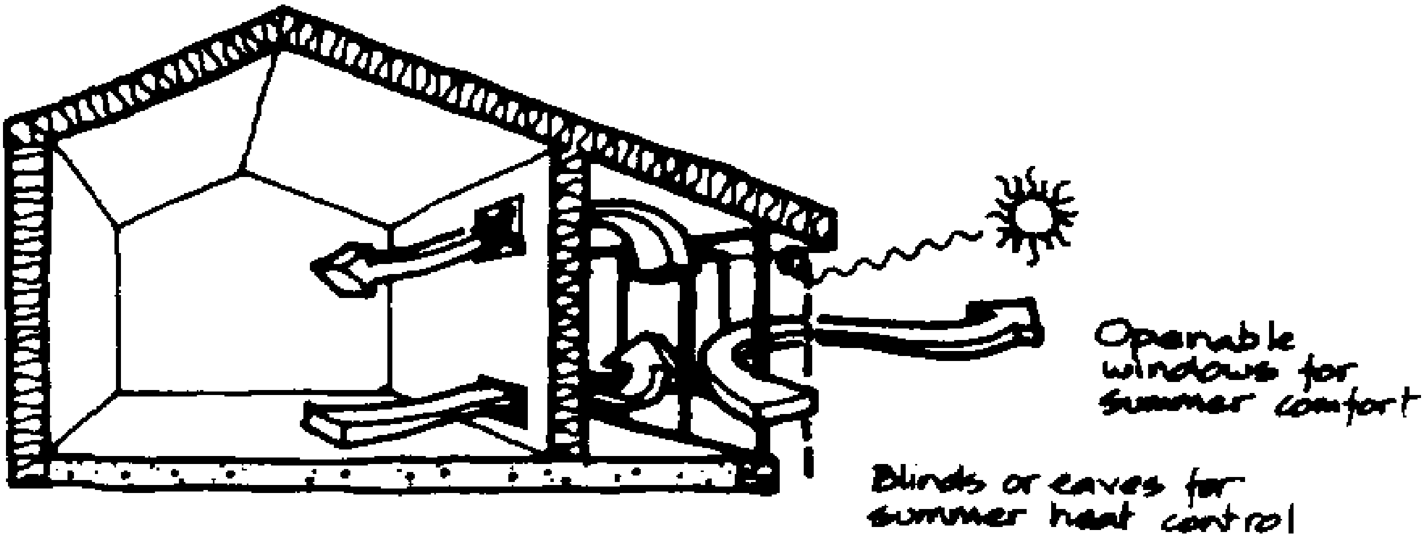


Figure 6. The sun porch concept.

In summer, it is important that the sun porch be well vented to the outside, so that the summer heat does not build up. One way to do this is to have sliding glass windows that allow 50 per cent of the glass to be opened. Another way of controlling the summer heat would be external shutters or blinds.

B. Importance of heat storage

Materials that are suitable for storing heat gained during the day so as to maintain warmth during cold nights are characteristically heavy. Those such as brick, concrete. mudbrick, stone and water are suitable whilst wood, plastic and other light materials are not, as the latter group has a low heat−storage capacity. In the temperate climates of Australia. and especially the hot−dry climates, every house should have plenty of heat−storing material Inside it. Anyone who has lived in an old, thick−walled building knows how cool it stays in the summer. Figures 7 and 8 show how two houses perform in summer. One has plenty of heat−storing capacity (double−brick construction) the other is timber frame without any heavy materials. In other respects, both houses are thermally well designed. As shown in figure 7 the brick building (B) has a smaller temperature swing than a timber building (T), and is more comfortable.

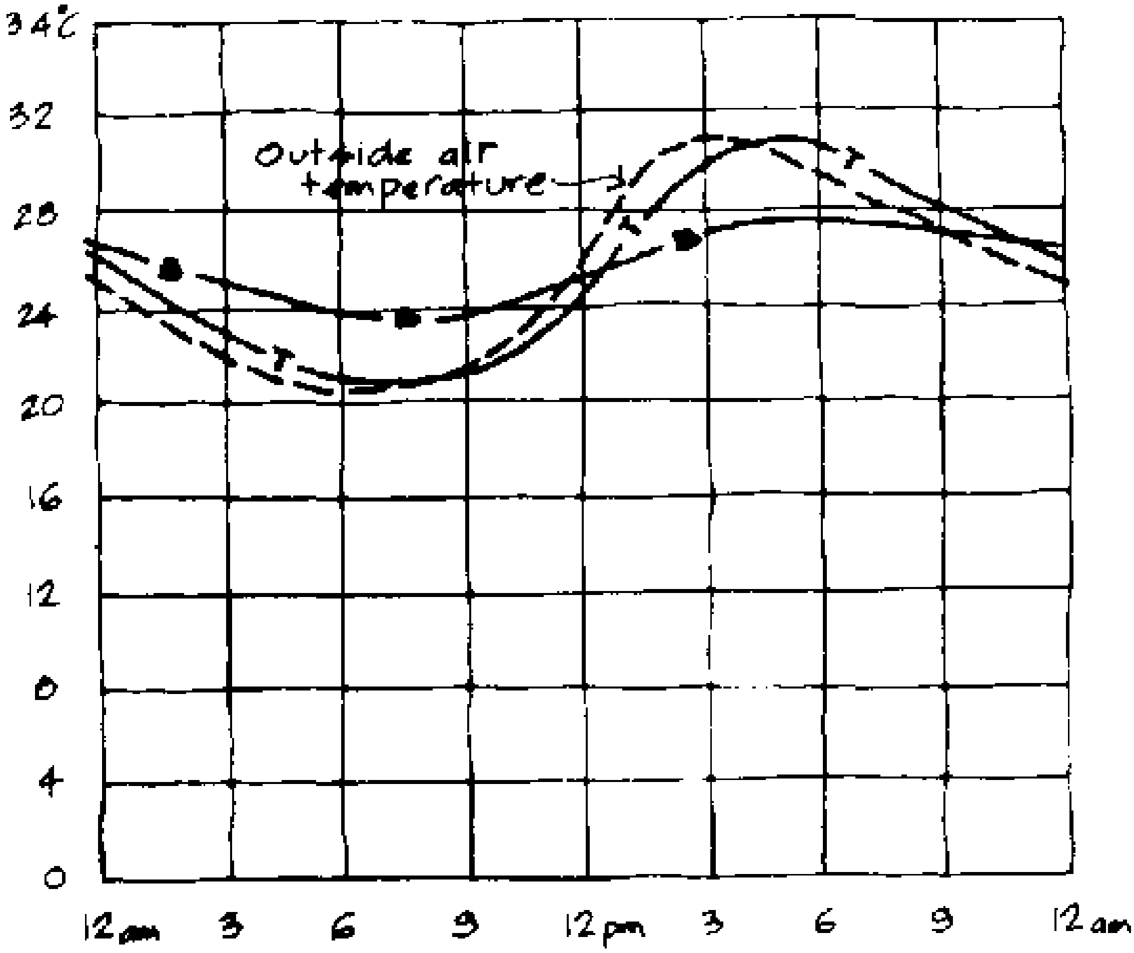


Figure 7. The effect of thermal mass in summer.

During the day, the heavy materials, such as the brick walls or concrete floors, soak up the heat that gets into the building. During the night it Is released to the cool night air which blows through when the windows are opened.

In winter, it is equally important to have heat–storage materials so that the sun's heat from the day can be stored to keep rooms warm into the evening. The figures show how the brick building (B) stays warmer than the timber building. Figure 9 shows how a concrete slab can be used in winter to store the sun's incoming energy. At night, when the room starts getting cold, the warm slab radiates heat back Into the space.

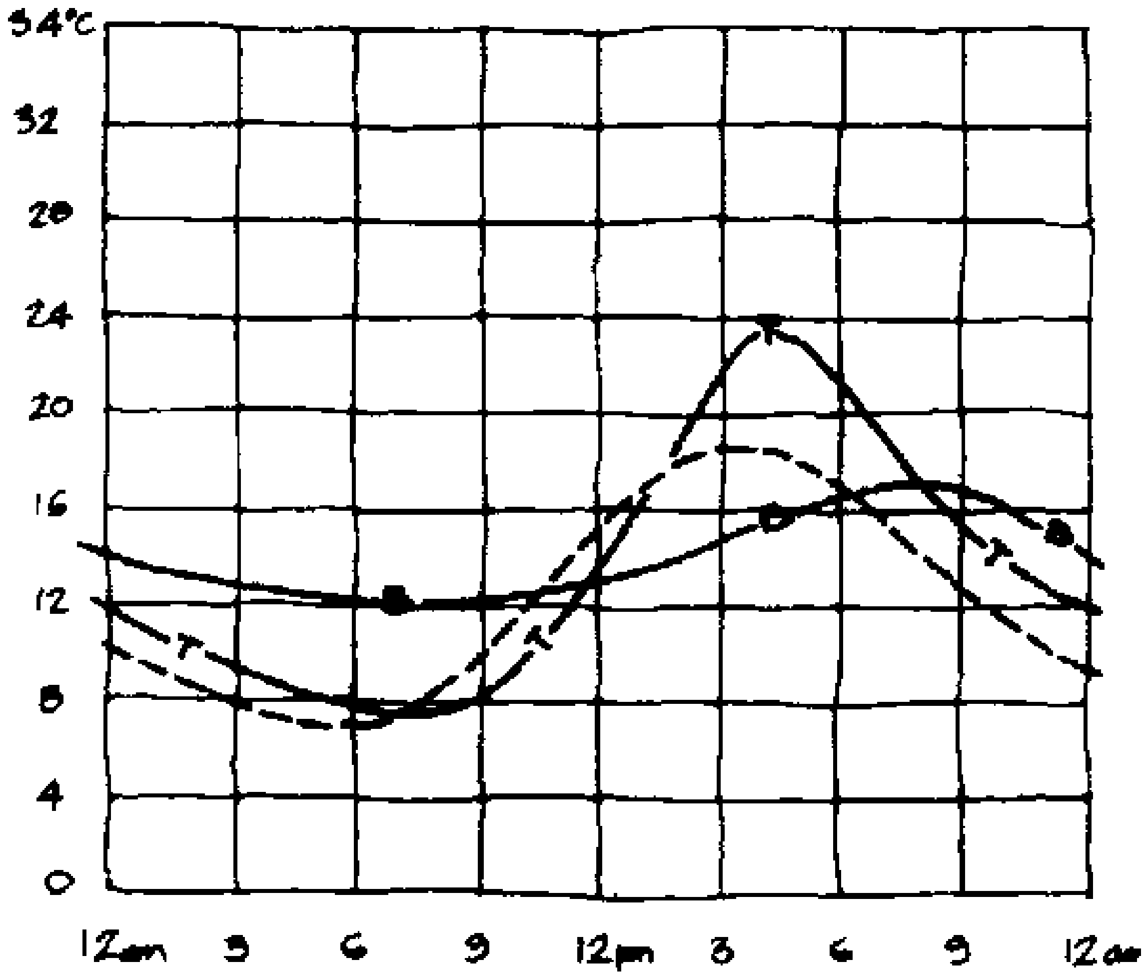


Figure 8. The effect of thermal mass In winter.

Water drums or bottles are another way of introducing heat storage into a building. There are a number of books available that illustrate ideas on how to introduce water as a storage material. Unfortunately, most of them are still only ideas and as yet many have not been fully proved.

There is scope here to experiment. The use of a concrete floor with quarry tiles or vinyl tiles is an excellent storage medium. especially where the sun shines directly on the floor. Wall–to–wall carpeting unfortunately insulates the floor from the room and so is not suitable. Scatter rugs can

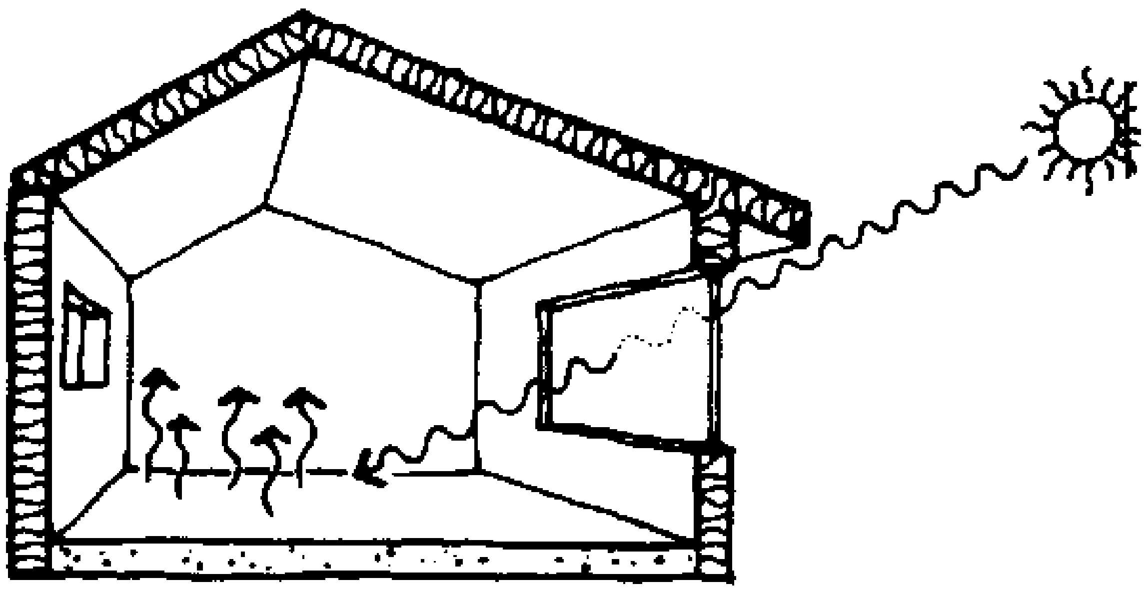


Figure 9. A concrete floor slab used In winter to store the sun's Incoming energy be used instead.

When insulation is being installed there should be no gaps. Holes in foil should be sealed with tape and glass fibre batts should fit snugly between the timbers.

Where there are existing walls of timber or brick veneer and it is not wished to replace the linings, there are a number of materials that can be inserted into the cavity, such as polystyrene beads mixed with a bonding agent, that set after a short time. In some cases various farm materials can be used.

Thermal insulation will help make a building easier to heat in winter by reducing the rate at which the heat is lost. Likewise, it will help to retain any solar heat that comes in. In the summer, it will help to stop heat from coming in through the walls and roof, thereby making it more comfortable inside. There will need to be plenty of shade for the summer, otherwise the building will still heat up, and then the insulation may make it hard for the heat to escape. Insulation should be left out because it will help in winter. Adequate shade should be arranged for the east and west as well.

There are many types of thermal insulation on the market today, and they can be classified as either reflective−foil or bulk insulation. The type of bulk insulation chosen might be made from glass fibre, paper pulp. acrylic fibres, U/F foam or even seaweed (eel grass). All these materials are suitable, and the choice should therefore be based on the particular application. the availability and price.

Buildings perform better with insulation when adequate heat− storage materials are included inside the rooms. Insulation will not improve the heat−storage capacity of a timber cottage with wood floors. Such a building will be warm during the day, but it will still cool off at night. It is important to add heat storage materials.

C. Using earth to save energy

As mentioned before, the use of concrete floors on the ground helps to include the earth as part of the heat storage medium. Earth. like other materials, does provide some thermal resistance, but in principle earth is not a good insulator. The benefit of earth is derived from its ability to slow down temperature change. Earth will slow down the variations between inside and outside. The temperature of earth about two and a half metres below the surface is relatively constant (at greater depths, there is almost no change year−round). The advantage of the temperature beneath the surface of earth is that it tends to be cooler in summer than outside and warmer in winter than outside.

It should be noted that earthberms (or banks) and earth− sheltered buildings require careful attention to waterproofing, drainage and structural support.

D. Energy losses through draughts

If heaters are used in winter, a lot of energy may be used to heat air which flows out through gaps. cracks and ventilators. In a fully−heated house, the cost of those draughts and leaks could be considerable.

In existing buildings, it would be worthwhile to stop up cracks around doors and windows. Where floors have shrunk, the gaps between skirting and floor, and of ventilators on the inside of walls and in ceilings should be closed. In bathrooms and kitchens, it is less wasteful of energy to install an exhaust fan for use when needed; but fans should have some type of shutter which closes when they are off, again to stop draughts. Fireplaces should have a damper or a tight fitting cover for when they are not in use; it is easy to feel how much warm air they are drawing out when they are open. There are many sealing materials available today from hardware stores for doors and windows. These will reduce the need for heat, and thereby increase comfort. When the desire is to be comfortable in winter, draughts are expensive.

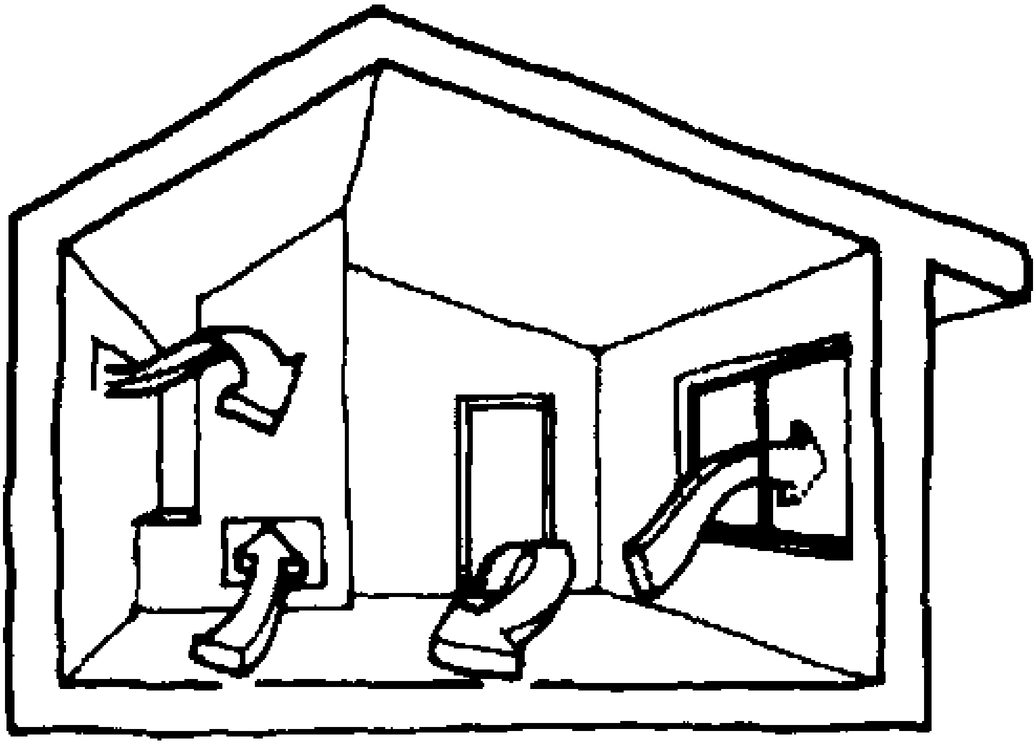


Figure 10. Possible infiltration paths.

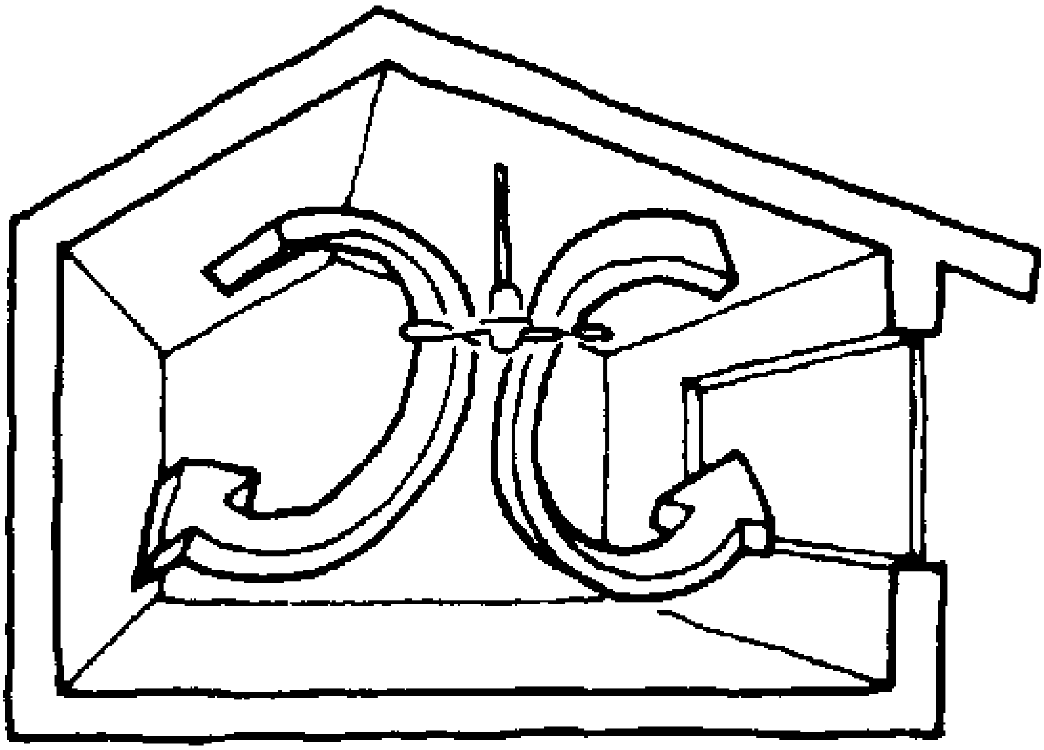


Figure 11. Use of celling fans to create cooling air movement in summer. and In winter to shift warm air near the ceiling down to where the room's occupants are.

To get the fresh air needed, the most energy efficient way is to open windows during the day when it is warmest outside and to close them fight at night. In summer. to keep the inside cool. the opposite is done to use the cool night air. Ceiling fans in summer will produce air movement which tends to cool. This is better than letting in the hot daytime air.

There are many houses around the world that do not need heating or cooling, yet they are always comfortable. By careful design and simple management of a building it should be easy to make it more comfortable in both summer and winter.

II. The Australian climates and people

A. The population

More than half of the Australian continent is regarded as desert. Although it is the hottest and driest non–polar continent it has, however, a large range of climates which greatly influence the life–style of its population, the majority of whom live in the more temperate areas, although that is changing slowly as the population expands.

The population of Australia is in excess of 15 million people, most of whom live in the urban centres around the eastern and south–eastern coast. The climate of the coastal areas is generally temperate. The central region is generally hot and arid, not unlike other large land masses.

B. Climatic influences and lifestyles

Australian climates differ from those of Europe and North America (from where most of the available literature on passive solar design comes) in that for much of the year the diurnal ambient temperature range moves in and out of the accepted comfort range. Generally, In summer maximum temperatures are above the comfort zone whilst in winter the minimums are below. For many locations, comfort conditions are not achieved outside during winter at any time of the day. The problem of comfort in some locations such as Sydney, Adelaide, Perth, Canberra and Brisbane has to do with summer overheating whilst in others such as Hobart it is more one of underheating in winter.

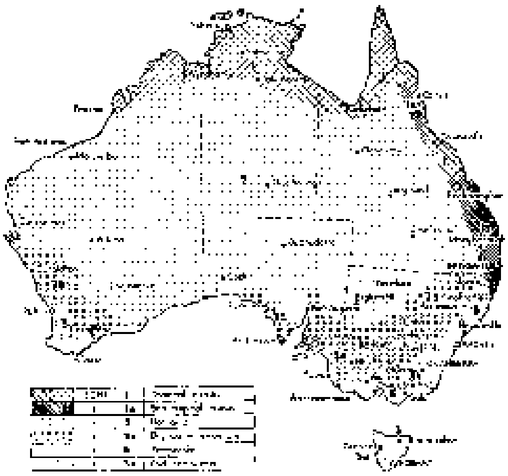


Figure 12. The Australian continent climatic zones.

Locations such as Canberra, the country's capital, are both cold in winter and very hot in summer. Winters are more sunny than those of Northern Europe and so solar energy can play an important role in reducing domestic energy consumption. It has been shown In many studies that passive solar design and energy–conservation techniques are very cost–effective in Australia. These climates allow enjoyment of the outdoors generally throughout the year except on days of temperature extremes. This, along with the relatively low cost of energy in the domestic sector, has contributed to a lack of concern about energy matters.

The Australian continent (see figure 12) can be described generally as having an arid central region with a border of tropical, monsoon climate in the north and a predominantly Mediterranean climate with hot dry summers and cool to mild, wet winters in the south. The eastern coastal strip and adjoining uplands have a more evenly distributed rainfall. In northern New South Wales and along the Queensland coast the climate is moist tropical whilst along the coast of southern New South Wales, Victoria and Tasmania it is generally classified as moist temperate. The mountain ranges and tablelands along the east coast could be described as cool temperate.

It is always difficult to relate the general meteorological description of a country's climates to that of climatic characteristics for thermal comfort in buildings. The general description is usually intended to cover the agricultural aspects, and is quite inadequate for building–design purposes.

This guideline document will address the design parameters for three general climatic types in chapter V.

The hot arid climates. to some extent, also includes the dry summer climate of the southern coast (Mediterranean style). These areas are characterized by hot, low−humidity summers and cool to chilly but generally sunny winters. In the central arid zone summer temperatures are generally very high (35−40C during the day) with cooler night−time conditions and varying breezes (usually approximately 20−25C).

The cool temperate climates are those where the winters are cold and the need for heating is far greater than the need for cooling in summer. Tasmania and many locations in the southern and northern tablelands of New South Wales are locations with such a climate. The major design consideration in such a climate will usually be winter heating. In summer the concern is to avoid overheating by good design. Cooling should not be an issue as the daytime ambient temperature is normally in the desired temperature range for thermal comfort (less than 27 °C).

The hot humid climates in Australia are characterized by high humidity levels in the wet season and the lack of a heating season. The strategies for good climate design are quite different from those suited to the other climate zones.

The three climate categories described are an over− simplification of the specific local climates that can be found throughout Australia. They are, however, adequate to describe the basic approach to design for passive solar heating and natural cooling of small−scale buildings. Some of the more detailed aspects of climate will be addressed with the specific design strategies and details where appropriate in the text. An excellent and extensive source of climate data for building−design purposes has been prepared by Szokolay and is available through RAIA bookshops, ARCHITEXT.

Australian houses are generally larger than one might expect to find in Europe, the average area being 120 to 140 m. In recent years Australians tended to follow more the American model of open−plan living and clear visual connection to the outside. This has produced houses that are energy−inefficient, with glazing oriented with little regard for the sun's movement, despite the resultant overheating effects that occur in summer. and the lost opportunities provided by generally sunny winters.

Although most people consider Australia to be a warm sunny place, many of its centres of population are very cold in winter (Canberra 2270 heating degree days and Melbourne 1500 heating degree days). About 14 per cent of all primary energy and about 50 per cent of all electricity generated is used in the domestic sector. Rising expectations for standards of living are resulting in a growth in per capita energy use while peak energy demand is also growing. particularly through the increasing use of air conditioning. In Melbourne approximately 50 per cent of energy used in the domestic sector is used for space heating and cooling. In New South Wales, the state with the largest population, 45 per cent of all electricity is used in the domestic sector. The result is that issues affecting the consumption of electricity (either up or down) become very politically sensitive. Australia relies mostly on coal−fired thermal generating plants for electricity due to the abundant coal supplies.

Figure 13 shows the relative severity of the climate of the major population centres and approximate per capita energy consumption in the domestic sector. About 70 per cent of Australia's population lives in urban centres with 60 per cent living in five of the main cities or their satellites, Sydney, Melbourne, Adelaide, Hobart and Canberra. All of these cities have a significant heating and cooling load by Australian standards.

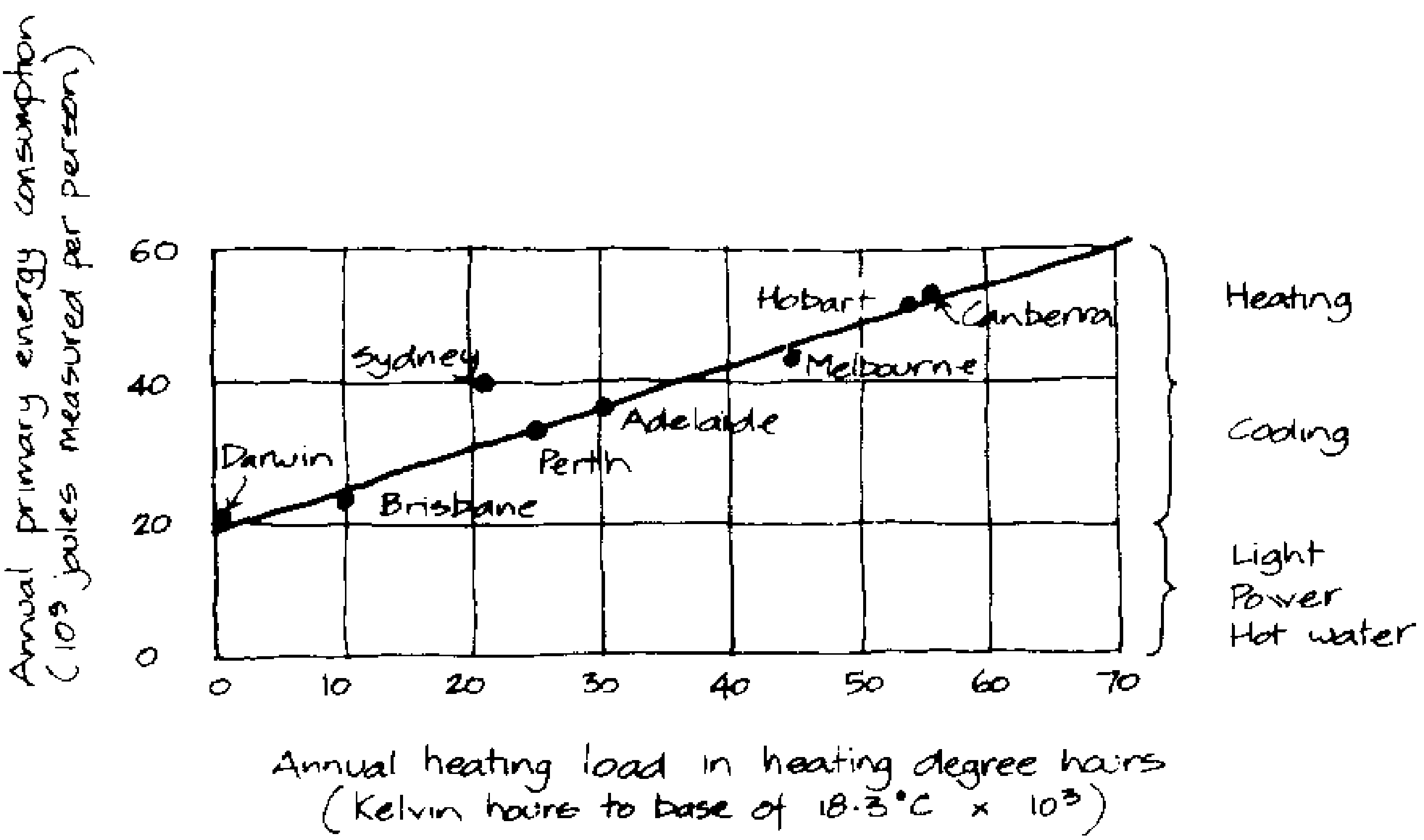


Figure 13. Graph of per capita energy consumption In the bulit environment for Australian capital cities compared to winter climate In terms of heating degree−hours.

The results of surveys conducted to determine public attitudes to energy conservation. show that saving energy Is perceived to be a reduction in standards and not an action to aspire to. Yet. it has been found that people always seek higher standards of comfort. If this can be achieved at no increase in running costs or even a reduction in running costs, then it is desired. The problem then is to market these ideas to the home−buying public.

Unlike most other developed countries of the world, there are no regulations relating to energy conservation such as mandatory insulation levels in Australia. An attempt was made a few years ago to introduce regulations requiring very moderate levels (R1.0 m K/W) of insulation to ceilings of all new houses in Tasmania, the coldest and most southern state of Australia. This was thwarted by a state government election. At present, there is a draft code In Victoria which many hope will be presented to Parliament in the near future. The proposal, if adopted in full, would require that all new houses be built with a minimum of R2.0 m K/W added resistance in the ceiling and R 1.0 m K/W added resistance in the walls. There is a strong feeling that there should not be regulatory controls over the use of insulation, due to the increased costs that would be Imposed on building costs. In spite of the lack of regulation, ceiling insulation is used widely in most states. Wall insulation is being introduced gradually and some project builders (builders of standard−design houses) are now offering full insulation of ceilings and walls as a bonus in their sales package.

III. Fundamentals of heat flow

A. Simple heat flow

There are three basic modes of heat transfer and all heat or energy movement must be by one or more of these three.

Conduction is the transmission of energy between two bodies which are in direct contact. An example is a pot placed on an electric heating element: it receives energy by conduction (or direct contact).

Radiation is the transmission of energy by electromagnetic rays. These rays are felt when standing in the sun's path. Only these rays can travel through a vacuum such as outer space to heat the object that intercepts them. The earth, therefore is warmed in this way by the sun.

Convection is the transmission of energy through a fluid. An object heats the particles that make up the fluid such as air or water. The warmed fluid travels to nearby objects or surfaces and warms them if they are relatively cooler than the fluid mass. The movement usually occurs because the warmed fluid is less dense and tends to float up, unless the fluid is being moved by a fan or pump. A fan−blower heater is an example of heating by convection. and a cool breeze cools by convection.

Heat (energy) will always flow from a hotter body towards a cooler body rather than vice versa (the second law of thermodynamics). The rate at which that heat will flow is proportional to the temperature difference and inversely proportional to the resistance of the heat path. As an example, in the case of heat flow from, say, the inside to the outside of a building element such as a wall, the rate at which heat is lost will be proportional to the temperature difference between the air on one side of the element and the air on the other side. Likewise, the rate of heat−lost will be reduced as the resistance of the wall is increased. Designers can do little to change the temperature difference unless they simply accept a temperature inside too low for comfort in winter or a high temperature in summer. This may be chosen as a solution to a design problem, but most people will find it less than acceptable. If they can afford it they will use more energy to overcome the greater heat−loss rate. This should be unacceptable to designers today.

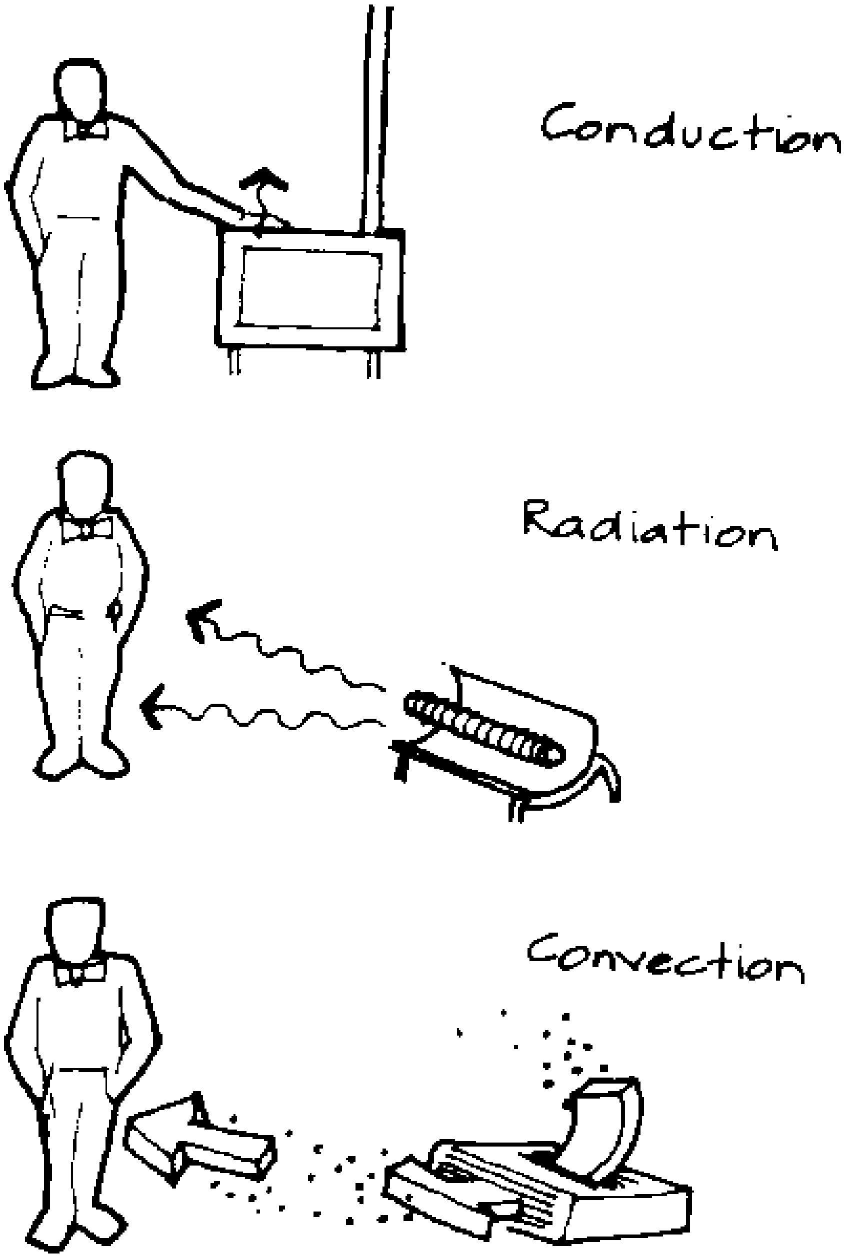


Figure 14. Modes of heat transfer

The alternative is referred to in jargon as "leak plugging which is what this is all about. There is a lot that can be done by choosing the right materials to reduce the rate of heat flow. The unit of heat flow in SI units is the watt (W), i.e., 1 joule/second. Consider a material in an environment where the temperature differs by 1 C from one side to the other. If heat flows at the rate of 1 watt per square metre and the material is 1 metre thick, then it is said to have a conductivity of 1 W/m.degC. This measure is a good technique to compare materials but it is also necessary to know the actual heat flow rate through the unit area of a given thickness. This is known as the thermal conductance (C) and its units are W/m.degC. Given the conductivity (k) of a material, one can derive the conductance (C) from k/b, where b equals the thickness of the material in metres. A table of conductivities for various commonly used materials can be found in annex VII.

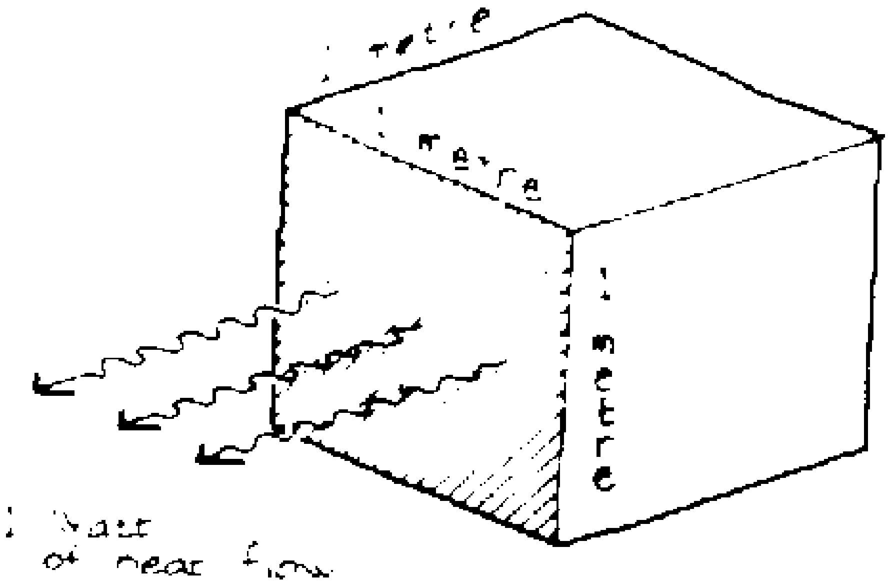


Figure 15. Thermal conductivity – unit heat flow through unit area and unit thickness

B. The conductivity of different materials in groups

Heavy material such as masonry

Heavy materials such as stone, concrete, and clay (brick) are considered to be rather cold to feel. They have a conductivity in the range of unity (approx. 0.5 to 1 .5 W/m.k) and so in building terms are not particularly good in resisting heat flow.

Metals

They have a much higher conductivity and so "feel cold as steel" because they conduct heat very effectively compared with other materials (conductivity: steel 47.5 W/m.k, aluminium 220, and copper 350). These materials are excellent conductors and so can present problems in terms of heat bridges in walls and multi–pane windows.

In the other direction the so–called warmer materials have a much lower conductivity.

Wood

The conductivity of timber is an order of magnitude lower than that of the masonry materials, approximately 0.1 to 0.15 W/m.k, and so, relative to materials such as stone and metal, it is considered to be a warmer material.

Insulators

The materials used to insulate buildings are chosen from materials with a conductivity an order of magnitude lower still. The conductivity of mineral fibre blanket (rockwool and glass fibre) is approximately 0.034 W/m.k. Air is in fact the basic operative component in all of these (conductivity of air = 0.024 W/m.k at 10°C). Glass by itself has a conductivity of 1.05 W/m.degC which is in the range of brick. stone etc.

C. Thermal resistance

To determine how a material fares in the make up of a structure, reference is made to what is called the thermal resistance (R) which is the reciprocal of the thermal conductance (C)

R= b/k

The R−value is a measure of the ability of a given thickness of material to resist thermal transfer.

Thermal resistance's can be added together to give a total resistance of the building element:

$$R_b = R_1 + R_2 + R_3 + R_n = \sum .R \quad \text{i.e.,} \quad \sum b/k$$

This is the total resistance of a material made up of n solid homogeneous slices, face to face (such as plaster and cement render on a single brick wall).

D. Surface resistance

To complete the picture, it is necessary to consider the effect of the air film on the two surfaces of the material or building section, because in evaluating a building element, what is of concern is the transmission of heat from the air on one side to the air on the other. Each face has a resistance effect due to the flow of heat passing from one medium to another (in this case from fluid to solid). This is known as a boundary resistance or surface resistance, often referred to in the literature as the film coefficient. It includes the combined effect of the convective and radiative components of the heat exchange at the surface.

Surface conductance (f) Is $W/m^2.degC$

Surface resistance (1/f) is $m^2.degC/W$

Generally in design computations the inside air film layer (fi) is considered to be still air whilst the outside layer Is considered as moving air. Relatively speaking the inside air can usually be considered to be still compared with the outside air movement.

The two values of outside surface resistance and inside surface resistance will always differ as they are subject to different constraints. Tables 1 and 2 show values for both high and low emissivity surfaces. Most common building materials have a high emissivity (i.e., approximately O.9). The low emissivity values should be used where the exposed visible surface is polished aluminium or similar material (for example, reflective foil lining in a factory ceilings). The values given will vary from reference to reference but for most purposes the differences are negligible.

Table 1. Inside surface resistances (1/fi)

			Surface resistance (m^2.degC/W)
Building element	**Heat flow**	**High emissivity (E = 0.9)**	**Low emissivity (E = 0.05)**
Walls	Horizontal	0.12	0.30
Ceilings or roofs, flat or pitched or floors	Upward	0.11	0.22
Ceilings and floors	Downward	0.15	0.56

Table 2. Outside surface resistances (I/f_o) (m.degC/W for "sheltered", "normal" and "severe" exposures.

Building	**Emissivity**	**Surface resistance for stated exposure**		
		Sheltered	**Normal**	**Severe**

	High	0.08	0.06	0.03
Walls	Low	0.11	0.67	0.03
	High	0.07	0.05	0.02
Roof	Low	0.09	0.053	0.02

The outside surface resistances for walls are computed on the assumption that wind speeds at two thirds of those at roof surfaces are appropriate. It should be noted that outside calculations are unaffected by orientation. All walls are assumed to receive little sunshine in winter heating design weather for the purpose of wind exposure assessment and thus are subjected to the same conditions of free wind speed based upon their geographical position and their height above ground, as follows:

Sheltered: Up to the third floor of buildings in city centres.

Normal: Most suburban and country premises: fourth to eighth floors of buildings in city centres.

Severe: Buildings on the coast or exposed on hill sites: floors above the fifth of buildings in country districts: floors above the ninth of buildings in city centres.

E. Cavity resistances

Not all building sections are made up of solid homogeneous compositions. Some. such as a brick−veneer wall or pitched roofs, have air spaces and cavities as part of their make−up. In such situations, air spaces can be treated as a medium with a thermal resistance because the total radiative and conductive heat transfer is approximately proportional to the temperature difference between the two boundary surfaces of the cavity.

Heat moves across an air space in three ways:

Radiation 61 percent
Convection 28 per cent
Conduction 11 per cent

However the overall thermal resistance of an air space depends to varying degrees on:

(a) Surface emissivity: Most building materials have a high emissivity in the range of 0.9 to 0.95 and so radiation accounts for about two−thirds of the heat transfer;

(b) Thickness of the air space: The thermal resistance of a tall vertical space increases with its thickness up to about 20mm. At greater thick−nesses the thermal resistance is virtually constant;

(c) Direction of heat flow: A horizontal air space presents a higher resistance to downward than to upward heat flow because downward convection is small in comparison with upward convection flow (since hot air rises);

(d) Inclination of airspace and temperature conditions The inclination of the air space has only a minor effect on convection transfer;

(e) Effect of corrugations or roughness If the upper surface of the air space is corrugated as in some roof spaces, the surface area of the upper surface is increased by about 20 per cent. This however has a negligible effect on heat flow;

(f) Effect of airspace ventilation: Airspace ventilation provides an additional heat flow path, which decreases the effective airspace resistance.

Table 3 (shown on next page) provides values for the resistances of cavities and attic spaces under various conditions. It should be noted that high emissivity surfaces should be assumed unless reflective foil is used as a lining to one of the cavity surfaces. Ventilation occurs through gaps between cladding sheets and tiles, so a tiled roof without sarking should be considered as being ventilated. The thermal resistance also depends, to some extent, on the relative temperatures of the boundary faces. i.e., the solid materials on either side.

Where the air space being considered varies greatly from the range given, it may be advisable to interpolate between values to obtain an appropriate resistance for the specific air−space thickness. Marcus and Morris 5 provides a full description of air−space resistances. For most purposes the values given should suffice as there are limits to the accuracy that can be achieved using a steady−state approach and as stated before many assumptions are made regarding the wind effects.

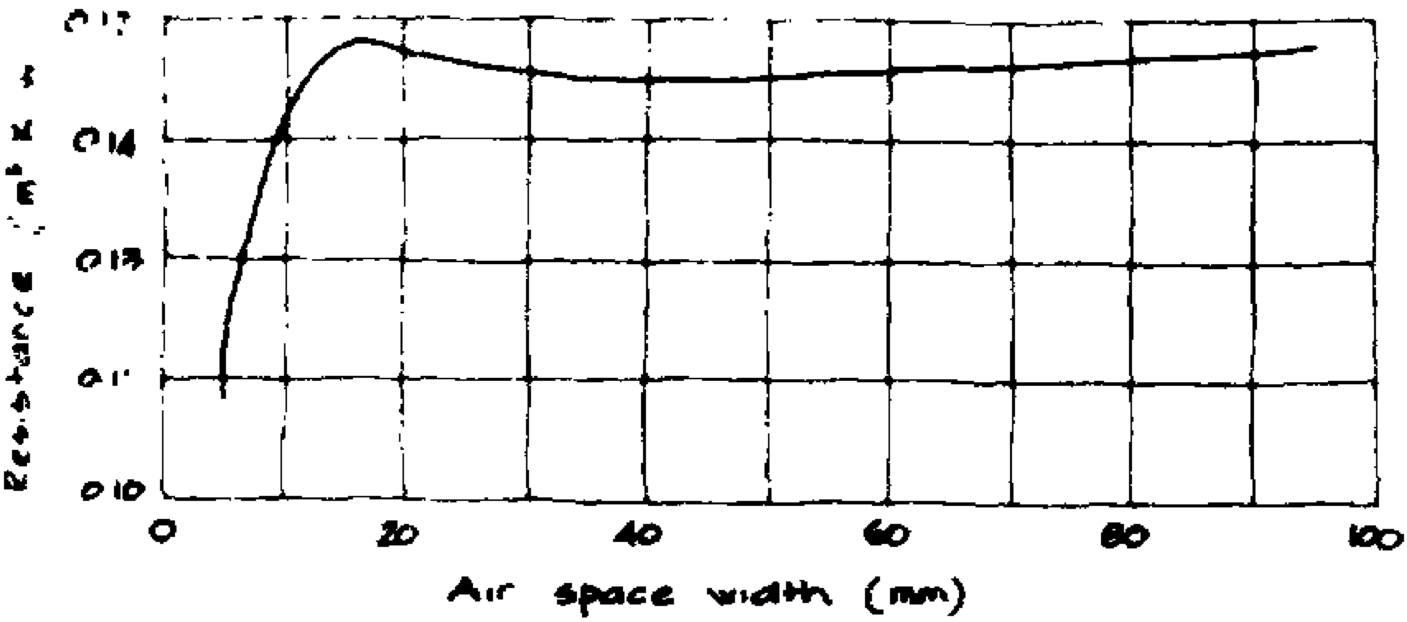


Figure 16. Variation of thermal resistance of an airspace with width of the airspace

Table 3. Thermal resistance of airspace (m.degC/W)

Heat flow direction	Airspace thickness	Conditions outside	Airspace	Surfaces non−reflecting
		Summer	.40	.13
	20 mm	Winter	.39	.15
Up		Winter (cold)a	.29	.14
	100 mm to approx. 250 mm	Summer	.48	.14
		Winter	.48	.17
		Winter (cold)b	.36	.15
	20 mm	Summer	.57	.15
		Winter	.63	.18
Down	100 mm to approx. 250 mm	Summer	1.42	.17
		Winter	1.57	.22
	20 mm	Summer	.58	.15
		Winter	.61	.18
		Winter (cold)a	.49	.17
Horizontal	100 mm to approx. 250 mm	Summer	.61	.16
		Winter	.61	.18
		Winter (cold) a	.49	.17

Source: IHVE Guide 1977 − A3 − 7

a/ Refers to winter conditions in climates such as those which exist at Canberra (Ace. Bathurst (NSW), and Tamworth (NSW). where the main outside temperature can be as much as 17 degC below the mean Inside temperature.

F. Thermal transmittance

The foregoing provides all the basic ingredients for calculating the air to air transmittance of the buildings elements, more commonly known as the U−value with units of W/m.degC.

The U−value of a construction can be found from the following formula:

$$U = \frac{1}{1/f_o + b_1/k_1 + b_2/k_2 + b_n/k_n + 1/f_j}$$

where

$1/f_o$ = external surface resistance (m.degC/W)
$1/f_j$ = internal surface resistance (m.degC/W)
b = material thickness in metres
k = conductivity of material W/m.degC (or W/m.degK)

The construction may comprise 1 to n elements.

This is the reciprocal of the sum of all the resistance (not the sum of all the reciprocals of the resistances).

Table 4. Suitable values for Rattic (m.deg C/W)

	Summer	Winter
Non−vented, non−reflective	0.282	0.176
Vented. non−reflective	0.458	Nil
Non−vented, 1 RFL surface E=0.05	1.092	0.564
Vented, 1 RFL surface E =0.05	1.356	0.335

The U−value of a pitched roof.

$$U = \frac{1}{(R_{os} \cdot C_{os}) + R_{attic} + R_2 + 1/f_j}$$

Worked example No. 1

To find the U−value of a solid brick wall 230 mm thick with 20 mm cement render on out side and 10 mm plaster inside.

(Look up tables in the annexes to obtain surface resistances and conductivities)

1 $/f_o$ = 0.06m.C/W
1 $/f_j$ = 0.12m.C/W

Cement render	k = 0.53 W/m.C
Brickwork k	= 1.15 W/m.C
Plaster	k = 0.46 W/m.C

U−values for a pitched roof with attic space.

R1	= total resistance of sloping roof section
R2	= total resistance of ceiling section
$1/f_o$	= outside surface resistance
$1/f_j$	= inside surface resistance
R_{os}	= Resistance of outer skin including outside surface
	= (R1 + 1/fo)

Modification values for R_{os} as a varies

a	– 22.5° pitch	= 0.95 R_{os}
	– 30° pitch	= 0.87 R_{os}
	– 35° pitch	= 0.82 R_{os}
	– 45° pitch	= 0.70 R_{os}

$$U = \frac{1}{1/f_o + 0.002/0.53 + 0.23/1.15 + 0.01/0.46 + 1/f_j}$$

$$U = \frac{1}{0.06 + 0.038 + 0.2 + 0.022 + 0.12} = 1/0.44 = 2.273$$

(rounded off) = 2.3 W/m^2.degC

Worked example No. 2

To find the wintertime U−value of a 270 mm cavity brick wall (face brick both sides). (Look up tables in the annexes to find surface resistances, conductivity. and air space resistance)

$1/f_o$ = 0.06 m.C/W
$1/f_j$ = 0.12 m.C/W
Brickwork k = 1.15 W/m.C
Airspace resistance R_a = 0.17

$$U = \frac{1}{1/f_o + 0.11/1.15 + R_2 + 0.11/1.15 + 1/f_j}$$

$$U = \frac{1}{0.06 + 0.096 + 0.17 + 0.096 + 0.12} = 1/0.54 = 1.85$$

(rounded off) = 1.9 W/m.degC

IV. Thermal comfort

The principal reason for constructing buildings is to provide protection from the environment and security of person and property. What is sought is protection from the environment when there is inadequate thermal comfort. A building can control the environment to provide for thermal comfort by either active or passive energy mechanisms. Unfortunately, too many buildings designed today are dependent on non−renewable energy sources to provide the desired thermal comfort instead of making use of the energy from the sun and the natural capacity of the climate.

The human body is a complex mechanism that is comfortable under a relatively limited range of environmental conditions. It needs to maintain a relatively stable "deep body temperature" at approximately 37C. The body continuously produces heat at rates that depend on its level of activity and. depending on the conditions of the environment, it gives off heat at various rates. If someone feels cold, it means that the body is giving off heat too quickly. Likewise, if someone is too hot then it is because the body cannot rid itself of body heat fast enough. Under normal sedentary conditions in a comfortable environment an average person gains or looses heat in three ways in approximately the following proportions:

Evaporation 25 per cent
Convection 30 per cent
Radiation 45 per cent

Only a minimal amount of heat is dissipated by conduction. Table 5 gives some examples of the rate of heat dissipation by an average sized human in good health for various activities:

Table 5. The body's heat production

Activity	watts
Sleeping	min. 70
Sitting, moderate movement, e.g. typing	130−160
Standing. light work at machine or bench	160−190
Sitting, heavy arm and leg movements	190−230
Standing, moderate work, some walking,	220−290
Walking, moderate lifting or pushing	290−410
Intermittent heavy lifting. digging	440−580
Hardest sustained work	580−700
Maximum heavy work for 30−minutes duration	max. 1100

A. Variables influencing comfort

There are six main variables that influence the conditions of thermal comfort and the first three can be influenced by the design of buildings. Buildings can be designed to assist or hinder the occupants in their control of the fourth variable; humidity. It is important that the last two be taken into consideration, although it is not possible to control them.

(a) Air temperature:
(b) Mean radiant temperature:
(c) Relative air velocity;
(d) Humidity (water vapour pressure in the ambient air):
(e) Activity level:
(f) Thermal resistance of clothing.

Air temperature is the most commonly referred−to measure of thermal comfort but it is not the complete definition. It is called shade temperature when describing the outside or ambient temperature and dry bulb temperature when used to refer to the indoor air temperature.

Mean radiant temperature is defined as the weighted average temperature of all the exposed surfaces in a given space (obtained by averaging the temperatures of the surfaces to which the body is exposed. weighted by the solid angle subtended by each). For example, the mean radiant temperature of a room in winter will be considerably influenced by a large uncurtained window which Is very cold.

Relative air velocity or air movement is an important aspect of thermal comfort, especially in warm or hot climates. Air moving over the skin increases heat loss by convection and if the skin is wet further cooling results from evaporation.

Humidly is usually an important consideration only when the air temperature is close to or above the upper limits of thermal comfort and the relative humidity is above 70 per cent or below 30 per cent. When the relative humidity levels are high then air movement becomes an important mechanism for removing the heat the body generates.

Another important variable is state of health, It is not usual to consider this in building design, except for hospitals and accommodation for older people or the very young, where the environmental conditions will directly influence the health and well−being of the occupants. In such situations the upper and lower temperature limits may require special consideration in determining plant.

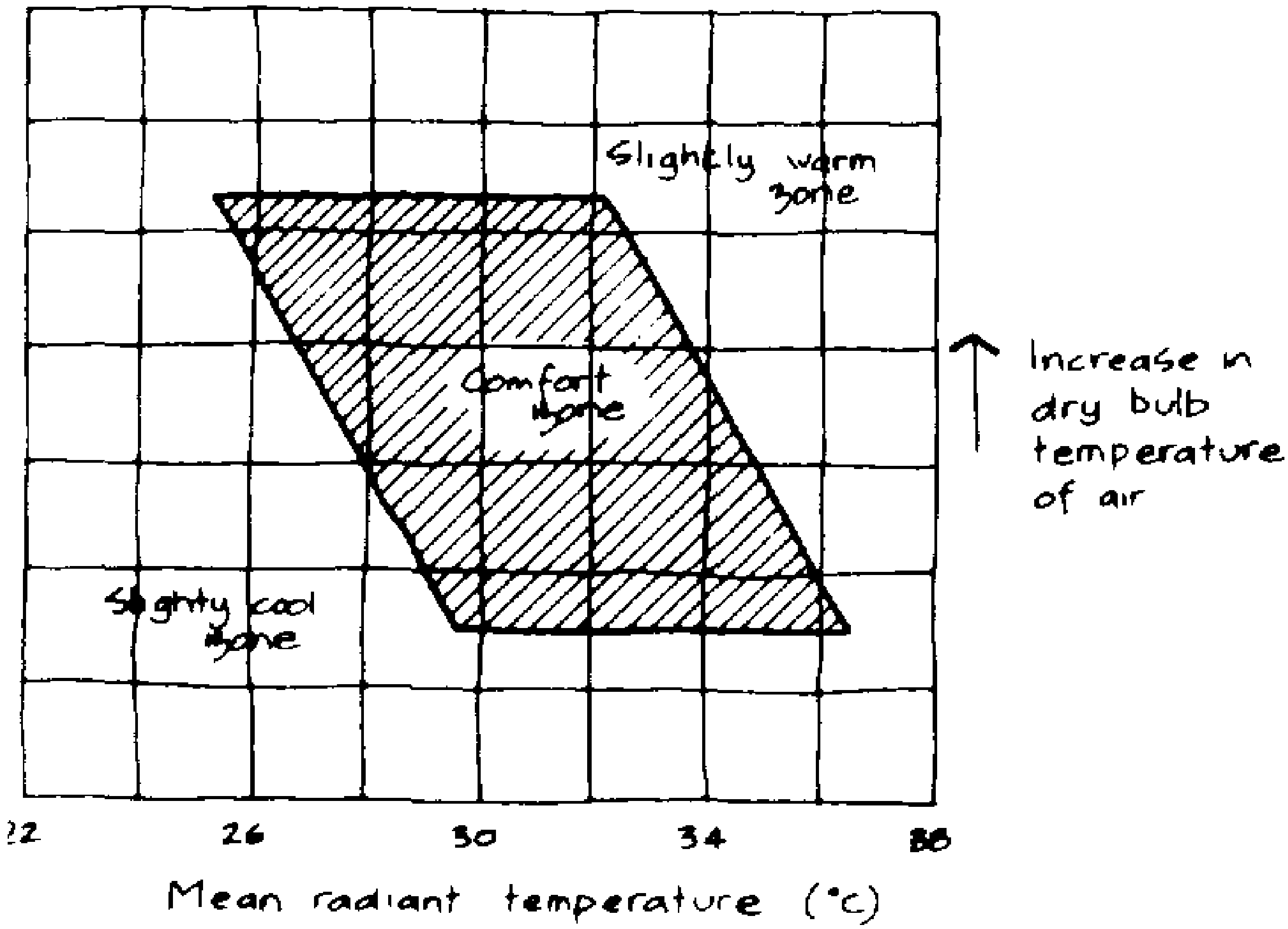


Figure 18. The effect of changes In MRT and air temperature on comfort

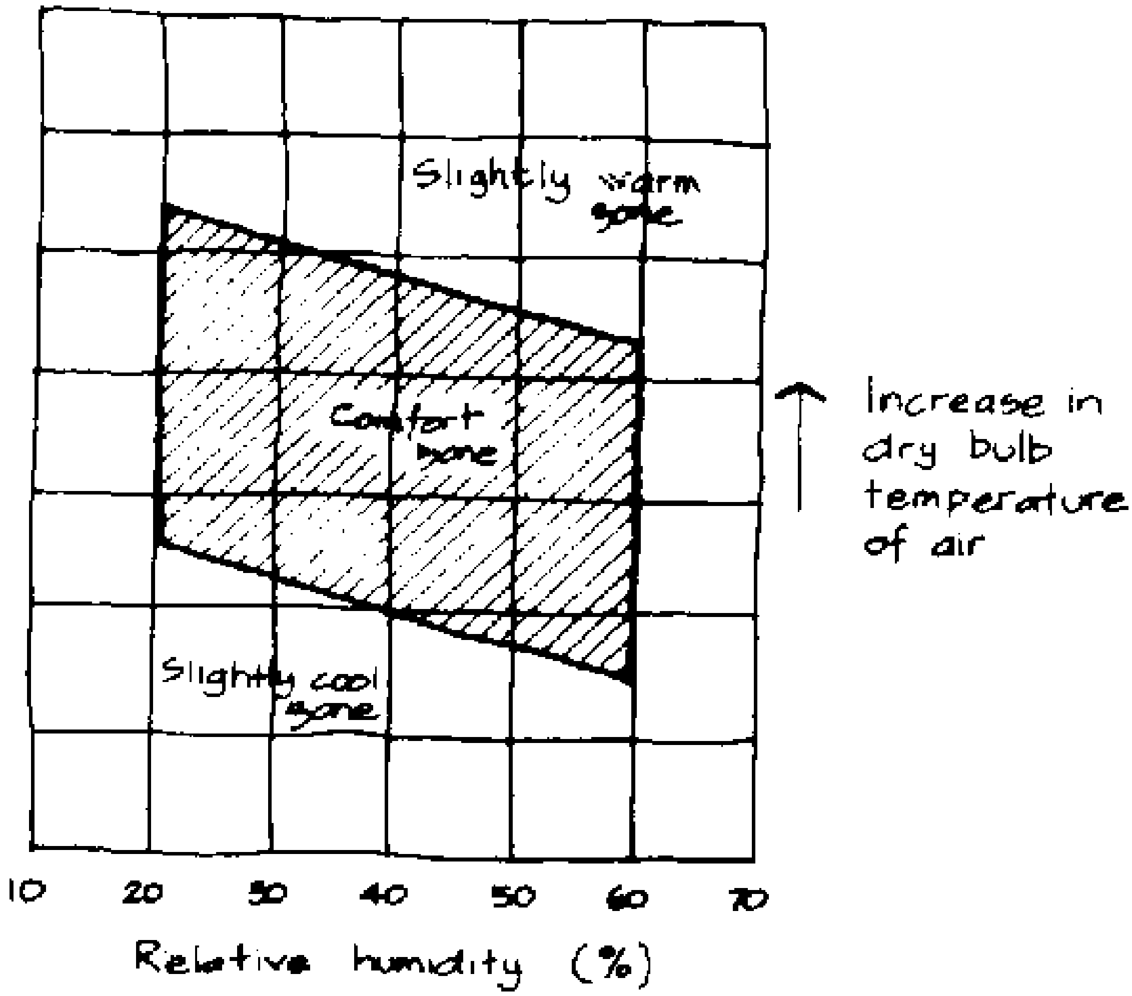


Figure 19. The comparitive effects of altering the relative humidity and the dry bulb temperature of the air.

B. Environmental comfort

The term environmental temperature is used in this publication instead of dry bulb temperature or air temperature to define comfort zones because it combines the effect of both air temperature and mean radiant temperature. It is considered by many to be the best of the simple measures of what is sensed as thermal comfort and is defined as follows:

$$T_{ei} = \frac{2}{3}T_r + \frac{1}{3}T_a$$

where:

T_{ei} = environmental temperature
T_r = mean radiant temperature of surfaces of enclosure
T_a = air temperature (dry bulb temperature)

There is no device for the direct measurement of mean radiant temperature and so, instead, use is made of a globe thermometer. The mean radiant temperature (MRT) can be derived from a nomogram.

Environmental temperature can also be defined approximately as follows:

$$T_{ei} = \frac{6}{5}T_g - \frac{1}{5}T_a$$

where T_g = globe temperature

Figure 18 illustrates how relatively small changes in mean radiant temperature have a far greater effect than similar changes in air temperature. Figure 19 illustrates the lesser influence that relative humidity has on comfort compared with air temperature and figure 20 demonstrates the effect on comfort of air movement and the temperature of an incoming airstream compared with the room air temperature.

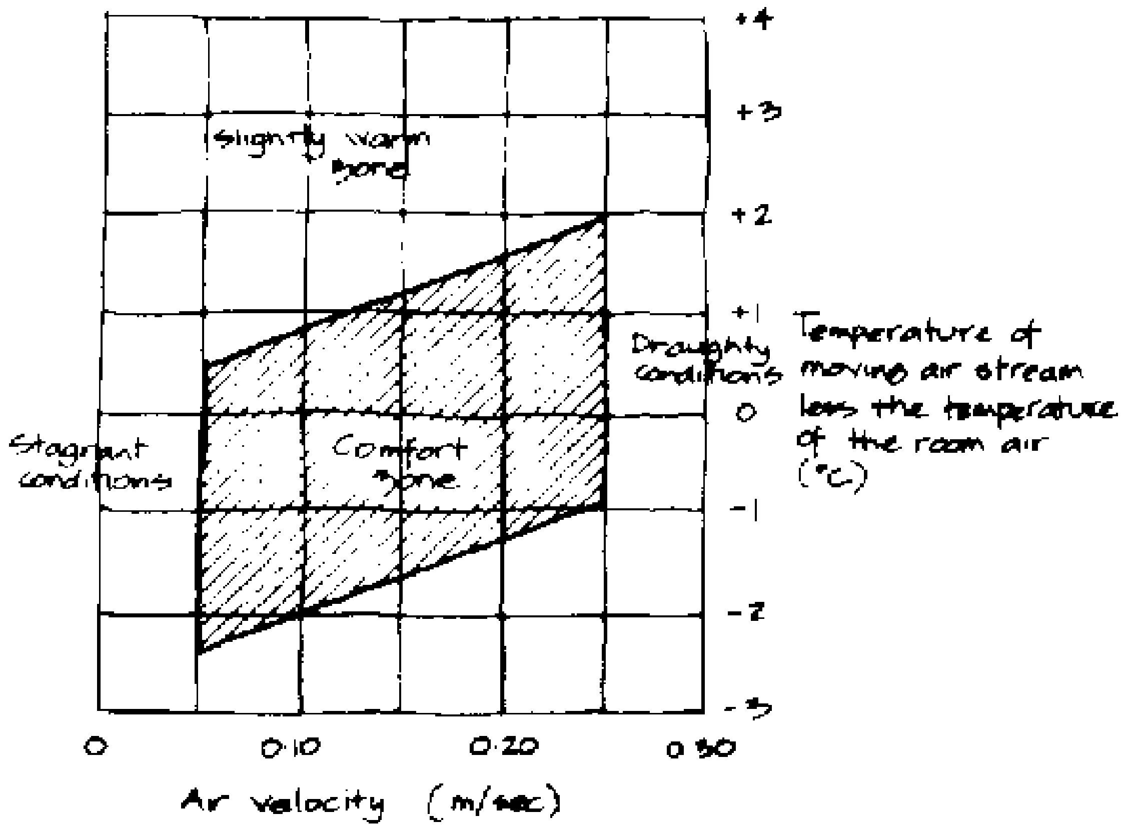


Figure 20. The relative effect of incoming air compared with room air.

Everybody has a different idea of what is thermally comfortable, and so it is necessary to define comfort in broad zones. From figure 21 it can be seen that the acceptance of particular conditions is dependent on activity (active or sleeping) and the level of dress and seasonal acclimatization (summer or winter).

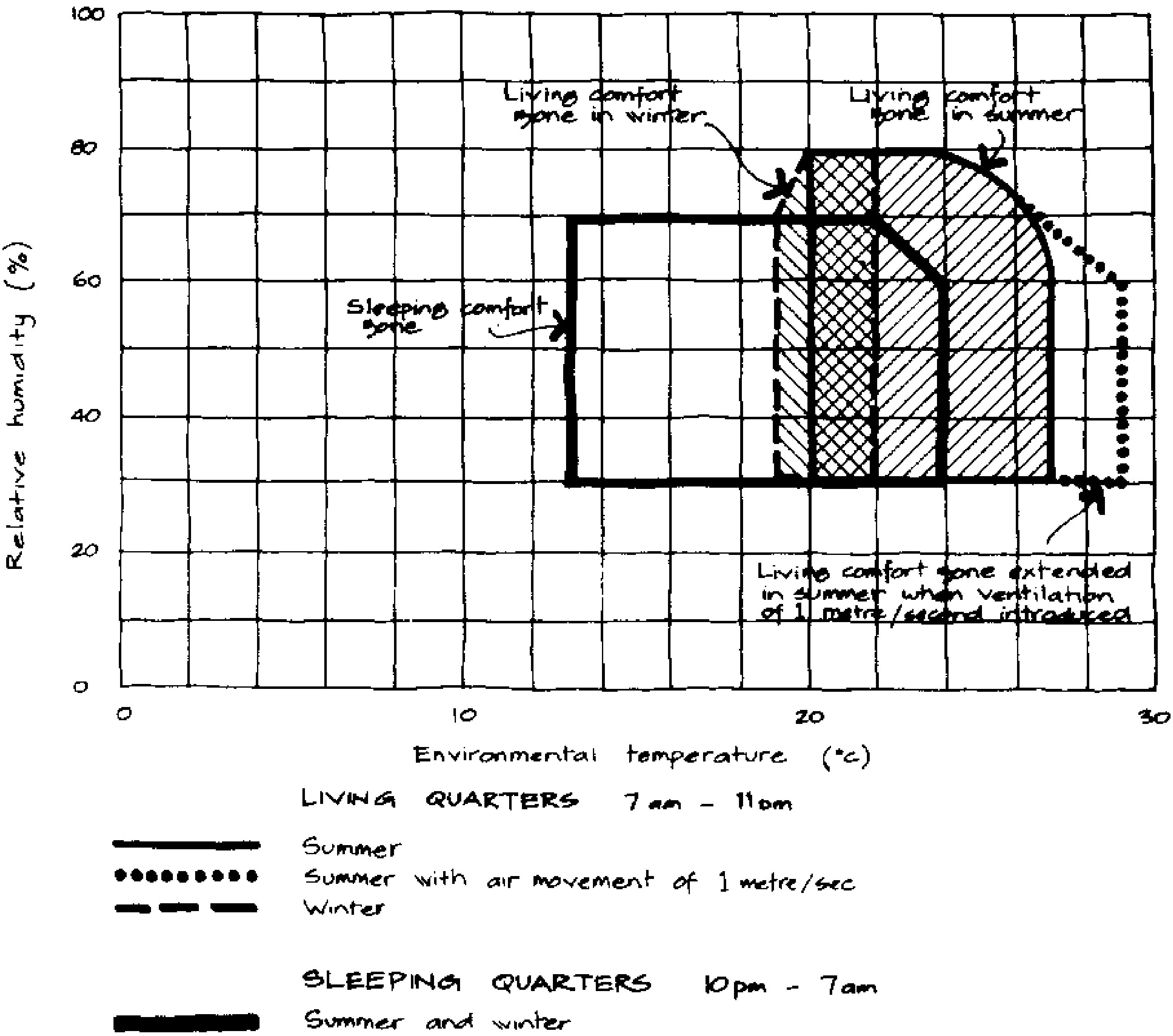


Figure 21. Domestic comfort zones.

Source: T. Williamson and A.B. Coldicutt. "Comparison of performances of conventional and solar houses – a computer simulation ", Proceedings of the Institution of Mechanical Engineering Symposium on Solar Energy Utilization in Dwellings. Melbourne. 1–2 1.

V. Basic design principles and strategies

A. Climates

1. Hot–arid climates

In such climates where the daily (diurnal) temperature range often exceeds 20 degC the most important principles are to have a large thermal mass (masonry or concrete walls and concrete floors), a well insulated external skin and effective summer shading of windows and walls where possible. As winter daytime temperatures are relatively low. good solar access to the northerly–facing windows is most important. East and west windows should be avoided unless full shading and thermal insulation can be provided. The insulation is necessary for both the heat of the summer day and the cold of the winter night. The design should include breezeway−style living areas for summer evenings. Evaporative cooling is very effective and appropriate in this climate.

2. Cool−temperate and temperate climates

The majority of the country's population lives in either the temperate or the cool−temperate zones. In design terms the winter requirements vary little because of the relatively sunny winters experienced in Australia compared with many other countries. The major differences are related to insulation levels and the like.

In summer there is a greater need for thermal mass in the warmer temperate areas to suppress daytime temperature peaks. In the cool−temperate areas such as Tasmania and the New South Wales tablelands the outdoor temperature in winter rarely rises above the comfort range and so thermal mass is less important for summer as natural ventilation and good shading are quite adequate. In winter the thermal mass is important where solar energy is desired for heating. Where intermittent heating is used in non−sunlit rooms, thermal storage materials will tend to increase the energy needed for heating.

Where east and west windows are required for views etc., effective shading must be provided for summer. With the exception of very hot periods there should be no special requirements for ventilation other than those of fresh air and air movement to avoid stuffiness.

3. Hot−humid climates

The problem of high humidity levels is not easily solved with building design. Although temperatures may not be as high as in the arid zone climates the combination of high humidity and moderately high air temperatures causes discomfort. This is especially so at night when lower temperatures are needed for a sound sleep. The aim is, first, to ensure that indoor temperatures do not exceed outdoor−temperatures. This is achieved by extensive shading (especially on the eastern and western sides of the building), insulation of roofs (reflective foil is appropriate) and most of all, unimpeded natural ventilation. Shading of east and west façades by heavy planting can be most effective in providing both the sun protection and a cool place to sit during the day. The use of ceiling fans to induce air movement is strongly recommended. Elevating the building above the ground has been found effective in low−density areas, but it makes shading from planting more difficult. The design of openings to facilitate airflow is important. The building structure should be of lightweight construction to aid cooling whenever the temperature drops. A concrete slab on the ground is effective in providing a limited heat sink but this must be weighed against the greater need for relief by air movement.

B. The sun's movement

To obtain the best use of the sun's energy, the designer must be aware of the pattern of the sun's movement as well as the specific considerations for house and site design.

The pattern of the sun's movement over Sydney (latitude 34 South) may be taken as an example. In mid−summer, approximately 22 December (the summer solstice), the sun rises at about 5 a.m. slightly to the south of east. From there it climbs sharply to be nearly overhead at noon, and sets at about 7 p.m. to the south of west.

In mid−winter, the sun rises to the north of east and travels low through the northern sky to set north of west.

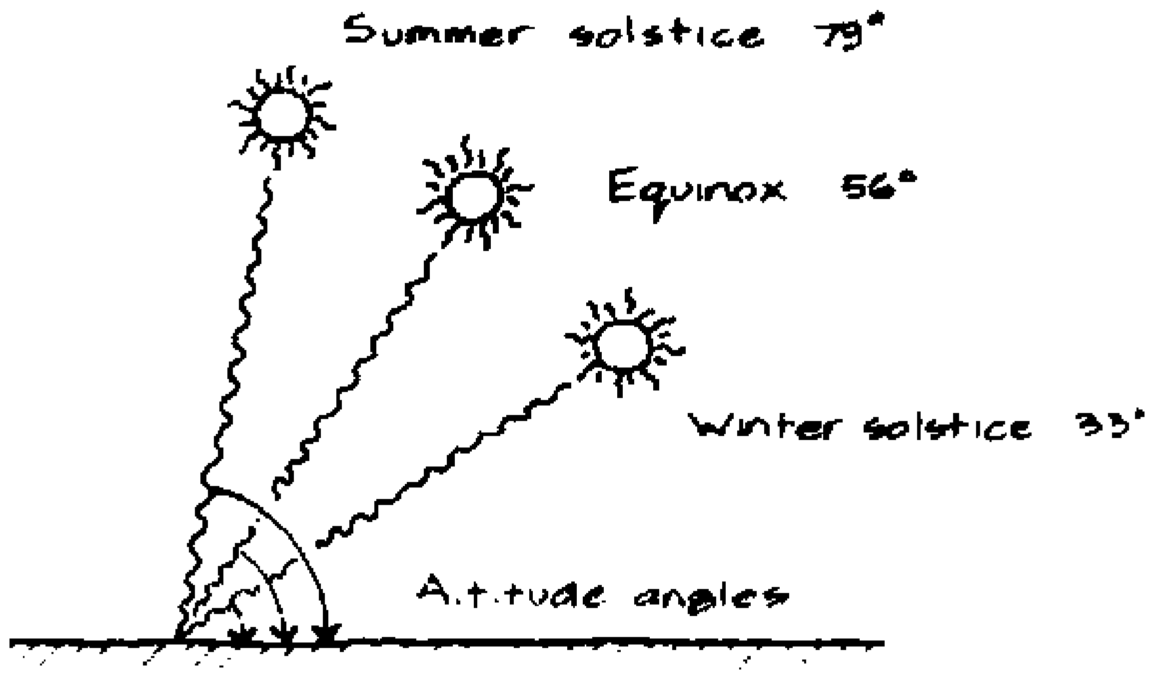


Figure 22. Elevations of the sun at different periods of the year at Sydney.

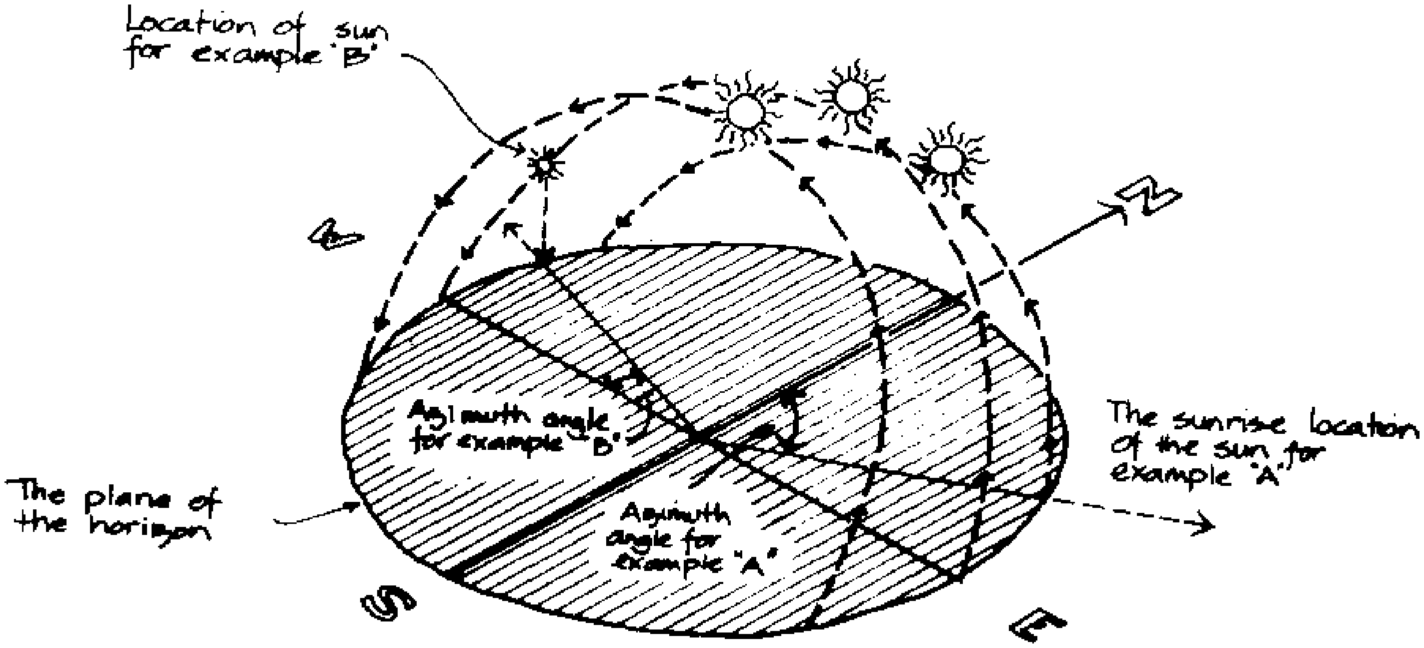


Figure 23. The azimuth of the sun.

At the equinox (21 March and 23 September) the sun's path is between the winter and summer paths. Therefore the sun rises and sets due east and due west. At noon the altitude of the sun (its angular height above the horizon) is 90 degrees minus the latitude of the observer.

C. Orientation for solar access

Because the sun's path across the northern sky (in the southern hemisphere) is low in winter, and high in summer, a house can be designed to allow the sun to enter and warm the house and warm outdoor living areas in winter and prevent the sun from striking walls and roof or from penetrating the house in summer.

Windows facing in a northerly direction receive useful sunshine for most of the day in winter and the desired period for access to the sun's rays in most of Australia is 9 a.m. to 3 p.m. In summer, unwanted sunshine can be very easily blocked by an overhang, pergola or other horizontal shading device.

Although the winter sun in the mornings and the evenings coming through windows facing east and west is pleasant visually, it provides very little useful heating. In summer those east−and west− facing windows receive a high proportion of the sun's energy and because the sun is low in the sky it is difficult to screen it out with conventional shading devices.

South−facing windows receive no direct radiation in winter and very little In summer. The low evening sun in summer may cause problems on an open site.

For the best passive solar design, the windows to living rooms and bedrooms should face in a northerly direction. Some flexibility of orientation is acceptable, however it has been found that the optimum orientation is within 20 degrees either side of north. A building oriented outside this range loses the benefits of winter sun. This is clearly demonstrated in figure 26 which illustrates graphs of mean daily solar radiation on vertical surfaces of various orientations in Sydney. Notice how the solar radiation received on a vertical surface facing north− east or northwest is almost the same year round. The importance of orientation is self−evident.

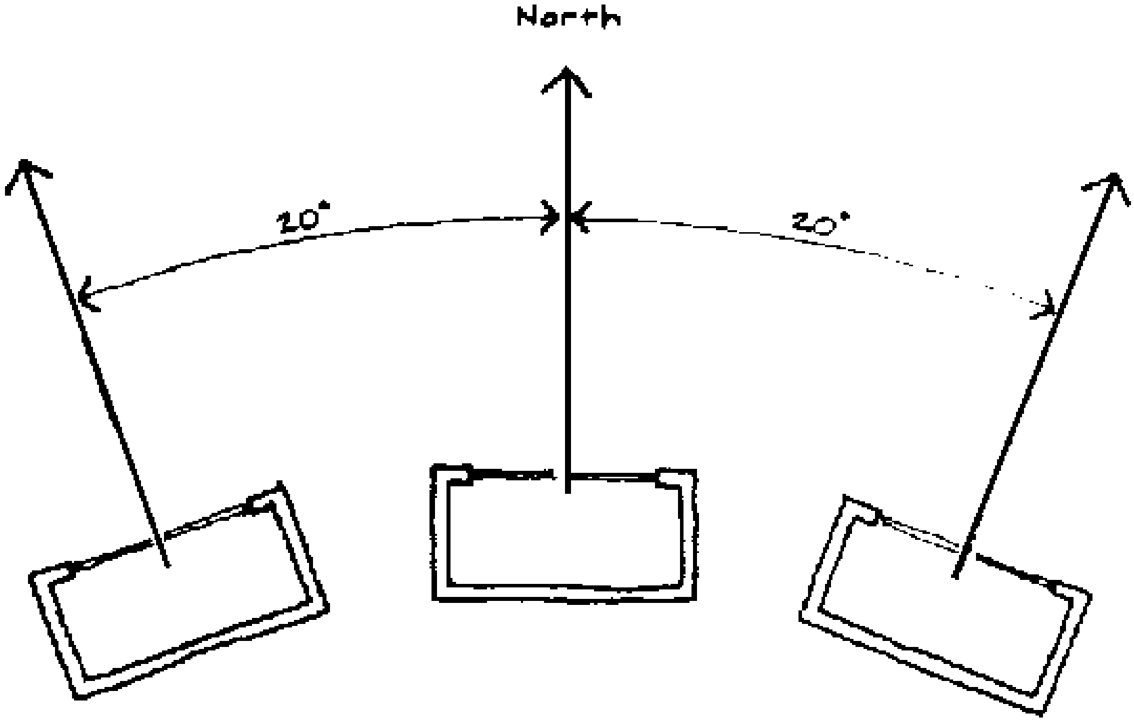


Figure 24. Optimum window orientation.

If there is a preference, then about 12 degrees east of north (approximately magnetic north in New South Wales) is best to let some sun in for an early warm−up in winter. Because north orientation is essential to passive solar design, it is important to choose a house block that allows north orientation to at least the major daytime living spaces. Trees or buildings could block access to sunlight, and this needs to be checked when siting dwellings.

The orientation of a building is determined usually by the position of the windows and the proportion of the plan. Excluding the internal spaces at this point the objective is to locate most glass on the north façade and to design the building so that its north and south façade are larger than the east and west façades.

Figure 26 also illustrates the relationship between Sydney's heating load profile and solar radiation incident on surfaces of different orientation. A diagram such as this is admittedly simplistic but it shows the effect of window orientation very clearly. The north orientation is the only one that is able to combat the heating load without creating enormous penalties in the summer.

It is often suggested that the optimum building plan proportions for a temperate climate is about 1: 1.5 with the longer façade to the north. This may be correct on the basis of simply the heat gains and losses but it will not necessarily be applicable to the requirements of a particular design and its site. The area of north−facing windows is perhaps more important and in Australia's temperate and cooler areas there is still a need for good cross−ventilation in the summer months. This requirement may well dictate a longer, thinner plan than the aforesaid optimum.

The way in which living units are planned effects the overall thermal efficiency. The greater the exposed external surface the greater the potential heat loss. Figure 25 shows that medium– density building is subject to smaller heat losses per living unit than detached cottages and likewise high–density building is subject to even smaller heat losses. In residential buildings this can be advantageous, provided the individual units have a reasonable access to sun from the north.

In high–density commercial buildings this compactness is often a disadvantage because it results in a year–round cooling load due to internally generated heat, and so a need for air conditioning. Figure 25 illustrates how density of planning relates to conductive heat loss. The heat loss rate will be proportional to the external surface area and its resistance ($A_{ex} \times$ U). Solar access usually becomes more difficult as density increases.

Likewise, the solar gains in winter can be enhanced by the orientation and grouping of the various units. In developing these arrangements, it needs to be remembered that the sun is low in winter and high in summer. A roof's exposure is therefore high in summer. Light–coloured roofs will reflect much of that radiation.

D. What is solar access?

Solar access can be described as allowing the sun to penetrate a building or be utilized by a solar collector on the surface of that building between 9 a.m. and 3 p.m. in midwinter. There are varying degrees of solar access. There is whole–site access where the area of yard to the north of the building, as well as the north wall and rooftop are protected from shading by other buildings and vegetation in midwinter. North–wall access refers to the protection from shadows in midwinter of only the north facade, which includes the north roof and north wall.

Although whole–site access is desirable for outdoor garden use, it can be very costly in terms of the use of land and may not affect household energy use. Energy–efficiency encompasses more than Just energy savings in houses and so the decreased density that results from whole–site access cannot be justified.

There is a third level of solar access, rooftop access, which aims to protect rooftop solar collector systems from shading at certain times. Although this level of solar access allows maximum density to be achieved, it forecloses too many options for future development. The definition of solar access depends on the definition of the solar collector (whether passive or active).

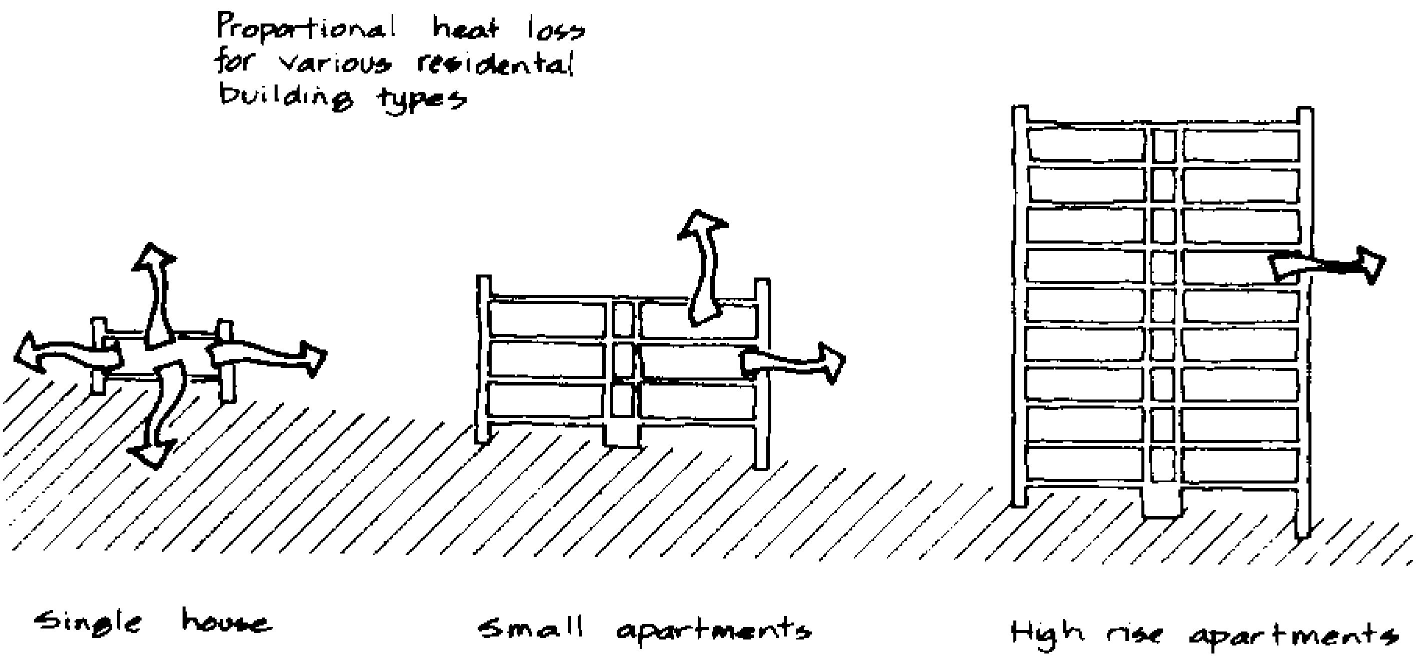
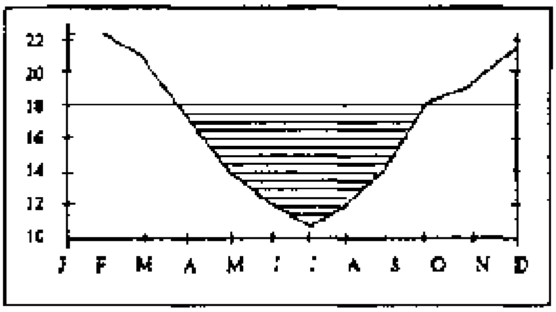
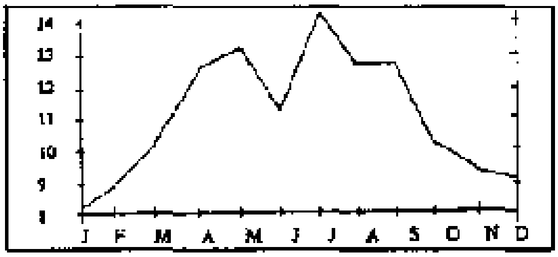


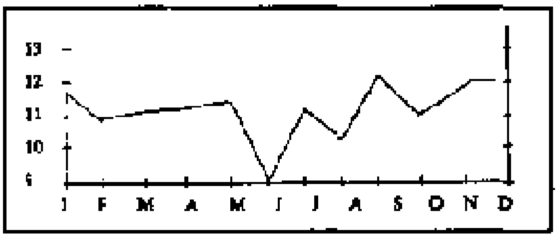
Figure 25. Heat losses from different residential building types.



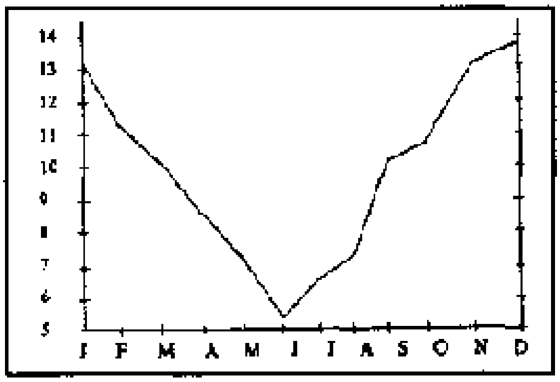
Graph showing monthly mean temperatures for Sydney's western suburbs. The curve below the line represents the typical winter heating load for a house in that area.



Graph of mean daily solar radiation incident on a surface oriented towards the north in Sydney.



Graph of mean daily solar radiation incident on a surface oriented towards the north-east or the north-west in Sydney.



Graph of mean daily solar radiation incident on a surface oriented towards the west or the east, in Sydney.

Figure 26. The effect of window orientation and winter heating load.

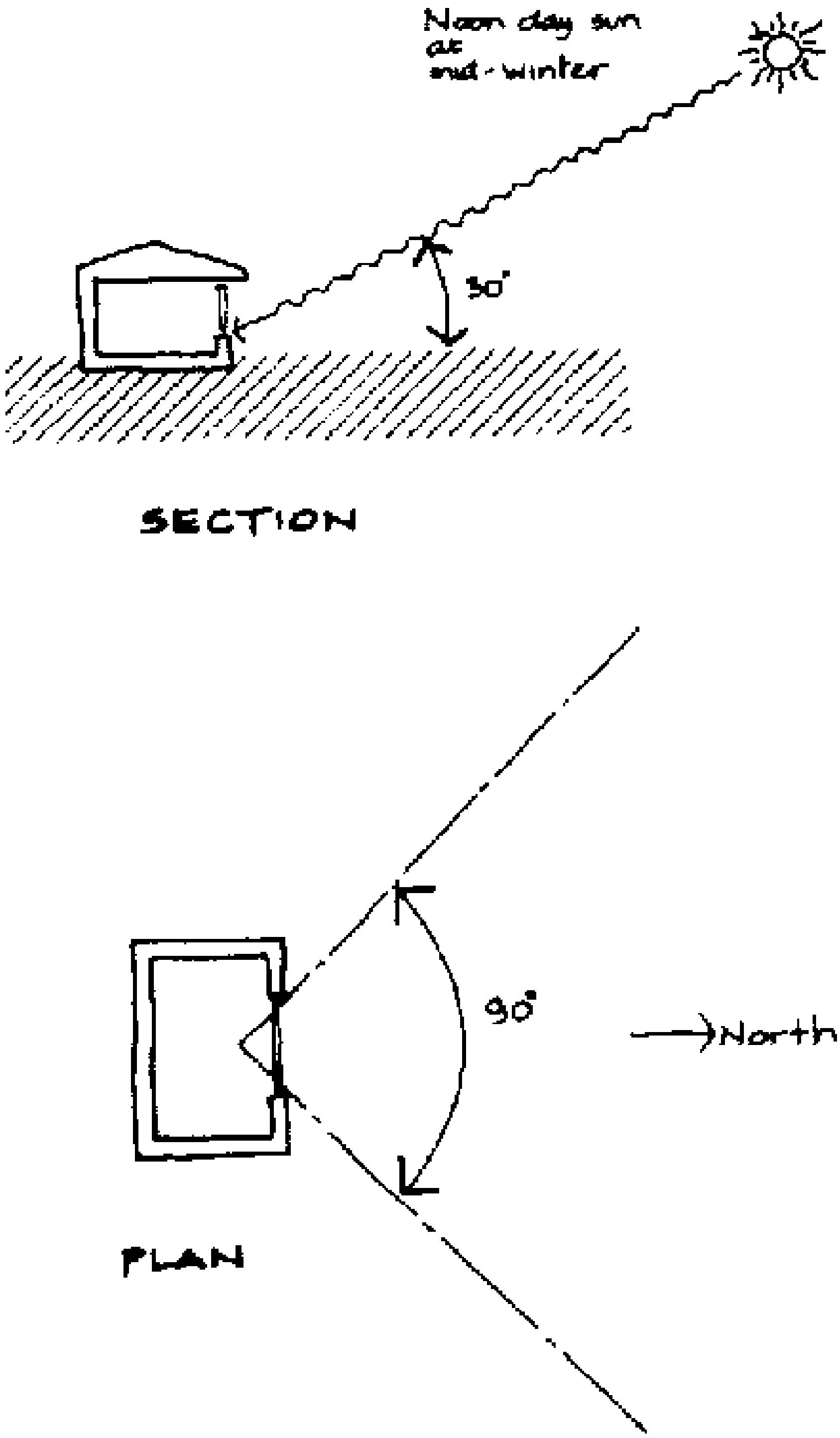


Figure 27. Solar access in Sydney.

North−wall access is the level of access designed for in this handbook.

The protection of solar access to dwellings is crucial to the performance of passive solar architecture. The period between 9 a. m. and 3 p.m. in mid−winter, as shown in figure 27, has been generally accepted as a measure of solar access.

For mid−winter in Sydney, the azimuth of the sun is approximately 45 degrees at 9 a.m. and at 3 p.m. At noon, the altitude of the sun is approximately 30 degrees. The protection of solar access is discussed in a later chapter under detailed design guidelines.

E. Solar energy collection

1. Sun and solar radiation

The energy (or power) from the sun is received by radiation. The sun is 1.4 million km in diameter and the temperature of its core is 14,000,000°K. The outer layer is called the photosphere and its temperature is only 6000°K. It can be assumed from the point of view of a person on Earth that the suns rays are parallel due to the vast distance between Earth and the sun which varies a little throughout the year from 150 million km to 155 million km. Even though it is 53 times larger than the Earth it appears as a spot. due to this enormous distance. The electromagnetic rays of energy emitted by the sun are Earth's sole source of energy except for a small amount of energy emanating from the radioactive decay of the Earth's minerals. This constant emission is called insolation (not to be confused with insulation, which means isolate). The value of the sun's energy at the outer surface of the Earth's atmosphere is known as the solar constant and is 1.353 kW/m².

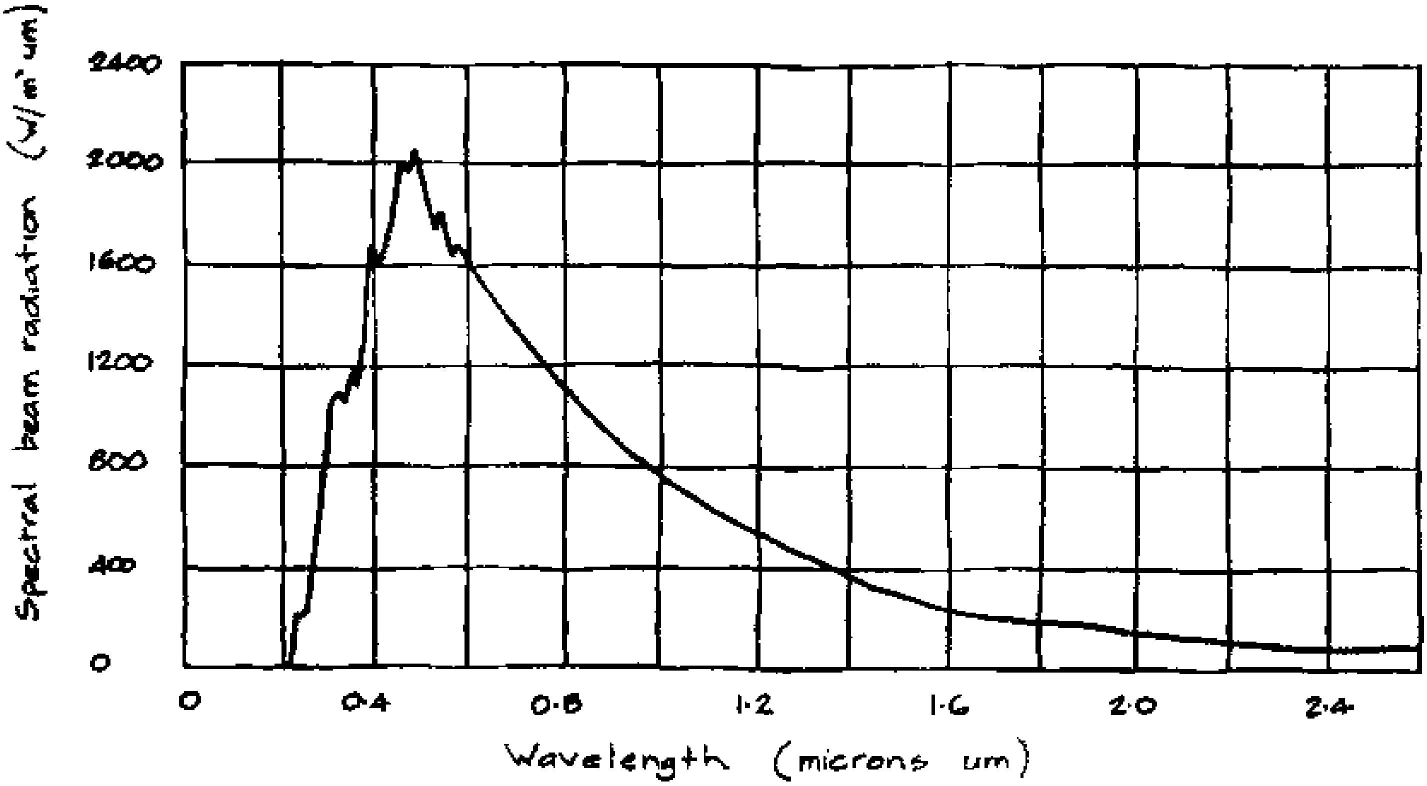


Figure 28. The NASA (1971) standard spectral irradiance at a point approximately midway between the sun and Earth.

Solar radiation or insolation is made up of various wavelengths mostly in the range of 0.22.5 microns with a peak at 0.5 microns. Figure 28 is based on data collected by NASA outside Earth's atmosphere. As the sun's rays pass through the atmosphere it is degraded and so at Earth's surface the shape of the graph is a little different. Some energy is absorbed by the water and ozone in the atmosphere. The ozone layer in Earth's atmosphere is the major element that absorbs the ultraviolet wavelengths and the use of CFCs is being blamed for its degradation.

Much of the sun's energy that reaches Earth is either absorbed by the atmosphere or is reflected back out into space. Figure 29 shows how that energy is dissipated. About 50 per cent of the sun's energy at the outer surface of the atmosphere reaches Earth's surface and is absorbed into the ground which must be dissipated otherwise the Earth would overheat. Earth's temperature is held in a very delicate balance as recent discussions about the effects of carbon dioxide build−up and the ozone layer depletion have shown. The energy absorbed by the Earth is dissipated through three mechanisms and approximately 20 per cent by long−wave length re−radiation, 20 per cent by evaporation and 10 per cent by convection − total 50 per cent.

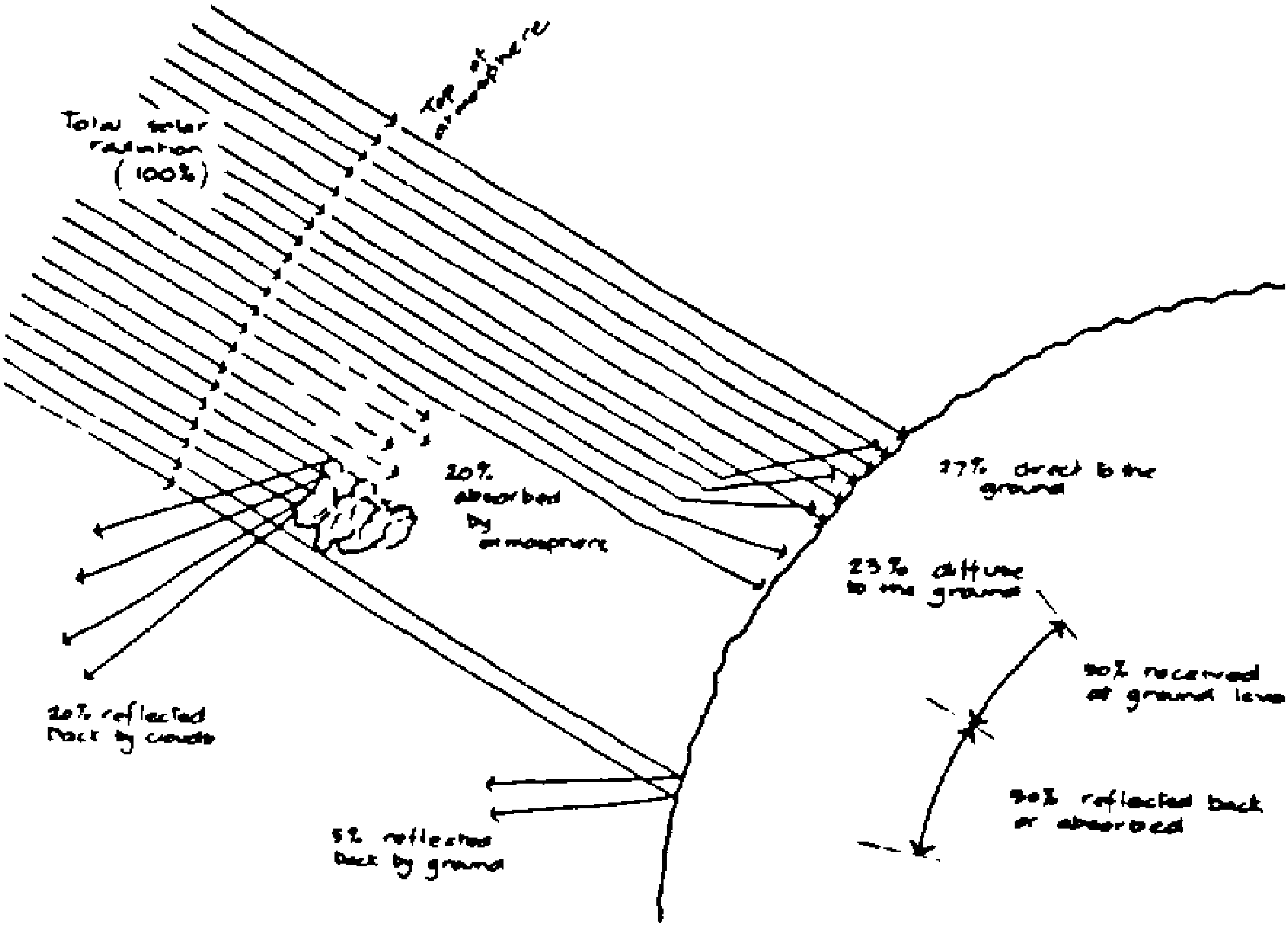


Figure 29. The passage of radiation through the atmosphere.

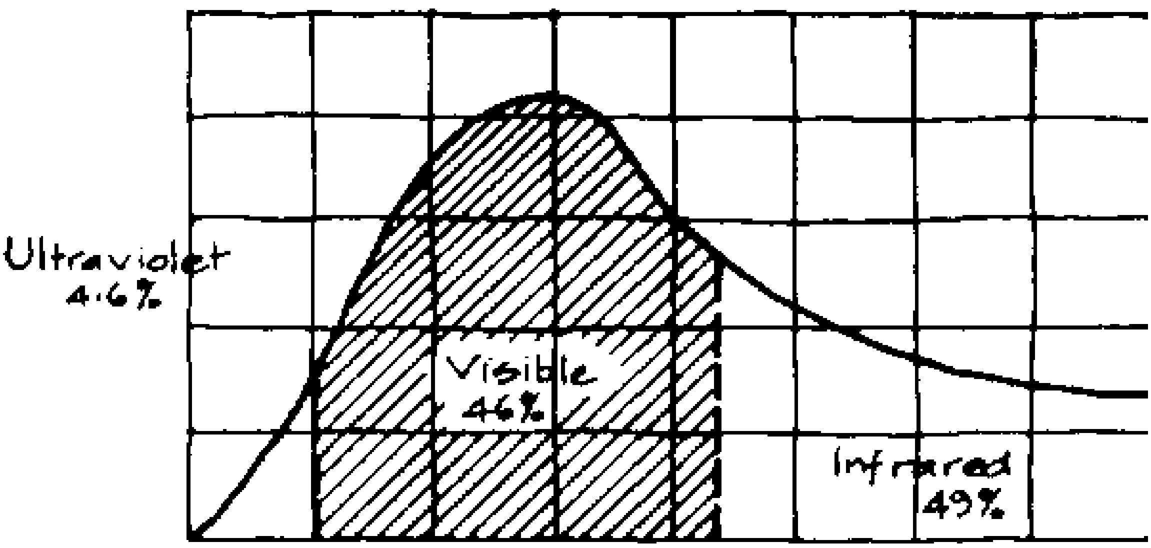


Figure 30. Approximate division of solar radiation at Earth's surface.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					North-facing vertical surface							
Diffuse	5.73	5.59	5.32	4.84	4.33	4.08	4.35	5.01	5.50	5.69	5.81	5.88
Direct	4.12	8.10	12.7	16.0	16.9	16.8	17.2	16.9	13.4	8.54	4.17	2.82
					Horizontal surface							
Diffuse	5.01	4.53	3.88	3.25	2.72	2.51	2.70	3.27	3.93	4.53	5.07	5.22
Direct	26.3	22.9	18.8	13.7	10.4	9.02	10.5	14.4	19.8	23.8	26.9	28.1

Table 6. Diffuse radiation compared with direct radiation based on CSIRO data for "clear sky" conditions in Sydney

When the sun's rays reach Earth's surface if is typically 4.6 per cent in the ultraviolet wavelengths, 46 per cent in the visible wavelengths and 49 per cent in the infrared wavelengths, depending on weather conditions.

The radiation reaching Earth is either of direct or diffuse in form, the latter reaching Earth's surface after being reflected off the particles of the atmosphere. The sum of the radiation reaching Earth's surface is referred to as the total or global radiation.

There are only a few places in Australia where solar radiation data are recorded and so CSIRO has developed a computer model to calculate the values for a large number of places based on a more commonly measured value – the precipitable water in the atmosphere. This is one of the more common Hems of weather information that is collected across the country. Tables of solar radiation give values for what is called a "clear sky day. and so do not take into account any dust or pollution that may be present in the atmosphere. In Sydney, the measured values tend to be about 70 per cent of the "clear sky day" values due to pollution.

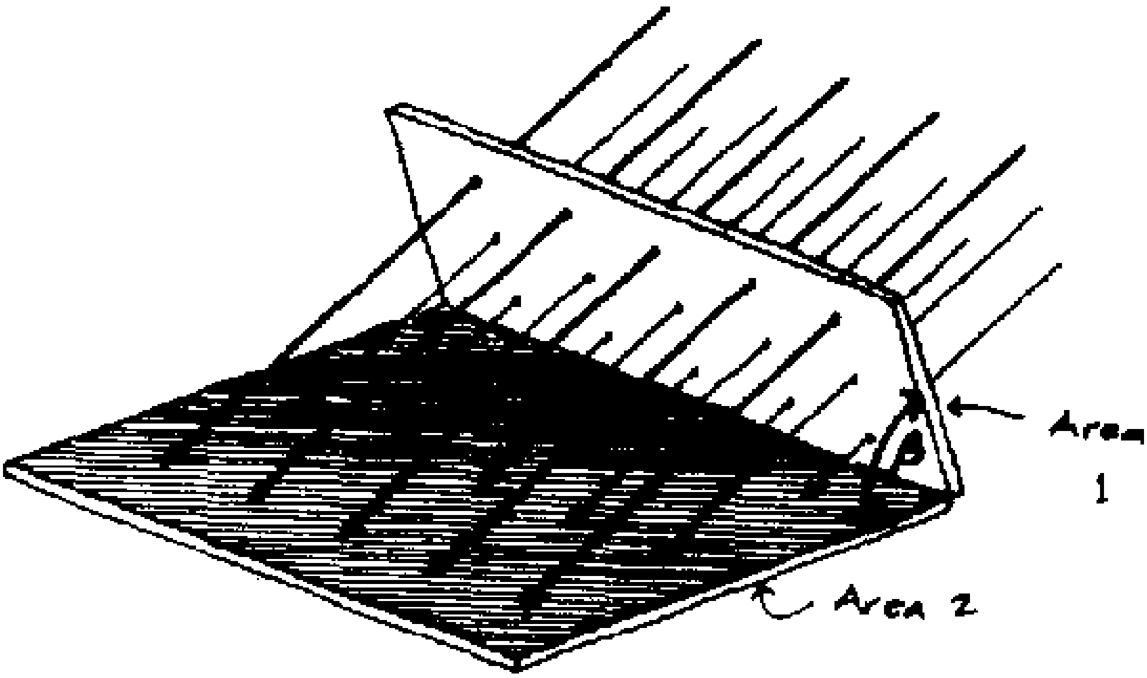


Figure 31. The 'cosine law' states that the intensity of energy coming In on a fitted surface (area 2 which represents Earth's surface) can be calculated by multiplying the intensity of the incoming energy (the sun's parallel rays) by the cosine of the angle of Incidence, I.e., intensity on area 2 = cosß × Intensity on area 1.

On cloudy days (especially when the clouds are at a high level), the diffuse component can be almost the same or greater than the solar constant due to refractive focusing. Extremes of 110 per cent of the solar constant have been measured.

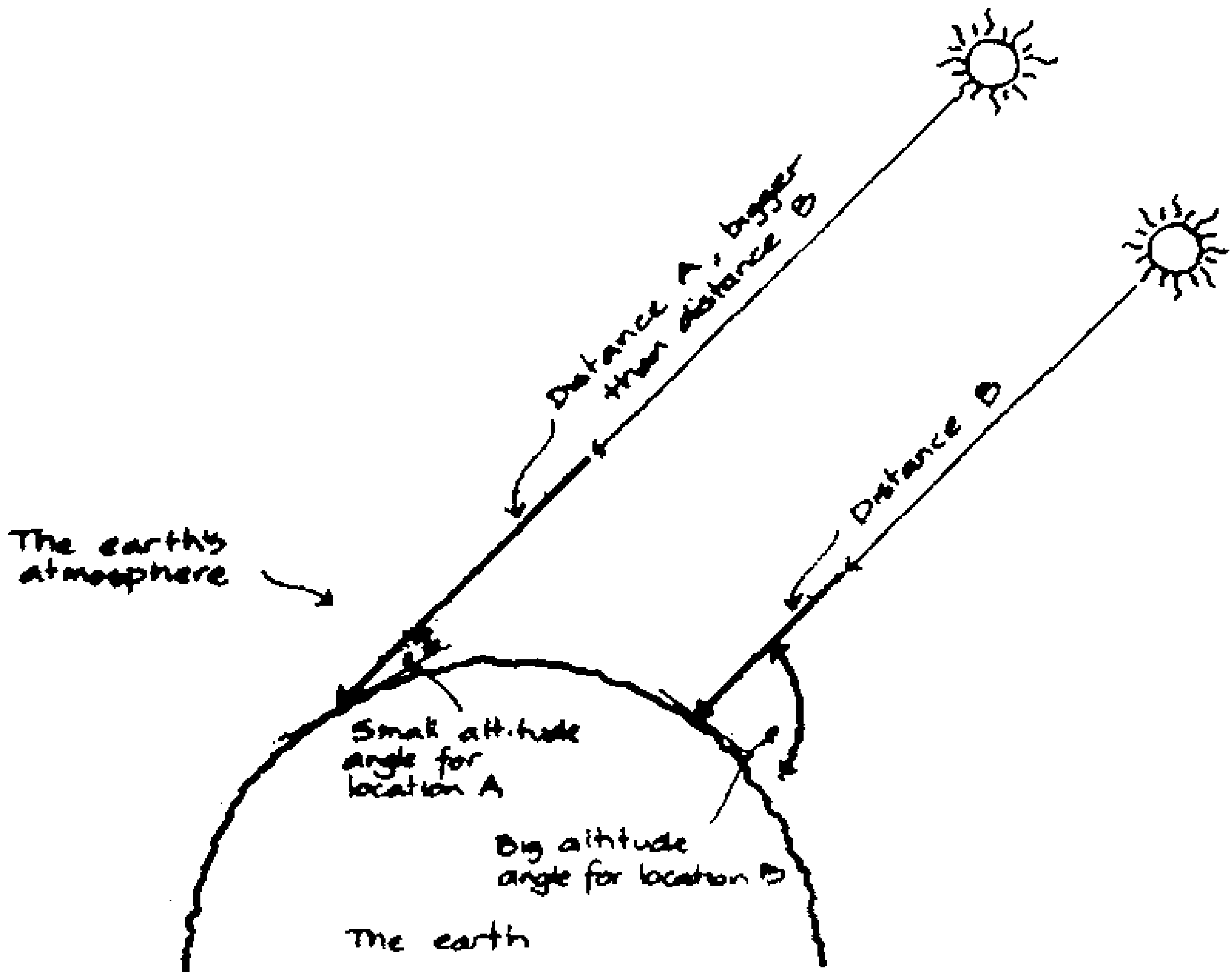


Figure 32. How the sun's intensity is reduced when it has to travel through more of Earth's atmosphere.

Figure 33 shows the relationship between the altitude angle and the solar radiation levels. The larger the altitude angle, the greater the radiation. Also the higher the reference point above sea level, the higher the radiation intensity. This is because the sun has less atmosphere to travel through. As the angle of incidence on a surface gets smaller (i.e., the solar altitude angle) the effective atmosphere thickness gets greater and so more energy is absorbed and reflected away from Earth's surface.

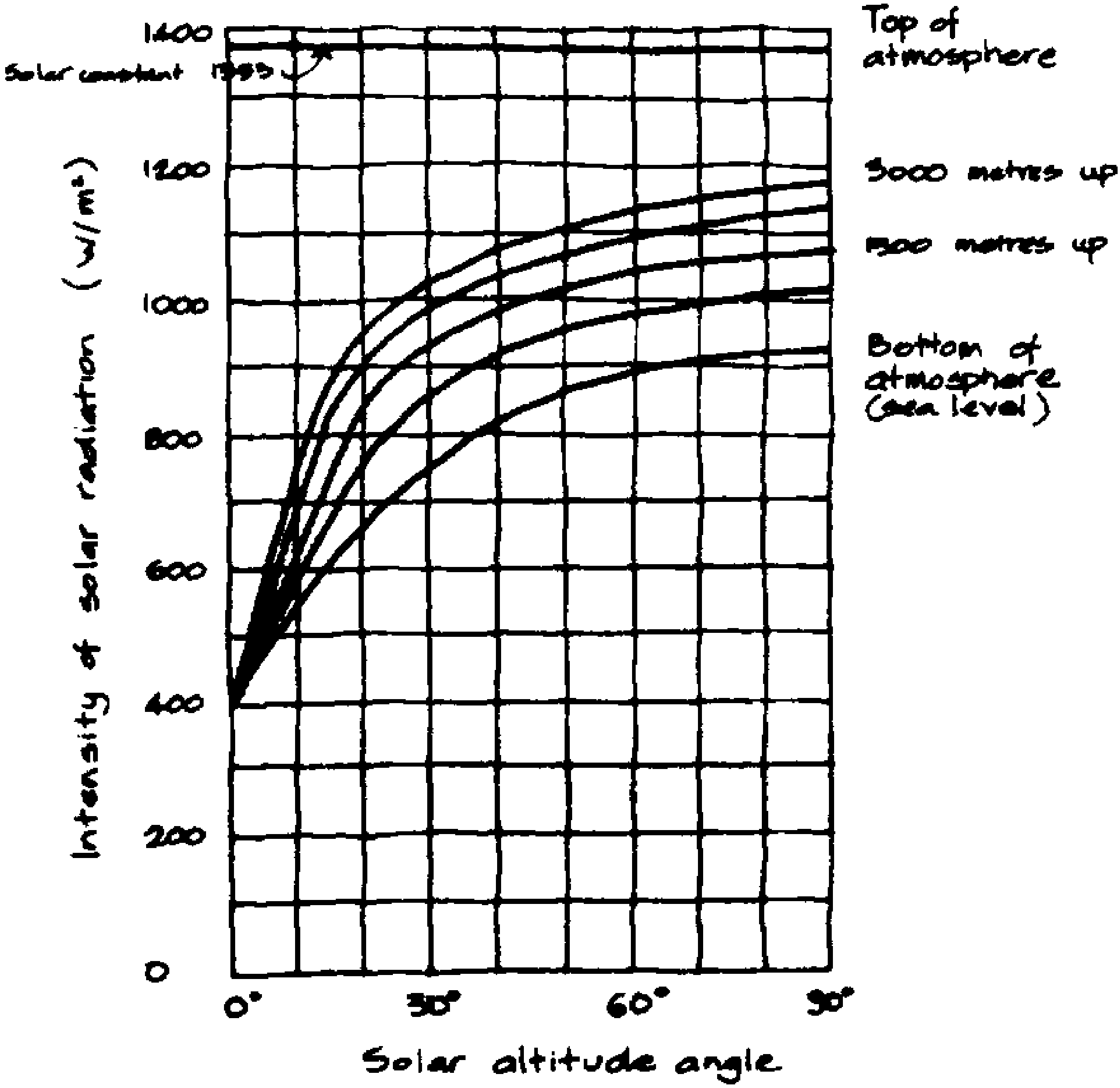


Figure 33. Solar intensity as a function of altitude and altitude angle.

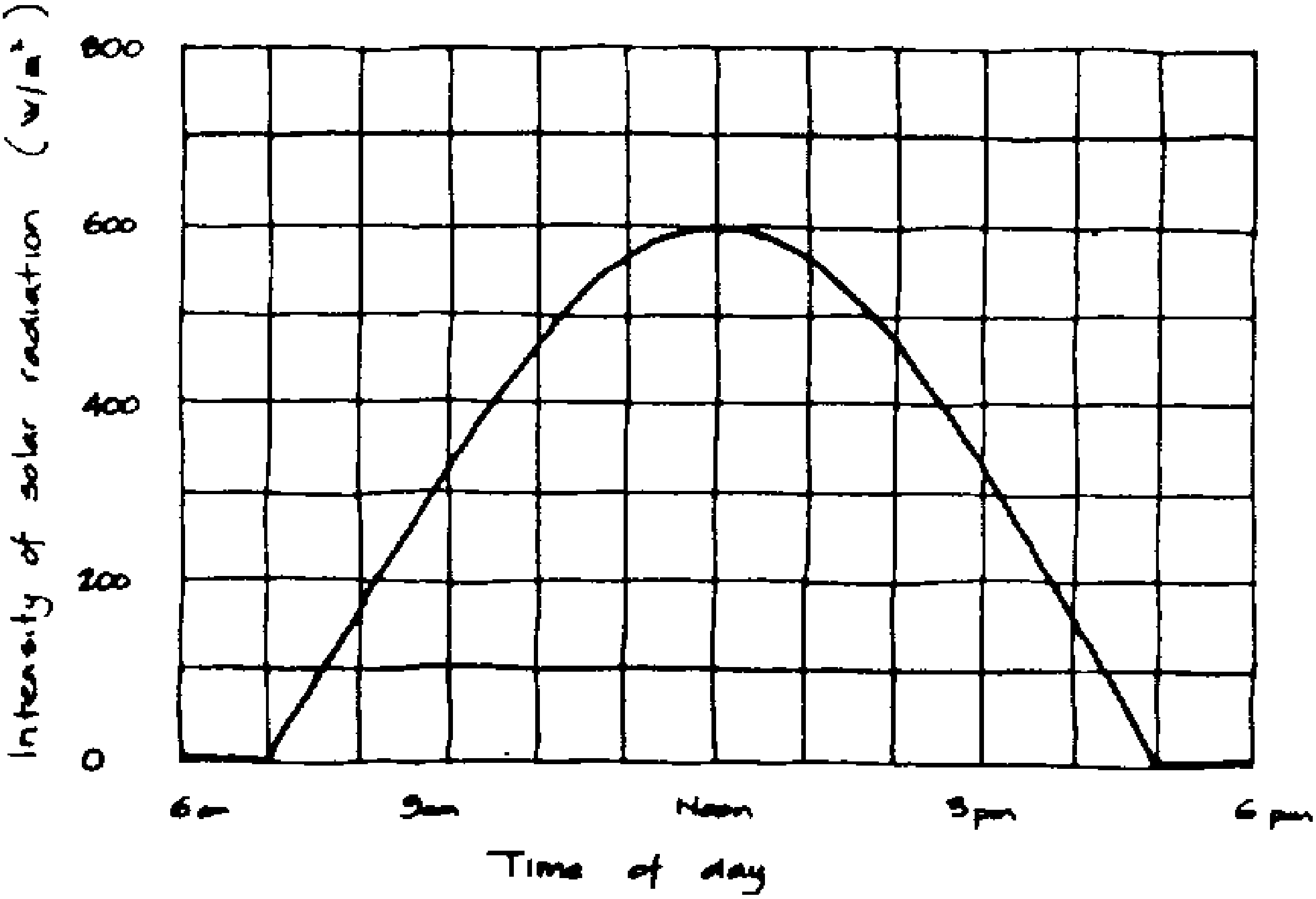


Figure 34. Typical graph of solar radiation over a full day.

The graph shown in figure 34 is the result of combining both the effect of the atmosphere and angle of incidence throughout a single day (remembering that the sun's output is unchanging throughout time).

So far the sun has been considered as a source of energy with a temperature of about 6000K, as has the path of that energy to and from Earth's surface.

Radiant energy is absorbed into the surface of objects it strikes and it then must be rejected later. The second law of thermodynamics states that energy must flow from a hotter body to a cooler body not vice versa. For the purpose of explaining how heat radiates from one object to another and the rate at which it does that, use is made of the term black body. A black body is a theoretical object with properties such that:

(a) It absorbs all radiation incident on its surface. i.e., it does not reflect or transmit any energy;

(b) It is able to re−radiate all that energy away again and the rate at which it does so is a function of its absolute temperature (°K).

Stefan's law $F = \sigma \mathrm{x} R^4$

F = emittance rate
s = Stefan Boltzman constant
T = absolute temperature

An example:

The sun radiates energy from its surface (photosphere) which is at approximately 6000°K and Earth has a mean temperature of 283°K (10C) and its atmosphere has a mean temperature of about 250°K (−23°C). As a result the sun's energy warms the Earth.

Another characteristic of this so called black body is that the wavelength of the radiation being emitted varies inversely with its absolute temperature.

Wien's law $$\delta(\max) = \frac{2897}{T} \text{ x } 10^{-6}$$

d(max) = wavelength
T = absolute temperature

In figure 35 the spectral distribution of energy from three bodies of different temperature is shown. The sun at 6000K and two others at 1000K and 400K (400K = 127C which is the temperature of a solar collector). The sun's radiation peaks at about 0.5 microns and cuts out at about 2.5 microns. Terrestrial radiation, i.e., from objects at earthly temperatures, peaks at about 10 microns with a range of about 4 to 100 microns.

Radiant energy with wavelengths of less than 2.5 microns is known as shortwave radiation while radiant energy with greater than 2.5 microns is known as longwave radiation. The implications of this are discussed further in the section on transparent elements.

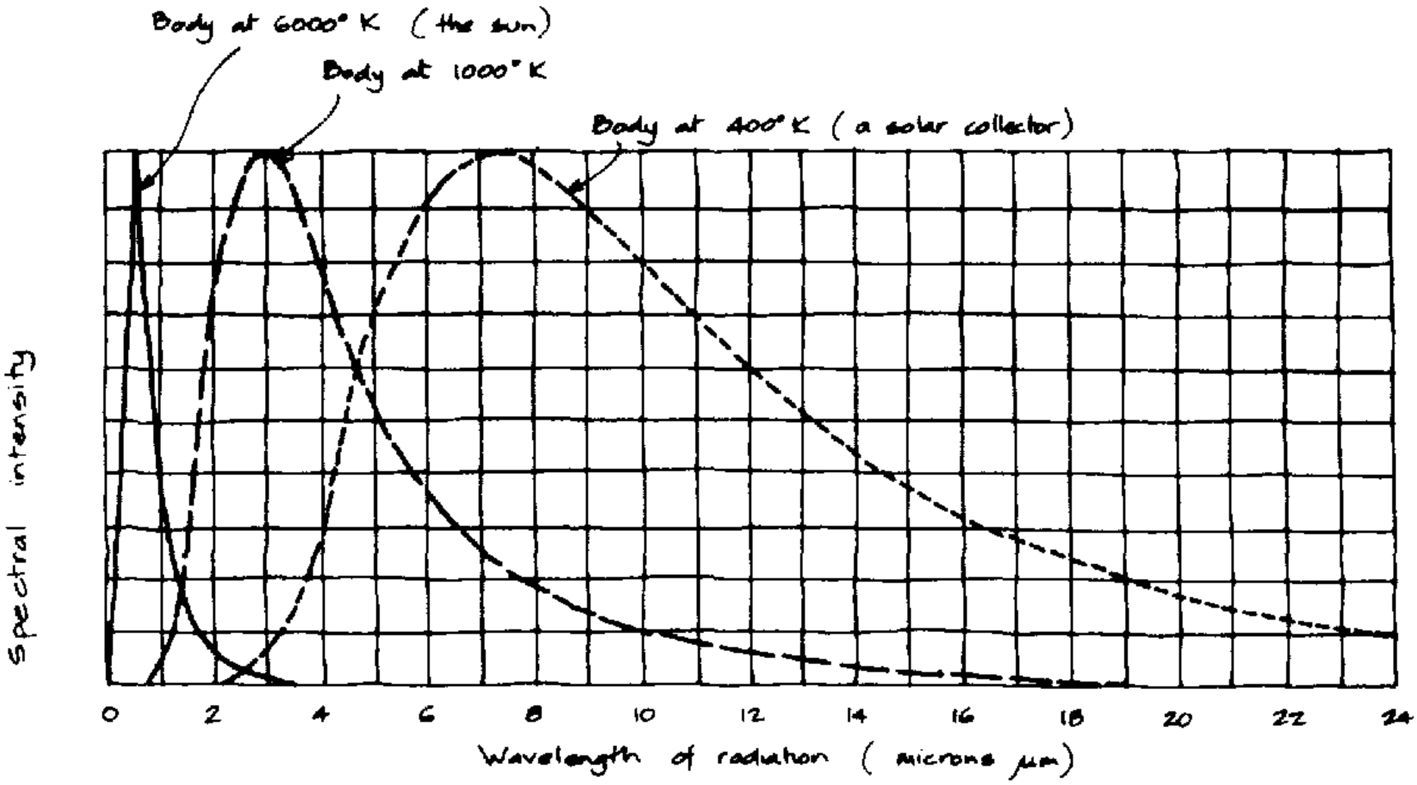


Figure 35. Wavelength for different bodies at different temperatures.

All materials have certain qualities that define their thermal characteristics. as shown below but in this chapter consideration need only be given to the first three on the list.

Absorptivity
Emissivity
Reflecffvity
Mass/density
Conductance
Transmittance
Acceptance
Specific heat

Absorptivity is designated by the Greek letter a and is defined as the ratio of thermal radiation absorbed per unit area of a surface to the thermal radiation absorbed per unit area by a black body or perfect absorber.

Emissivity is designated by the Greek letter ? and is defined as the ratio of thermal radiation emitted per unit area of a surface to the thermal radiation emitted per unit area by a black body at the same temperature. As a black body can emit all energy that it has absorbed, which is all the energy incident on its surface, then the emissivity is in effect also the ratio of the energy incident to the energy emitted. In other words it is a comparative value of its ability to give off or let go any heat energy stored in H.

An example of an application of a low emissivity surfaced material is the use of aluminium foil to keep food hot. It has an emissivity of 0.05, i.e., it emits only 5 per cent of what would be emitted by a perfect emitter (a black body). Black paint on the other hand has an emissivity of 0.9 and so it is used on radiators to help release heat. Motor car radiators are painted black for this reason. If they were chrome plated, they would not be as effective as a heat dissipator and there is a good chance that the engine would overheat.

Reflectivity is easier to define by deduction as follows. The first law of thermodynamics states that energy must always be accountable or energy cannot be destroyed, it can only be changed in state.

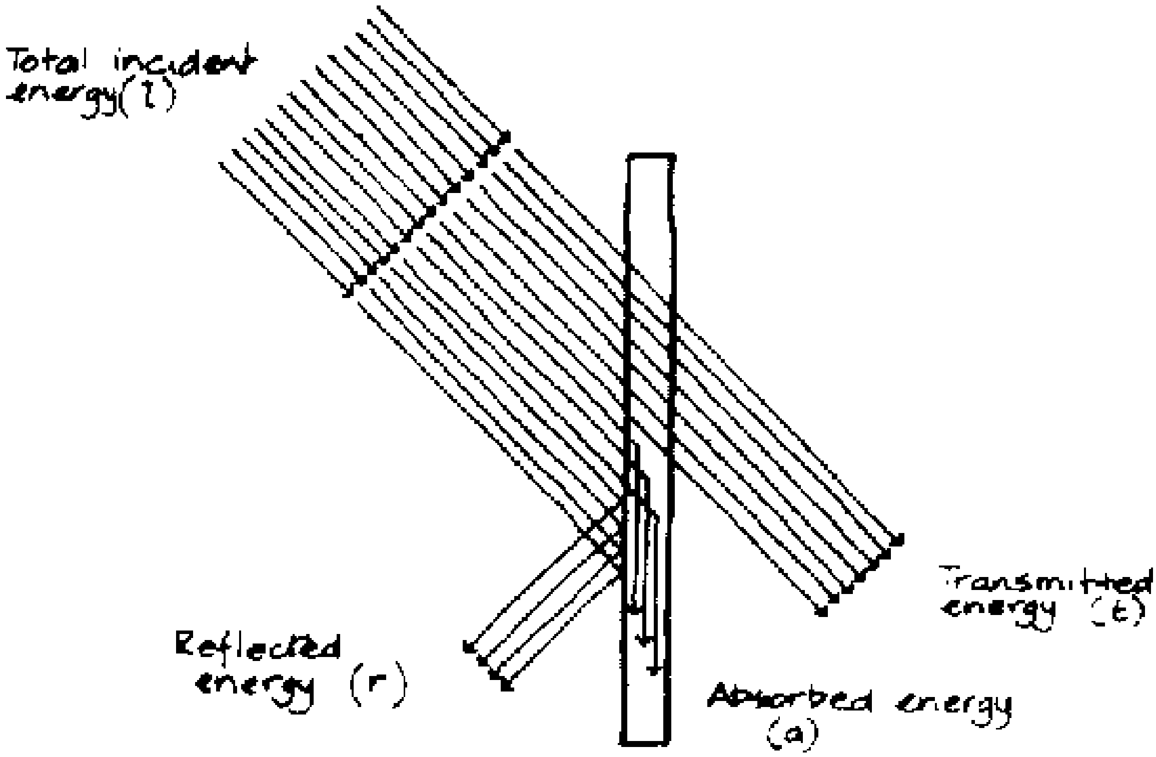


Figure 36. Radiant energy striking an object.

That being the case, then reflectance is the energy that is neither absorbed or transmitted through the surface in question. Aluminium foil is a poor emitter (?=0.05) and a good reflector whilst black paint is a good emitter (?=0.9) and a good absorber. White paint is a good reflector and a good emitter. The thermos flask is an excellent example of how use is made of all these factors. The escape of energy stored inside a thermos flask filled with hot water is restricted by the low emissivity of the mirrored glass linings and the vacuum between them that will only permit the flow of energy by radiation; not conduction or convection. The low emissivity surfaces limits the amount of energy that can be radiated to the outside, thus dramatically slowing down the rate of cooling of the contents.

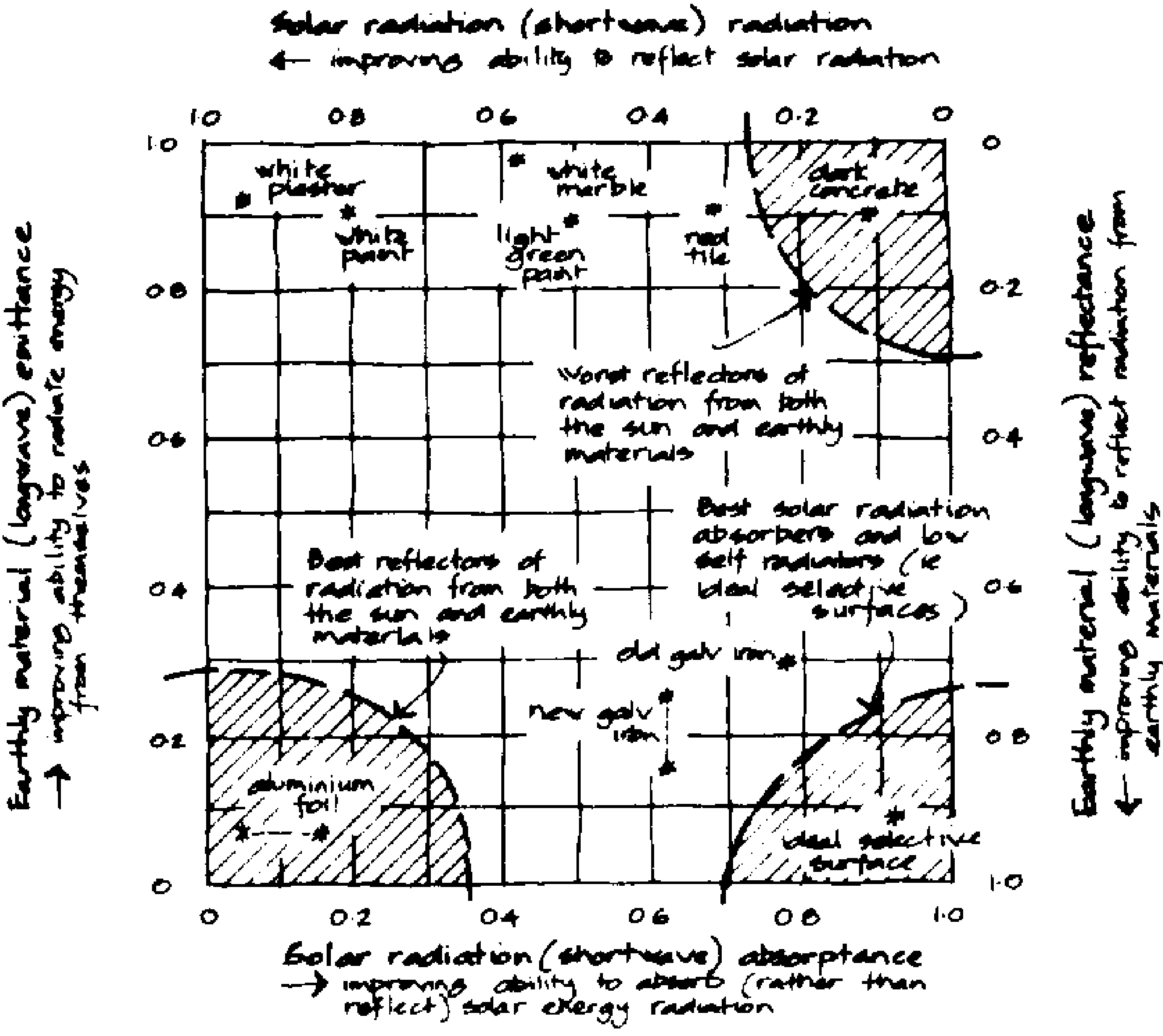


Figure 37. Graph of the absorptivity versus emissivity of various building materials.

The properties of absorptivity, emissivity and reflection relate to the surface qualities of a material. This is demonstrated by the fact that the emissivity of painted surfaces is unaffected by colour whilst the absorptivity is colour–dependent. Most organic surfaces have a relatively high emissivity. Note how some materials such as galvanized iron are rather deceptive given their shiny appearance.

2. Transparent elements

When the sun's rays strike a transparent element such as a window, some are transmitted. whilst some are absorbed into the glass and the remainder are reflected away. The ratio of transmitted, absorbed and reflected rays will vary according to the characteristics of the particular glazing being used. In passive solar design the transparent elements (windows, sunspaces etc.) are usually the main source of heating for the building and so their design is most important. The graphs in figure 38 illustrate the relative intensity of the energy emitted by the sun and a body at terrestrial temperatures at various wavelengths in comparison with the transmission characteristics of standard window glass.

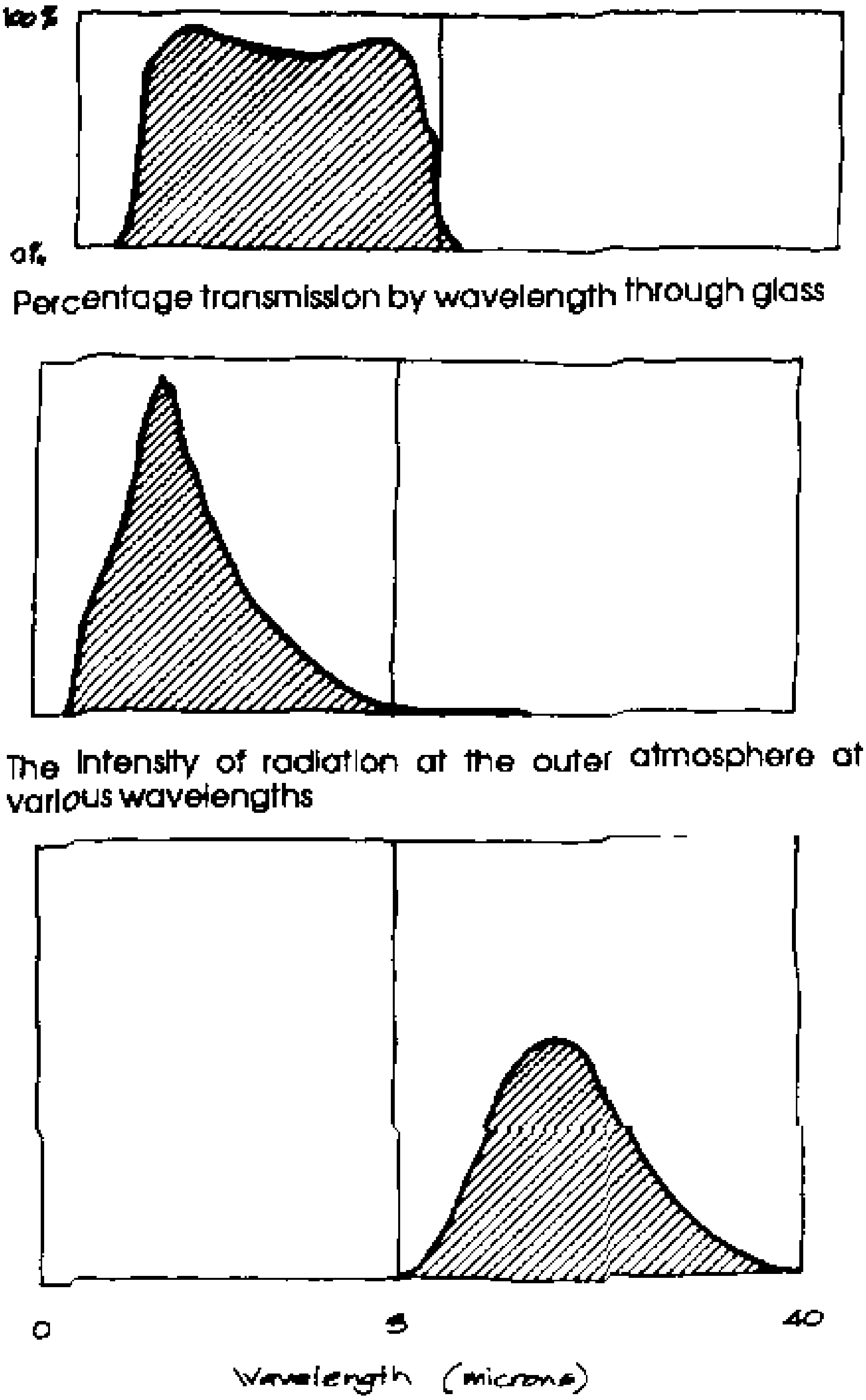


Figure 38. Graphs of sun and terrestrial bodies compared to transmission through glass.

3. The glasshouse principle

The wavelength of solar radiation received at the surface of the Earth is in the range of 0.2–2.5 microns, whilst terrestrial radiation (from various earthly temperature ranges) peaks at about 10 microns with a range of about 4–100 microns depending on the particular temperature.

Standard window glass will generally transmit radiant energy in the 0.3–3 micron wavelengths. At greater wavelengths it is more or less opaque. As a result, the energy reradiated from the interior and objects inside the building will not be transmitted back through the glass. This is known as the glasshouse principle. Energy can, however, still be lost by conduction as discussed later in the section on opaque elements.

4. Thermal behaviour of transparent materials (glass and plastics)

In the case of a transparent element in the external fabric of a building there can be two independent and separate heat exchange processes operating at the same time as is shown in figure 39. The temperature difference between the inside and the outside will cause a flow of heat energy from the hotter side to the colder side by conduction (this Is the same process of heat exchange that occurs in an opaque element and therefore is discussed fully in the section on opaque elements). At the same time, if the sun's rays are striking the glass, there will be a flow of solar energy (radiant energy) in through the window.

It is possible, therefore, to have a situation where heat is flowing out through a window by conduction (outside colder than inside) whilst at the same time energy is flowing in through the glass by radiation. In most cases of north−facing windows, this inflow from the sun will be greater than the outflow by conduction. However in some cases the sun's energy that does penetrate over a 24−hour period will not be greater than the heat lost over the same period (in winter, windows to the south and most skylights fall into this category). If the radiant energy that passes through the glass is not absorbed then it may well be reflected back out through the glass. Energy that is absorbed and then re−radiated will however, not pass back out by radiation. Glass is one of the few materials that transmits solar radiation but not terrestrial radiation of longer wavelengths. Most of the clear plastics such as acrylic, mylar and the like, tend to be less selective.

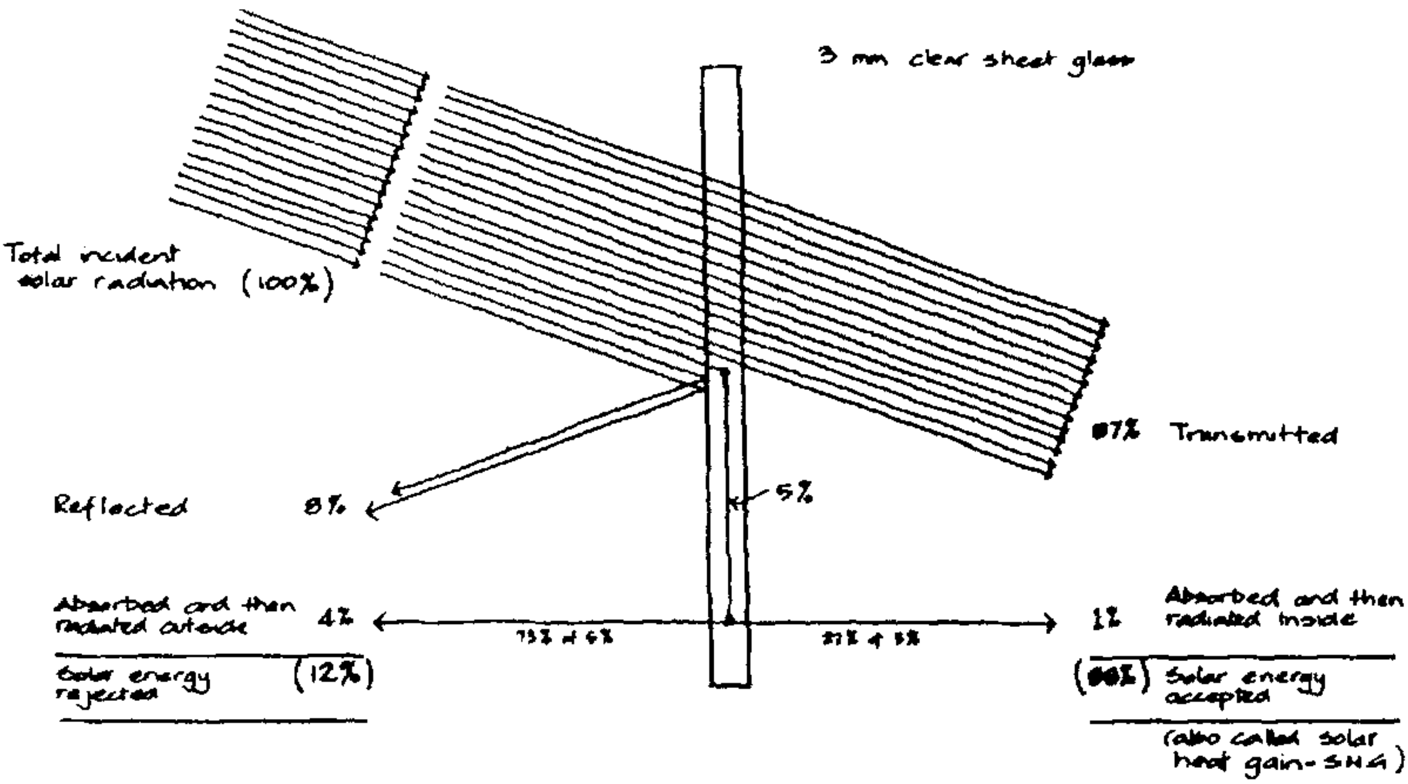


Figure 39. Diagram of heat flow through 3mm glass.

$$SC = \frac{SHG \text{ for selected window configuration}}{\text{SHG for 3mm glass}}$$

The standard conditions of 3mm plain glass are given as:

Reflectance (r) = 0.08
Absorptance (a) = 0.05
Transmittance (t) = 0.87

For standard 3mm clear sheet glass

Shading coefficient = 88/88 = 1.00

From figure 39 above it can be seen that the total heat gain by radiant energy Is 88 per cent.

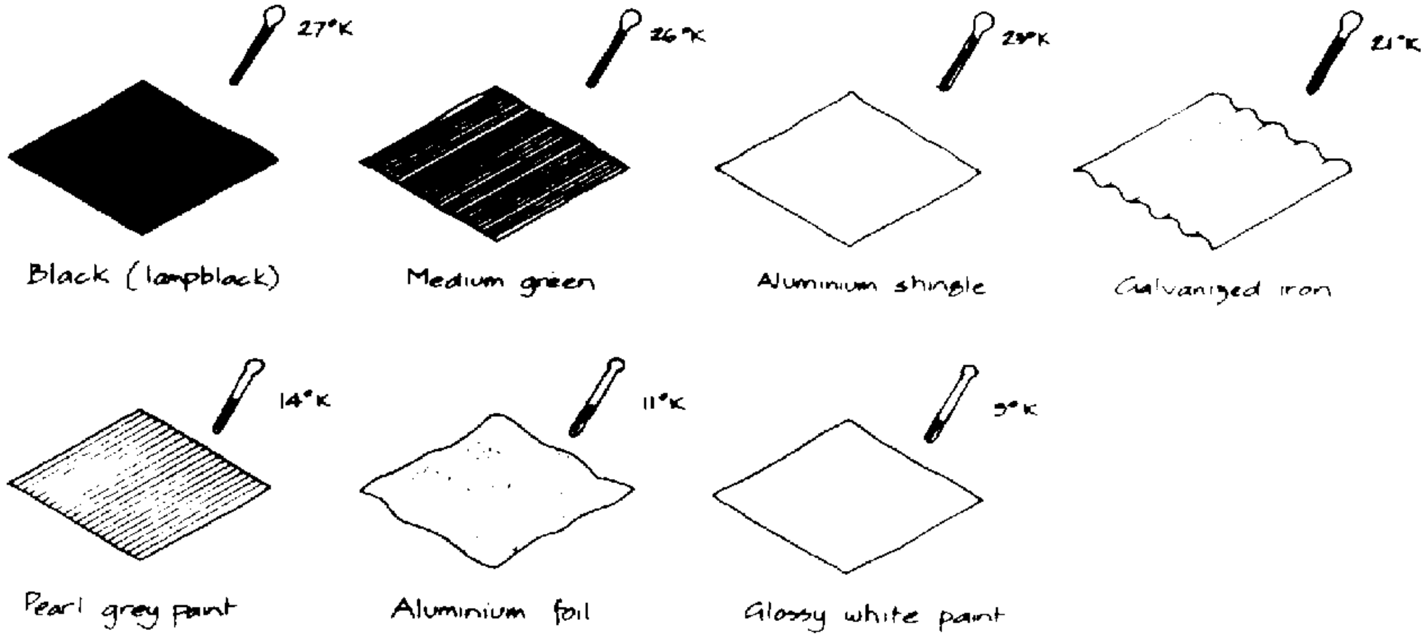


Figure 40. Graph showing temperature rise of different coloured materials exposed to direct sunlight.

The quantity of energy transmitted through glass depends on its composition. Australian window glass has a transmission of approximately 85 per cent. If it was low–iron (also known as "water white") the transmission could be as high as 98 per cent, but such glass is extremely expensive. For calculation purposes it is assumed that the transmission of standard 3mm glass is 88 per cent.

The shading coefficient is the ratio of the solar heat gain through the selected window to the solar heat gain for standard 3mm glass under exactly the same conditions.

5. Opaque elements

The process of heat exchange through an opaque element is by conduction due to the temperature difference between one side and the other, i.e., if the outdoor temperature is lower than the indoor temperature then there will be a flow of heat from inside to outside proportional to the difference in temperature as explained in the earlier section on fundamentals. The solar energy striking the surface of a roof or external wall element is absorbed causing the outer surface to be warmed above the temperature of the outside air, resulting in a change to the effective temperature difference. The resultant effect of the air temperature and the incident solar radiation is known as the sol– air temperature.

Figure 37 shows the relative absorptivity, emissivity and reflectance of different surfaces. If a material has a high alpha (a) and a low sigma (S), i.e., galvanized iron, then it will heat up much more than a material with low alpha and high sigma such as white paint. As a rough guide the darker materials will absorb more than light materials. However, some are deceptive such as aged galvanized iron.

Figure 40 shows the relative daily mean temperature rise of various materials exposed to the sun under the same conditions of wind and ambient temperature. The rate of temperature rise is dependent on the quantity or intensity of solar radiation falling on the surface and the absorptivity (a). Likewise, the rate at which the surface cools off or loses heat will also be dependent to some extent on the air movement over the surface (convective losses) and the surface emissivity (S), i.e., radiative losses (long wavelengths).

So, there is an outer surface which is heated by the sun's energy and "cooled" by air movement etc.. and heated or cooled by the ambient air. All of this is important when considering heat flow through a building element such as walls or roof exposed to the sun.

The simple heat flow Q through wall, say, of area A m due to conduction is:

$Q = A \times U \times Dt$

When a surface is exposed to both ambient temperature and the warming effect of the sun's rays, then there is a situation where the effective value of At is going to be different from the simple value of To − Ti

There are a number of variables that will influence the situation; solar irradiance (1), absorptivity (a), emissivity (S) and ambient temperature (To), the combined effect of which is called the sol−air temperature.

Sol−air temperature is an imaginary temperature of a layer of air adjacent to the surface being considered. It is the equivalent of the effect of solar radiation and air temperature combined. It will vary throughout the day and year just as the solar radiation on a surface does.

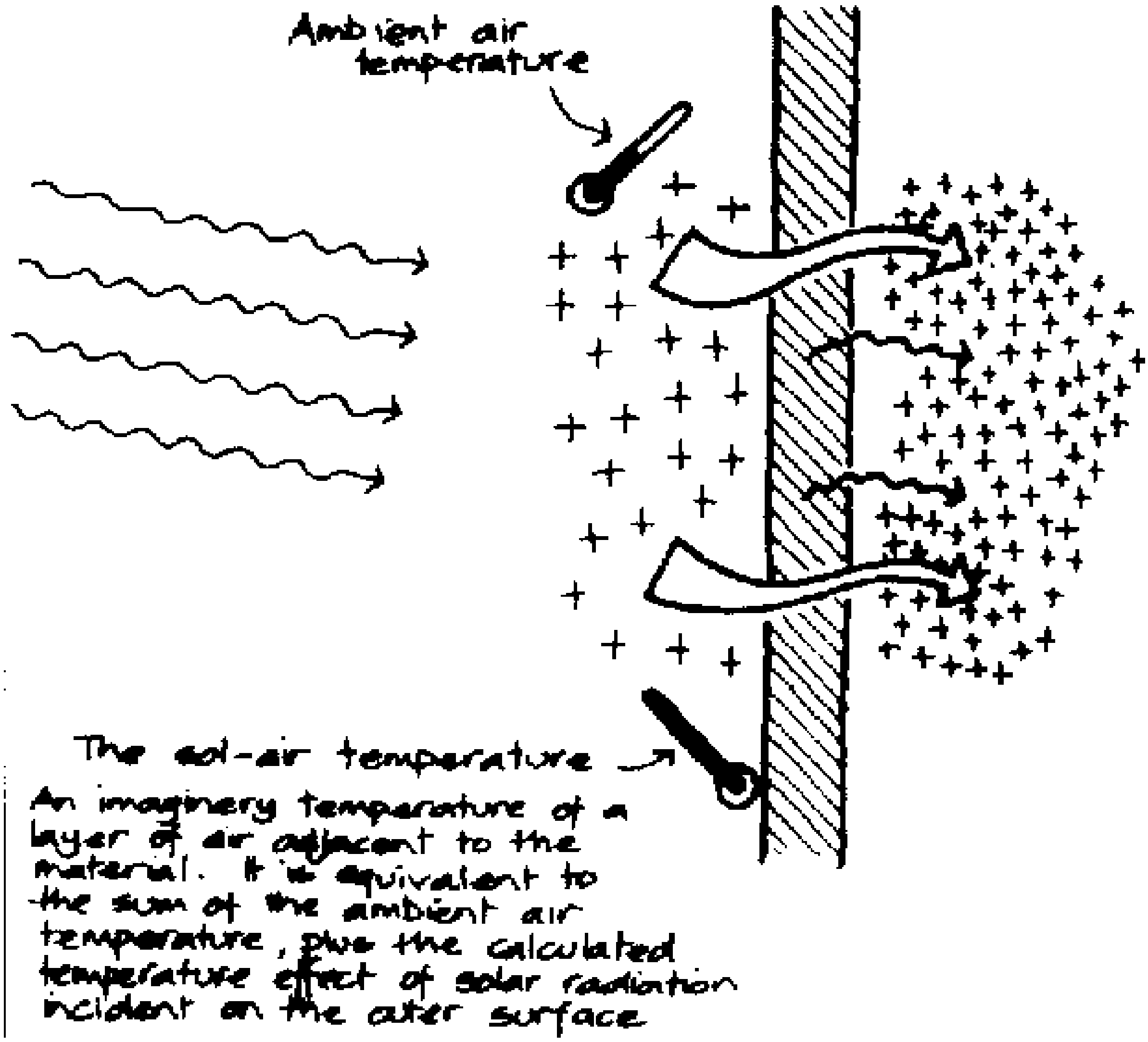


Figure 41. Sol−air temperature.

The formula for sol−air temperature is given by the American Society of Heating Refrigeration and Air−conditioning Engineers (ASHRAE).

$$T_s = T_a + \frac{I.\alpha}{f_o} - \frac{\sum \Delta R}{f_o}$$

T_s = sol−air temperature C
T_a = ambient temperature (outside) °C
I = Radiation incident on the surface W/m².°C
a = absorptivity
f_o = surface conductance reciprocal of $1/f_o$
S = emissivity
R = difference between longwave radiation incident and radiation emitted by black body at temperature T_a

Part of this equation can be standardized. It has been found that for horizontal surfaces (roofs) an optimistic view can be taken as follows:

S = 1; DR = 63 W/m² and f_o = 20

The answer then becomes −3

For vertical surfaces it has been found that AR = 0 and so that part is cancelled out.

Therefore for horizontal surfaces assume −3

$T_s = T_a + \frac{I.\alpha}{f_o} - 3$ (related sky temperature) to and for vertical surfaces assume 0

$$T_s = T_a + \frac{I.\alpha}{f_o} - 0$$

For surfaces in between interpolation can be made between 0 and −3.

The term given to this value is T_{sky}.

This generally makes the calculations complex and very long. If the building Is reasonably insulated, it is reasonable to assume a pessimistic view for winter and ignore the solar temperature effect. Especially if the walls and roof are well insulated and the absorptivity () is low, because the extra heat flow into the building due to solar gains will be quite small.

Consider an example of a white roof a = 0.2 and f_a = 20

assume I = 540 W/m² at noon on June 22

$$T_s = T_a + \frac{(I.\alpha I}{f_o} - \frac{\Sigma\Delta R}{f_o}$$

$$T_s = T_a + (0.2 x 0.055 x 540) - \Sigma\Delta R/f_o = T_a + 5.4 - 3a$$

T_a might be about 1 5C. Therefore T_s = 17.4C.

Note: This is a maximum effect – at other times the effect is much less. It is possible to estimate the daily overall effect. It may be found that the effect overall will be very marginal.

At best the sol−air temperature must work to help in gaining comfort in winter. However, the effect in summer is not to be neglected. In winter its effect improves the situation slightly and so helps. In summer it is the other way round. This excess only aggravates the already higher than desirable ambient temperatures, especially on the roof. The graphs in figure 42 show that the radiation is higher on a horizontal surface in summer compared with winter.

Instantaneous or hourly integrated values of solar radiation on the particular surface are needed to calculate instantaneous sol− air temperatures. At present the only data available for this purpose are the CSIRO "clear sky" solar tables. They do not take into account the local conditions of pollution and cloud cover and so need to be modified. A value of 0.7 – 0.8 is a suitable modifying factor for much of New South Wales. A more useful value in heating load calculations is the "daily mean sol−air temperature', that can be used when calculating the total daily or monthly structural heat loss or heat gain. In solar architecture design evaluation it is easier to handle.

In many calculations it will be necessary to derive a value for the mean sol−air temperature. The values given at the back of this publication for radiation incident on various surfaces are daily totals. These will have to be converted to mean hourly values. The equation below allows calculation of the mean daily sol−air temperature of a surface using those daily totals.

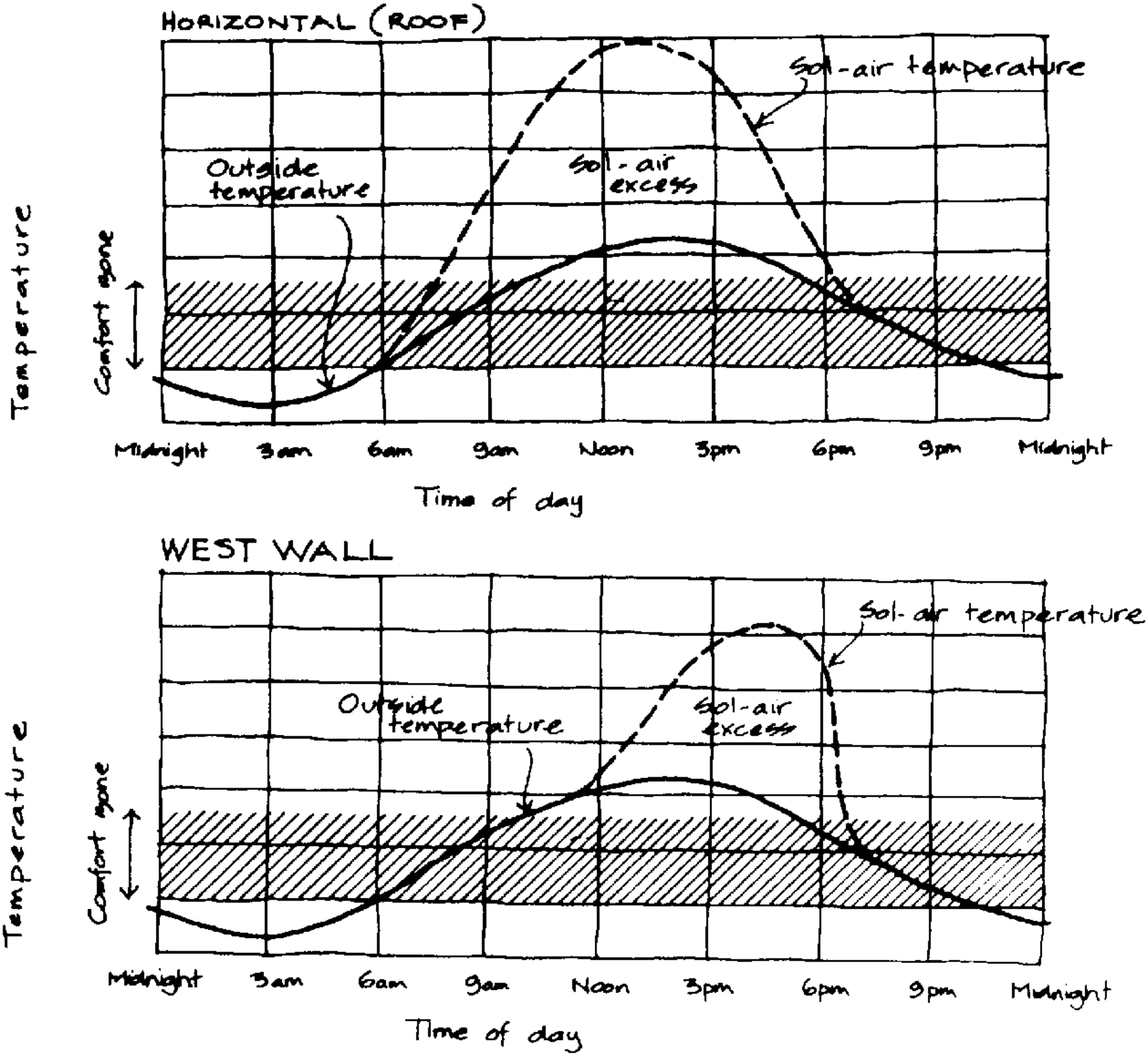


Figure 42. Graphs of sol–air temperatures on various surfaces

$T_s = T_o + ((G \times 1/f_o \times 10^3)/(24 \times 3.6)) - T_{sky}$

Note: The solar radiation value (G) is expressed in MJ/m² .day

Surface absorptance (a)

The absorptance of a surface may be apparent from visual inspection. The following are some values that may be appropriate for use in sol–air temperature calculations:

White paint	0.2	White washed roof	0.2
Polished aluminium	0.05 – 0.15	New aluminium paint	0.2
Cream paint	0.4	Old aluminium paint	0.5
Aluminium sheet	0.45	Red brick	0.55
Light concrete	0.6	New galvanized sheet	0.65
Aged galvanized sheet	0.8	Earth or sand	0.8
Dark concrete	0.9	Black paint	0.95

Table 7. Outside surface resistances (1/fo) (m2.degC/W for "sheltered" "normal" and "severe" exposures.

Building	Emissivity	Surface resistance for stated exposure		
		Sheltered	Normal	Severe
Walls	High	0.08	0.06	0.03
	Low	0.11	0.67	003
Roof	High	0.07	0.05	0.02
	Low	0.09	0.053	0.02

F. Energy storage (heat)

Thermal mass incorporated in the construction of a building interior can improve thermal comfort and reduce energy consumption. Thermal comfort is improved by a reduction in the daily temperature swings and the maintenance of temperatures closer to the comfort zone. Energy consumption for heating and cooling can be reduced or even eliminated if correctly designed. In spaces that are intermittently heated such as is often the case in many temperate climates. thermal−storage materials may have no significant effect on energy consumption. Thermal mass is especially important in hot−arid climates with high diurnal temperature swings. where the heat of the day can be stored for release at night to cool breezes on summer nights that will drain it away. or to the interior space in winter to maintain comfort.

1. Thermal mass and slabs on ground

The use of a suitable thermal mass in all buildings is vital. This is especially so in hot−arid climates where, with high diurnal temperature swings. excess heat can be stored when not needed for later use (winter) or disposal (summer). In temperate areas. the mass of the structure works in the same way to produce greatly reduced temperature fluctuations.

The ideal arrangement for the thermal mass of a structure is inside a protective envelope of insulation. This infers a "reverse brick−veneer" wall, where a light insulated shell is on the outside instead of the inside. In such a configuration the mass interacts more with the internal environment than the external environment.

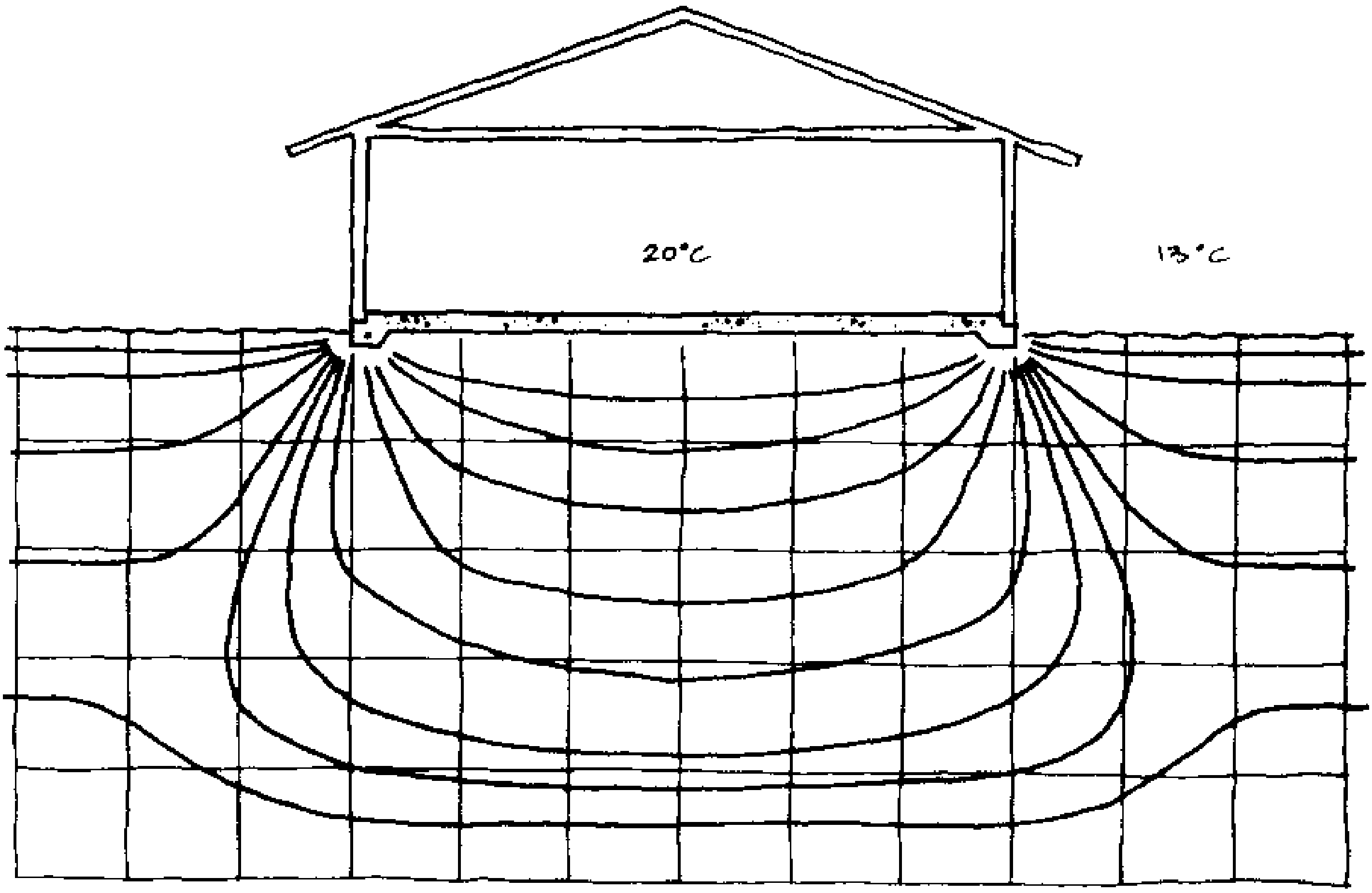
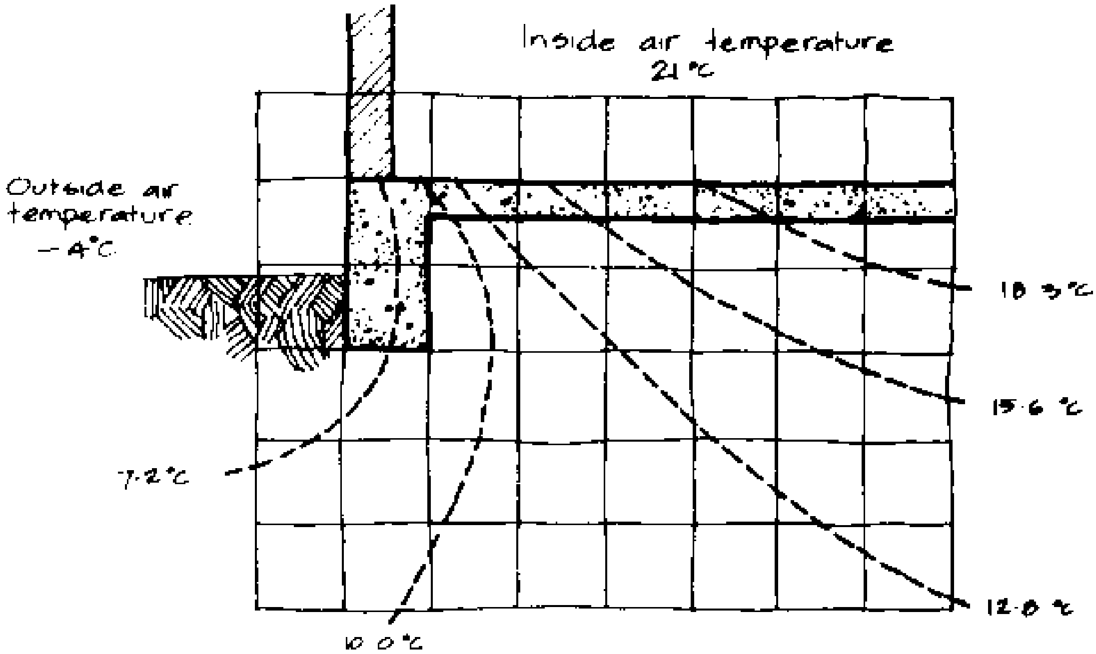
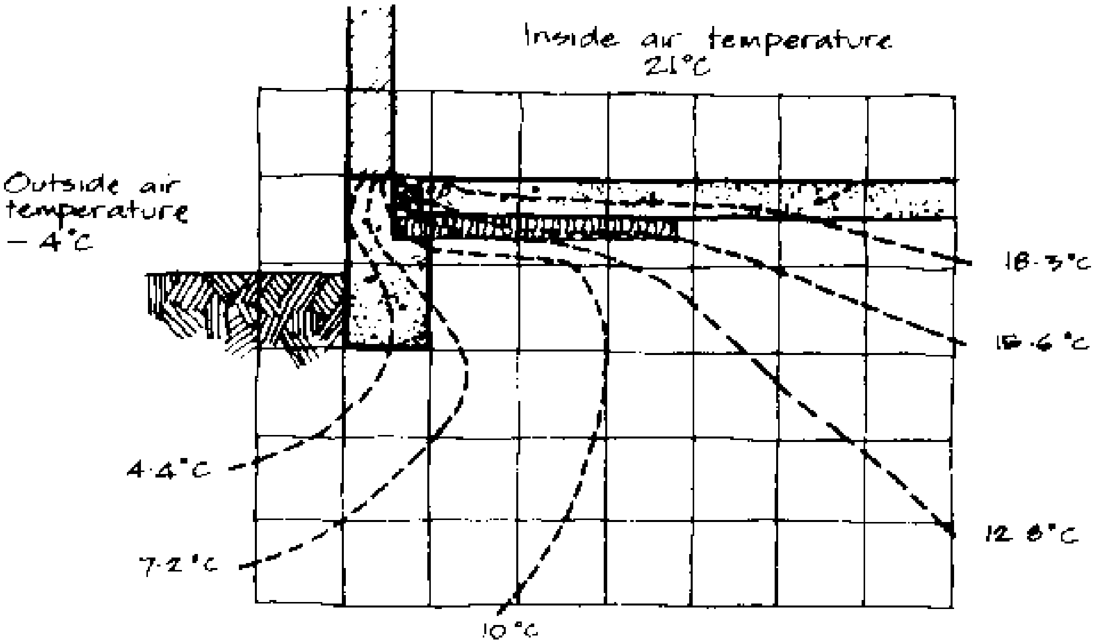


Figure 43. A schematic diagram of soil temperature profiles under a lightweight building with concrete slab on ground floor

When the "mass. is located on the floor (i.e., an insulated timber building. with a concrete slab) then the ground under the building contributes a stabilizing effect. Figure 44 shows how the temperature isotherms move as the mean temperature outside gets colder. The influence of temperature outside, via the ground and the floor slab, is considerably delayed a time lag in the order of one month. The ground under the house is being heated by the energy entering the house, either from solar energy or other energy sources such as space heaters. The ground acts as a thermal store or buffer where the house is thermally well coupled to the ground with, for example, a concrete slab floor. This is very useful in winter when there is plenty of solar radiation entering the house during the day. The heat is stored and then some is given back as the night−time temperatures drop and the building begins to cool down. In summer the floor acts in the same way by soaking up the heat energy that gets into the house. so helping to keep the inside temperatures down.



(a) With perimeter insulation



(b) Without perimeter insulation

Figure 44. Schematic profiles of a concrete floor slab with and without perimeter insulation

Figure 44 shows the influence of perimeter slab insulation. A considerable amount of the heat lost through a concrete slab floor flows out through the edges of the slab because it is in much closer contact with the cold outside air. Such measures are not thought to be economic in Sydney. In areas such as the Australian Capital Territory, Bathurst, Tam–worth and other such cold areas, perimeter floor insulation will help to reduce the loss of heat stored in the floor slab. For improved comfort conditions on tiled floors, however, it has been found effective in Sydney.

2. Thermal storage capacity

When developing a thermal storage system or simply comparing materials it is useful to look at the storage capacity of the proposed building materials which is referred to as the volumetric heat capacity (J/m².degC) or more commonly the specific heat v and the rate at which the material can take up and store heat (the Y−value). Some examples of common storage materials are given in table 8.

From these values can be determined the heat−storage capacity for a given temperature rise or if the heat gain is known, how much the material will rise in temperature. In an ideal situation. for any room into which sunlight enters. the surface area of the thermal mass should be as large as possible. even where not directly exposed to solar radiation. It must, however, be well Insulated from the outside so that it is mainly interacting with the interior.

In the case of a room that does not receive sunlight directly and is used and heated intermittently, it is advisable to insulate any heavy material surfaces from the room. In such places large amounts of heat would Just be soaked up by the thermal mass each time the heating is turned on and so the room might feel rather cool.

In the case of a building with a concrete slab floor on the ground, the ground underneath is being heated by the energy entering the slab from the room, either from solar energy or other energy sources such as space heaters. The ground adds to the thermal store of the floor slab where it is in contact with that slab. This is very useful in winter when there is plenty of solar radiation entering the house during the day. The heat Is stored and then some is given back as the night−time temperatures drop and the building begins to cool. In summer the floor acts in the same way by soaking up the heat energy that gets into the house, so helping to keep the inside temperatures down. The need for insulation under the slab and around the perimeter has been discussed under insulation, earlier in this chapter.

The thermal behaviour and energy consumption of 15 cottages was studied in a major research and demonstration project. Each of the houses were typical of a particular construction type in Australia and the plan layout of some was also similar to permit cross−comparisons of the results. Hourly data were collected from each dwelling over a three−year period with the houses unoccupied for the first eight months. Graphs of the daily minimum and maximum temperatures recorded in four of the houses are illustrated in figures 45 to 48. Daily minimum and maximum temperatures in the living areas are plotted against similar outdoor temperature data over approximately 18 months during the occupied period. The impact of the various quantities of thermal mass In each house is shown by the marked reduction in the temperature swing and the general suppression of the temperature extremes. In each of the figures the data above the X=Y line illustrate heat being returned to the interior of the space from the thermal mass at a time when the outdoor temperatures are low. The graphs show how each dwelling behaves under the same climatic influences. They are plots of the internal temperature against the outside temperature for each day using both the maximum and the minimum values. The data used include both summer and winter time measurements.

Cottage No. 359. for which the data in figure 48 are illustrated, is of standard timber frame construction with a timber floor over a crawl space. The only insulation is 4−inch thick glass fibre on the ceiling. The external cladding of this house is fibro−cement sheet, commonly used on many houses built In Eastern Australia in the 1940s and 1950s, whilst the interior linings are 3/8−inch plasterboard sheet. The living room windows are oriented to the west, south and north (north windows have a large fixed overhang). The results show that this house is unable to modify the

Table 8. Examples of commonly used thermal storage materials external climate to any extent and in summer it is often hotter inside than out.

Material	Density	Volumetric heat capacity		
	kg/m³	(lb/ft³)	J/m³. degC	(Btu/ft³.°F)
Water	1000	(62)	4186	(62)
Concrete	2100	(131)	1754	(26.2)
Brick	1700	(106)	1360	(20.1)
Store: marble	2500	(156)	2250	(32.8)
Materials not suitable for thermal storage:				
Plasterboard	950	(59)	798	(11.8)
Timber	610	(38)	866	(12.9)
Glass fibre matt	25	(1−5)	25	(0.37)

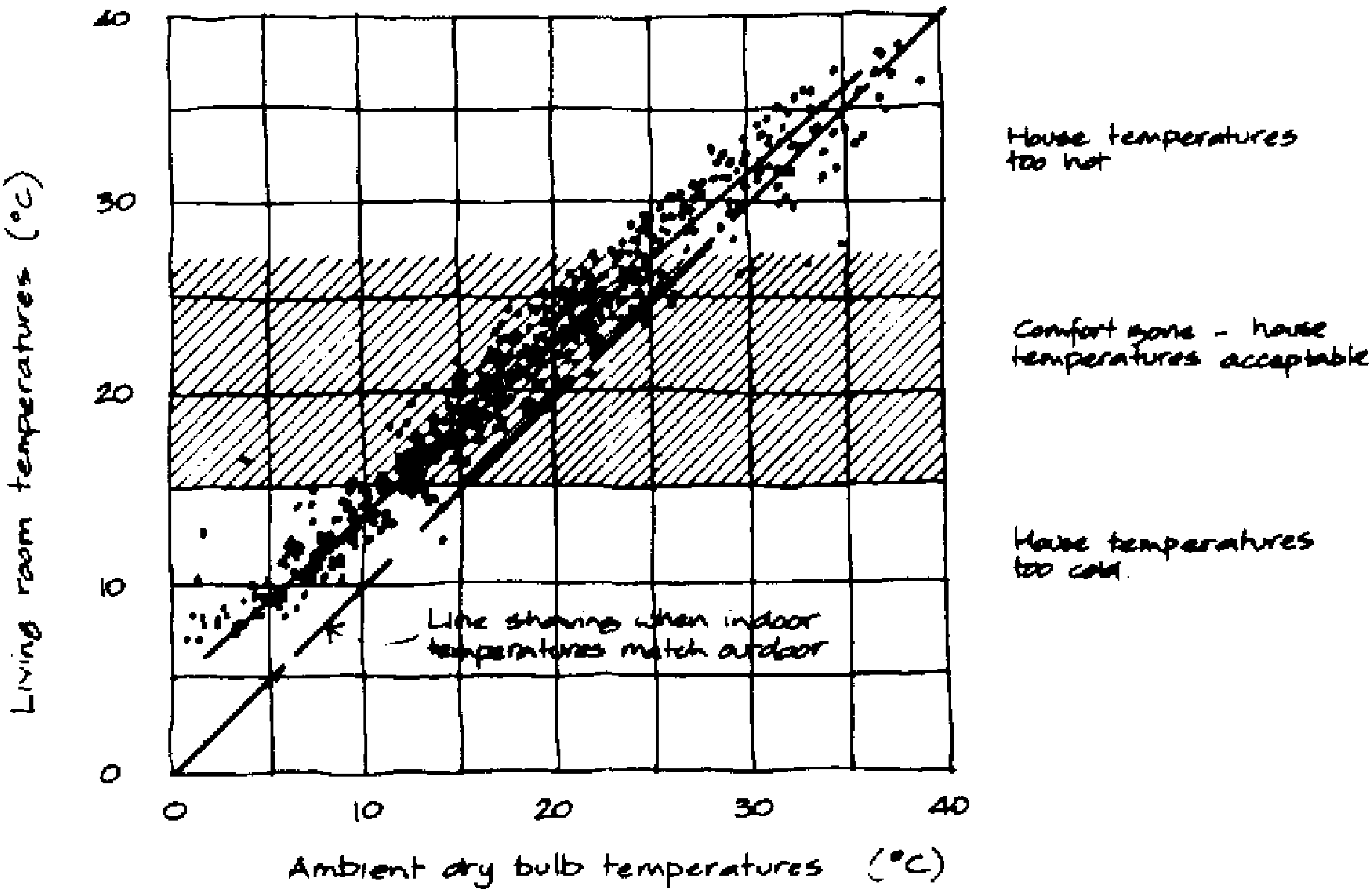


Figure 45. Cottage No. 359 of standard timber construction with timber floor and insulation only on the ceiling. The living room windows are oriented to the west. south and north (north windows having large fixed overhand).

The data illustrated in figure 46 are from cottage No. 357 of standard brick−veneer construction, with a timber floor and ceiling insulation. This construction system is essentially a timber−frame construction lined internally with plasterboard and with a single layer of brick built around the outside of the timber frame. The living room in this cottage has only equator− facing windows (north in Australia)

The performance of this house is not significantly better because it still lacks an adequate amount of thermal−storage material associated with the interior.

Figure 47 illustrates the results of data collected from a timber−framed cottage. No. 351, with a concrete floor slab in direct contact with the ground. As with the others the internal linings are plasterboard and the ceiling is insulated with 4−inch thick glass fibre blanket. The exterior wall lining is 10mm thick compressed wood−fibre planking laid over double−sided reflective foil insulation. All living area windows face towards the equator and the floor finish is hard vinyl tile with scatter rugs. The impact of the concrete floor slab is clear. The temperature swing is reduced and the interior conditions are buffered against the extremes of the outside. The "narrowness of the cluster of dots shows that the concrete floor slab is acting in conjunction with the ground as a substantial heat sink.

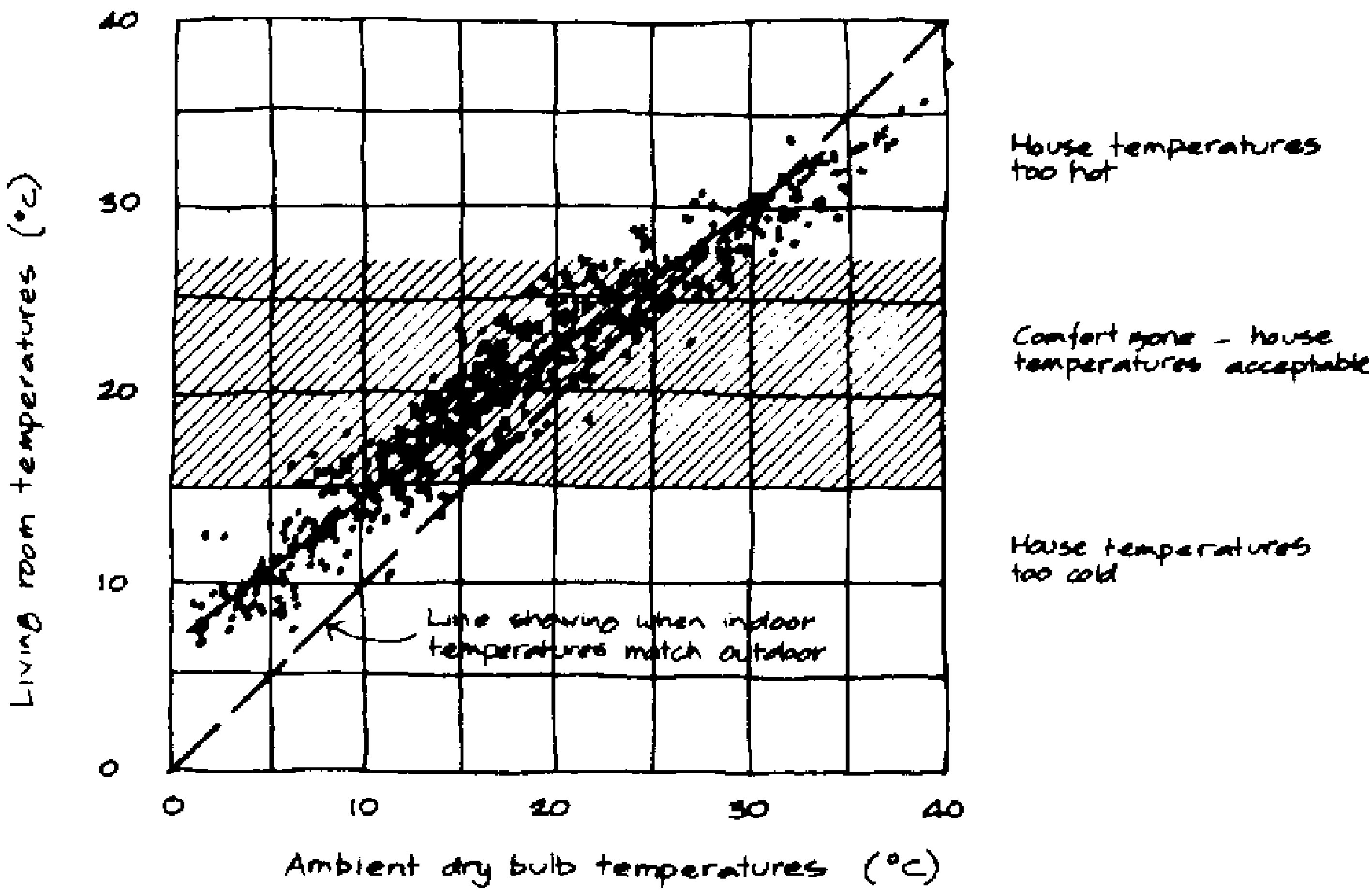


Figure 46. Cottage 357 of standard brick–veneer construction with a timber floor and ceiling Insulation only. but with north–facing living–room windows

The behaviour of a traditional passive solar house is illustrated in figure 48. Cottage No. 341 is constructed of double–brick walls with the cavity filled with urea formaldehyde foam. The floor is a concrete slab on the ground similar to cottage No. 351 in figure 46. The roof is insulated similarly to the other houses and all living area windows face toward the equator (north). This house is the best in terms of overall thermal performance as can be seen from the small number of dots above and below the accepted comfort lines. The dots in this example are clustered in a "fatter" pattern than those In figure 45 which displays the impact of the internal walls which are not ground connected. The energy stored in them must come from and go back into the interior space, thus causing the interior temperature to rise more slowly as the day warms up and to fall more slowly as the night comes on. It should be noted that some of the energy that enters the floor slab in both this example and that in figure 46 will flow away to the ground and be lost.

The following is a review of some important characteristics of materials that can store energy. First, when energy is absorbed into a material that material will rise in temperature. The effect of letting the sun into a room that has no significant storage capacity will be to cause the room temperature to rise – if the room is well insulated then the rise will be quicker because little heat is lost.

If the room surfaces comprise a significant area of high storage capacity material in the path of the sun. then some of the sun's energy entering the room will be absorbed without having any immediate effect on the temperature of the room. The temperature of the thermal mass will rise and the heat energy will be held until the temperature of the room begins to fall later after the sun is no longer entering the room.

If some surfaces are warmed by the sun's energy then the mean radiant temperature (MRT) will be higher and so people will sense that the room is warmer even though the air temperature may not have changed. Since the surface temperatures of a room have a significant bearing on thermal comfort, this factor can be utilized by careful placement of heat storage materials (refer also to chapter IV on thermal comfort).

If the thermal mass in the room has been cooled during the night, then during the day it will act as a sink and soak up the excess heat that flows into the room. In summer this can be very beneficial as a means of keeping the room cool (i.e., the environmental temperature is kept lower).

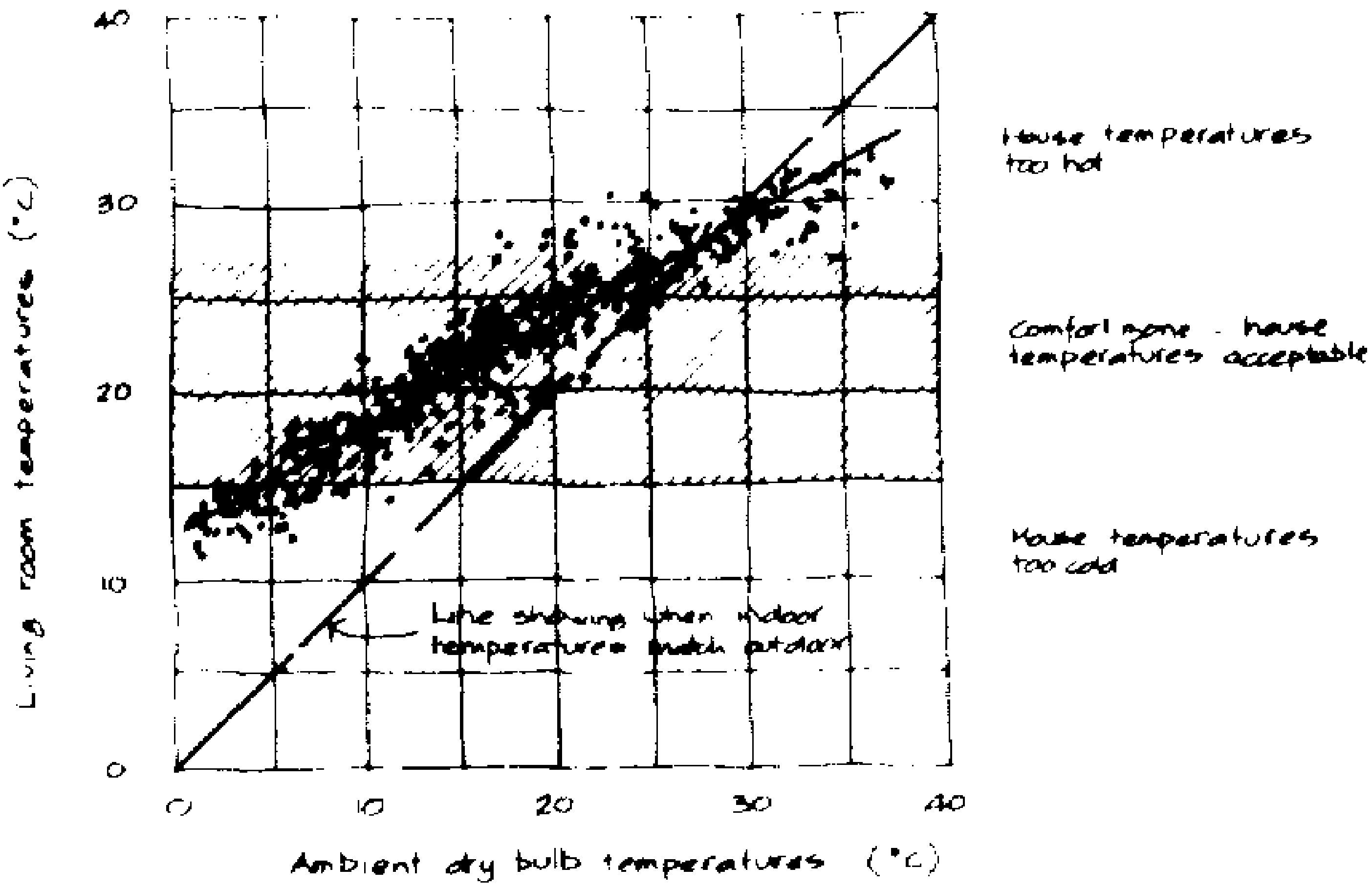


Figure 47. Cottage No. 351 of timber–frame construction with a concrete floor slab with Insulated walls and roof and all living area windows facing north.

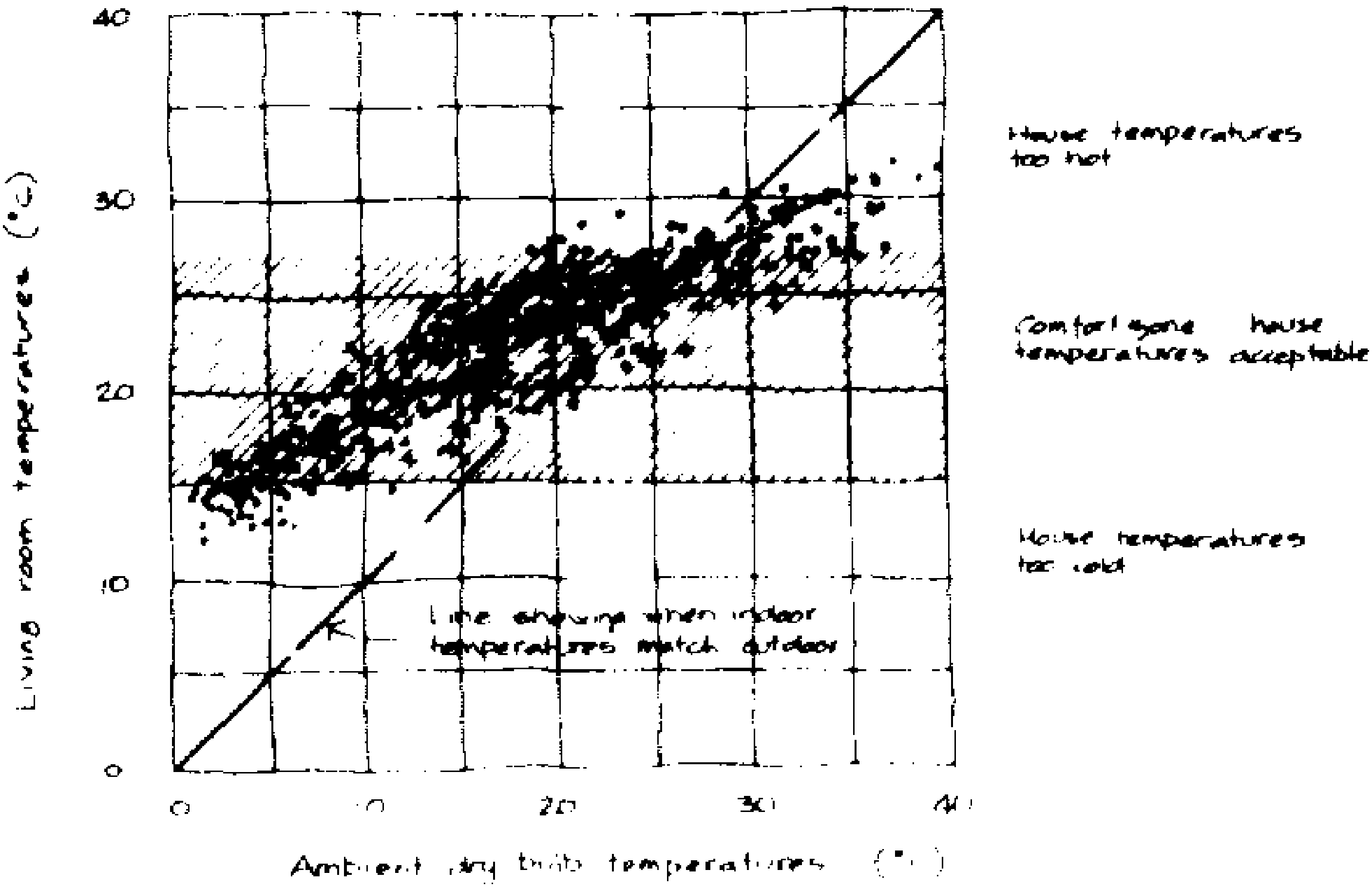


Figure 48. Cottage No. 341 fully brick construction with a concrete floor slab. Both the roof and the wall cavities are Insulated and all living area windows face north.

Where it is desirable to level out large swings in temperature from day to night, this can be achieved by the storage of heat from the warmer part of the day until a later time when it can offset the colder temperature of the evening. The admittance values (Y−value) give an indication of the performance of elements in this respect. They can also be used in calculations to predict internal temperatures using a technique known as the admittance method.

From all this some recommendations can be made about the desirability of thermal mass and its preferred qualities according to the climate of the location. In temperate climates and desert climates which are usually arid the desirable wall surfaces will have a low U−value, a low T−value and a high Y− value. In areas where it Is necessary to heat with auxiliary energy then it may be desirable to minimize all three values to maximize the heating effect when its needed.

3. Surface colour and texture

The floor is most commonly the main thermal storage medium in direct−gain systems because so often it is the most economical place to locate heavy masonry materials. Unless there is an adequate amount of thermal storage in the walls of the space (perhaps at least half the walls). the floor should be of a material with a high thermal admittance and have the least amount of thermally−resistive covering (i.e.. carpets or cork tile). The surface should have a low reflectance to absorb as much of the incoming energy as possible. Where there is a significant thermal storage component in the walls. the floor may be more reflective the better to distribute the sun's energy to the other heat storage surfaces.

4. Coverings and sheltering (interior finishes and furniture)

The type of floor covering or finish used on a ground−connected floor (i.e.. concrete slab. masonry or stone paving) will have an important bearing on the way such a floor interacts thermally with the room. Materials such as carpet. cork or foam−backed vinyl materials act as an insulator (see chapter IV) and effectively reduce the internal admittance of the floor surface. During winter an undesirable temperature rise can occur in spaces without alternative thermal mass that are heated by the sun entering directly into the interior (known as a direct−gain system and discussed elsewhere) because such coverings reduce the admittance of heat into the floor slab. Likewise, in summer a floor with an insulated covering is also less effective in acting as a heat sink to soak up the daily heat gains for disposal at night.

5. Time lag and decrement

As the outdoor temperature cycles up and down through each 24−hour period so the energy flow through the exterior elements of a building will also cycle (see figure 49). The time taken for heat to flow through each building element will vary according to the storage properties and the resistance and so some of the heat energy will still be passing Into the material when the external temperature has dropped below the inside temperature. This repetitive cycling produces what is called a periodic heat flow defined by the time lag and decrement factor.

Time lag is the time delay between when a temperature rise occurs on one side of a material and the onset of the temperature rise on the other side. The ratio of the two temperatures achieved over a cycle is known as the decrement factor. The two terms are illustrated in figure 49. Heavy materials such as masonry and concrete with a high volumetric specific heat capacity will take time to conduct the heat energy from one particle to another because each in turn can absorb considerable energy for a given rise in temperature. The term that describes this function is thermal diffusivity or temperature conductivity and is a function of the conductivity divided by the volumetric specific heat capacity. These are interrelated in figures 50 and 51.

In practical terms each element of the external building fabric such as the roof. walls and doors will have a different time lag and decrement. Heavy masonry walls of say 230 mm brickwork will have a time lag of about 8 hours whilst the lighter roof will have a time lag of only 1 or 2 hours. Each of these elements work together to generate a building time−lag (usually about two hours or so for a typical brick−veneer construction). Very heavy constructions such as earth−sheltered buildings well below the surface may have a time−lag of months. The benefit of heavy materials with a long time−lag, is that they can be used to soak up solar energy during the day and release it back at night when it is cool.

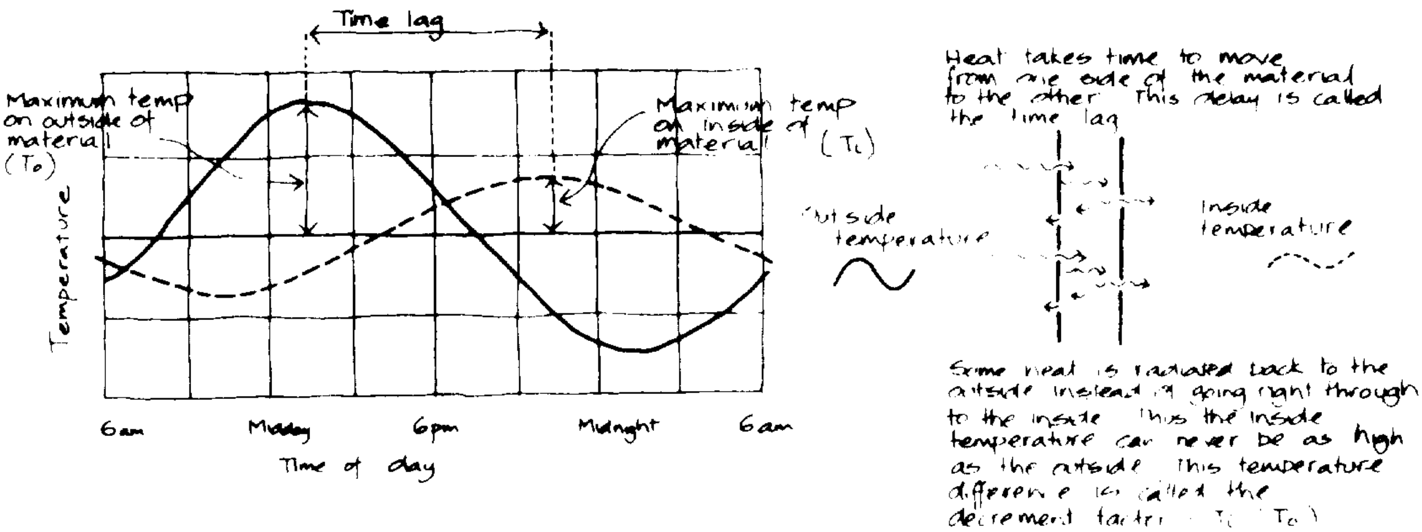


Figure 49. Periodic temperature swing showing time lag and decrement

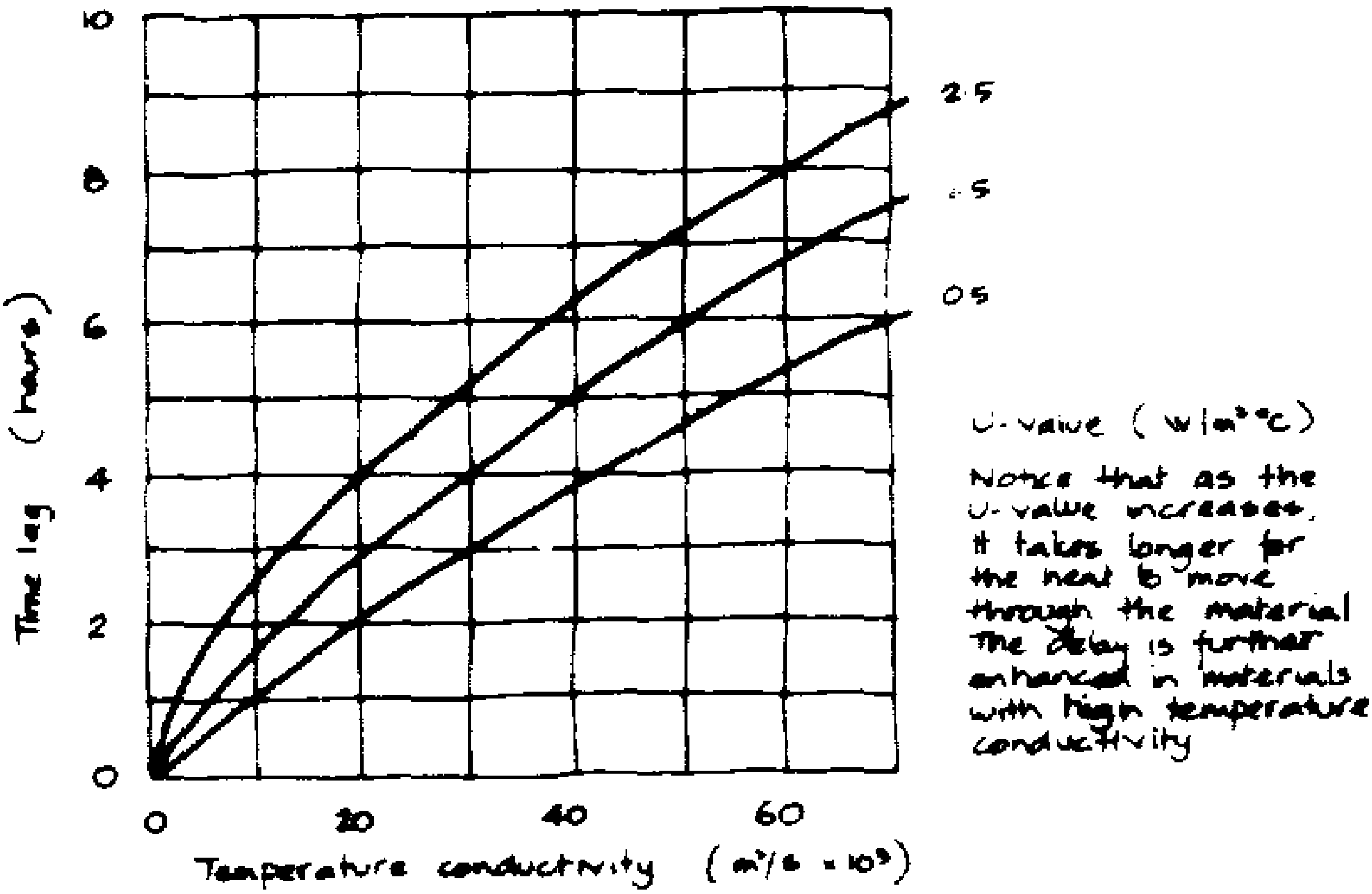


Figure. 50. Time−lag versus diffusivity and U−value.

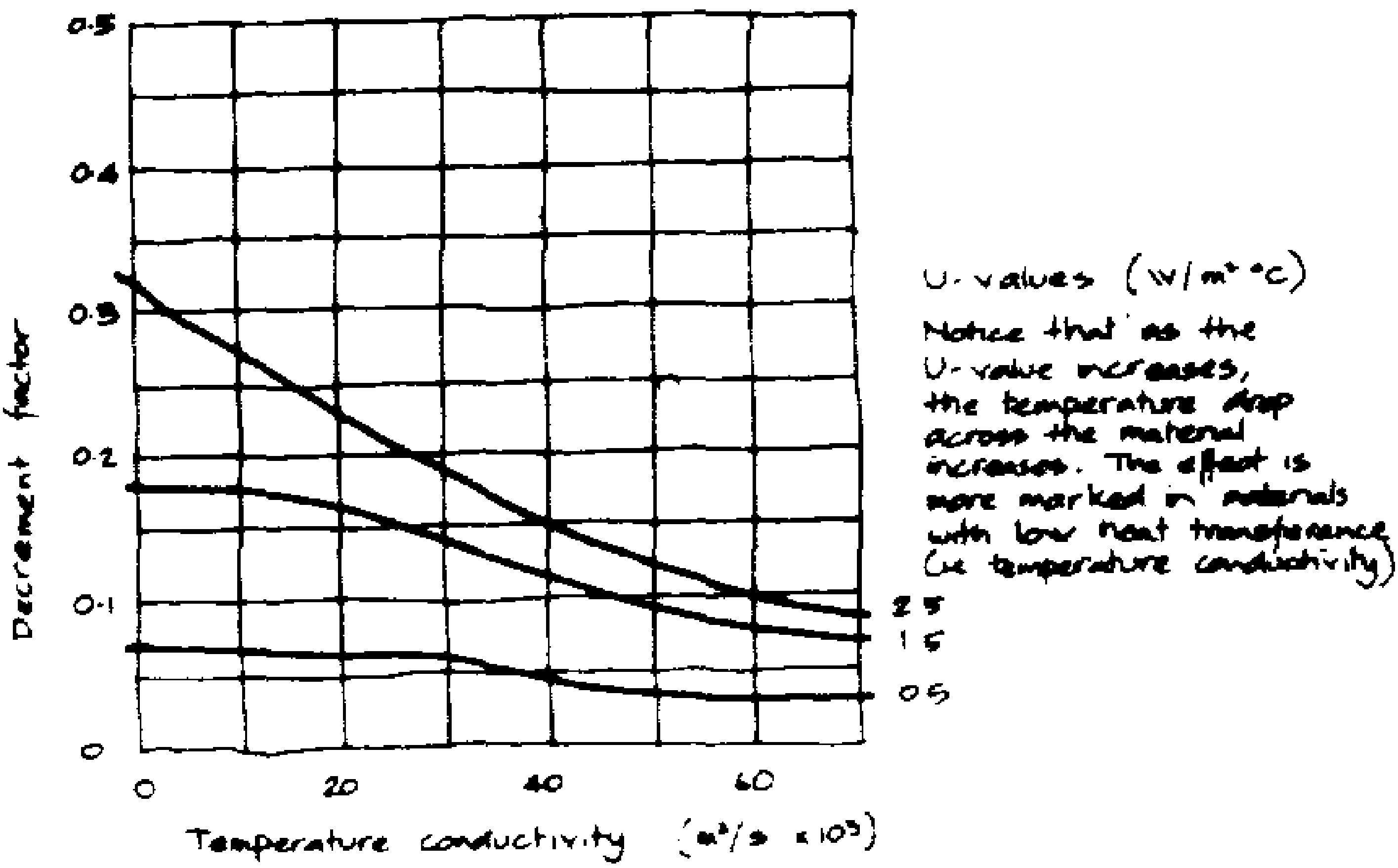
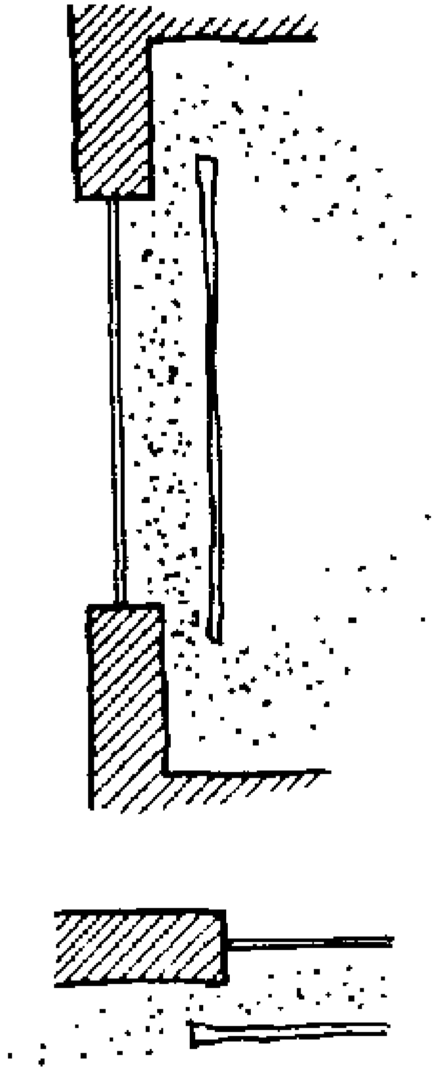


Figure 51. Decrement factor versus diffusivity and U−value

G. Heat retention

1. External fabric resistance

The U−value of single−sheet window glass has been found to be 5.98 W/m^2. degC. Whilst windows are usually uncovered during the day to let in daylight (and direct sunlight in winter) overall heat losses can be reduced at night by covering with curtains or blinds. Thermal comfort can also be improved by covering windows at night, because rates as high as 5.98 W/m.degC will cause a lowering of the overall mean radiant temperature (MRT). It is important that curtains or blinds be well fitted to windows to minimize heat losses at night. Ideally, curtains should wrap around to the wall at the sides, be fitted with pelmets and finish close to the floor or on a projecting ledge as shown in figure 52.



FREE AIR
MOVEMENT

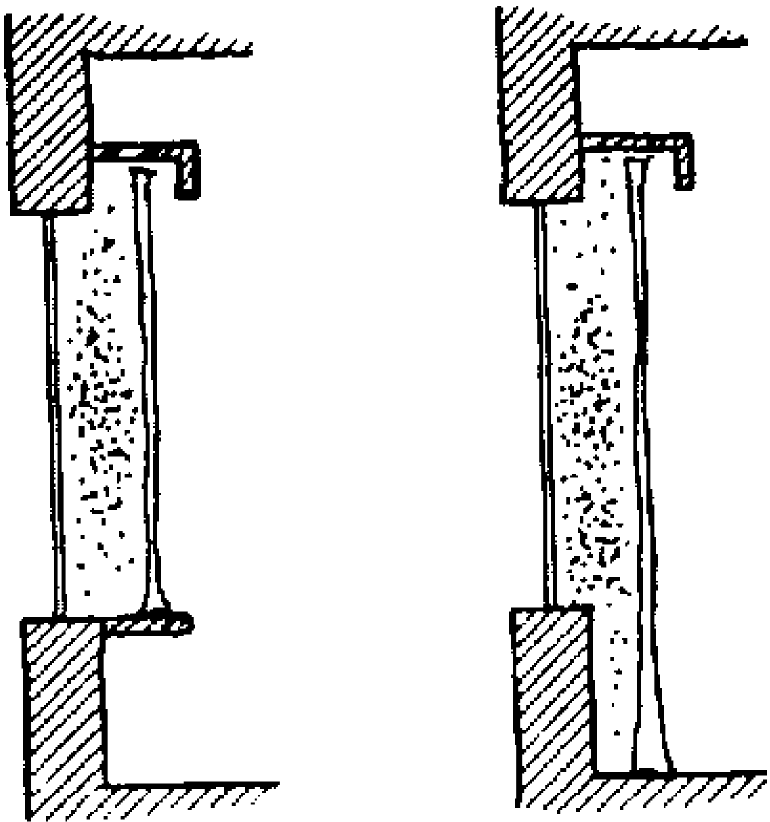


Figure 52. Restrict air circulation across windows to reduce conduction of heat

If sealed. Insulated shutters were fitted to a window then the reduced U−value can be easily calculated. However, the effect of less substantial elements Is more difficult assess. For that reason some basic values are given. First, it is assumed that one of two conditions prevail; either the space between the curtains or blinds and the glass is closed off at the perimeter as described above or it is open for free circulation to the room. The difference is quite marked. When the edges of the curtains are closed and the material is suitably lined so as to restrict air circulation, the "trapped" pocket of air is quite effective as insulation. These values, known as U−value modifiers (M) are as follows:

0.33	Heavy drapes with restricted air circulation
0.60	Light drapes with restricted air circulation
0.75	Heavy drapes with free air circulation
0.85	Light drapes with free air circulation

To determine the modified U−value for thermal evaluation calculations over at least a 24hour cycle the following equation can be used.

$U_m = U/24 \times ((M \times H_d) + 24 - H_d)$

where

U_m = overall modified U−value
M = modifier from above table
H_d = hours per day curtains are covering windows (i.e., 1800 hrs to 0700 hrs = 13 hours)

2. Thermal insulation materials and their application

Thermal insulation materials generally available for building purposes can be classified into two generic groups − bulk materials and reflective foil laminates (RFL). The first of these relies on the resistance of air trapped in pockets between the fibres of the blanket type materials (mineral fibre materials) or the cells formed in the foamed structure of board or slab type materials (usually made from plastics such as polystyrene and polyurethane foams). The second reflects radiant energy away from the object or surface being protected. The basic principles of heat transfer by radiation and conduction have been covered earlier, along with the principles of operation of such materials.

Thermal insulation in the outer fabric of a building is a vital component of an energy−efficient design strategy. The key to successful energy−efficient design is the control of heat flow through the external fabric. All the solar energy gained could be easily lost from an inadequately insulated building before it is able to be of benefit.

(a) Roof insulation

The major heat path in both cold and hot weather is through the roof. Generally the roof is the largest single exposed surface and is usually built of relatively light−weight materials. The basic insulation of roofs should be resistive material to minimize heat loss in cold weather with the addition of a layer of reflective insulation under the roof cladding where summers are warm enough to cause overheating inside the building (which is the case in most localities except those with cool summers). In predominantly warm−hot climates where no winter heating Is required. the use of reflective insulation only may be appropriate. Reflective insulation has a greater resistance to heat flow down (summer) than to heat flow up (winter) because it resists radiant energy flow better than conductive flow. The use of resistive insulation will reduce the conductive losses available from any nightsky cooling effect or air cooling of the roof surface. which is undesirable in warmer climates.

The air space below the reflective insulation in the attic space of a pitched roof need not be ventilated for summer where resistive insulation is included on top of the ceiling. The temperature of a ventilated roof space may be maintained at close to the outside air temperature and although this may be beneficial in summer to reduce heat build−up in the roof space. in cold weather it tends to negate any insulating contribution provided by the roof cladding and the associated reflective insulation. The difference in heat flow through a well−insulated vented roof and a well insulated non−vented roof into the occupied space below is very small. The U−value of a pitched roof with only reflective insulation under the roof cladding is in the order of 1.06 W/m^2.degC for heat flow in an upward direction and 0.64 W/m^2.degC for heat flow in a downward direction.

(b) Wall insulation

Insulating framed external walls is generally not difficult because the outer cladding material is usually designed to be a barrier to moisture. In such construction it is important, however, to ensure that a vapour barrier is installed on the warm side of the insulation layer (in cold climates this will be near the inside lining and in the hot humid climates near the outer lining).

Heat bridges in metal frame construction could be a problem in cool temperate climates where condensation will occur, and in hot−arid climates where the walls are exposed to the sun. In such circumstances it is advisable to use an outer layer insulation that covers and thermally isolates the framework from the external cladding material.

(c) Insulation d framed floors over ventilated crawl spaces

In cold climates it is advisable to insulate the underside of framed light−weight floors.

Generally the air under such floors is ventilated to minimize problems caused by dampness. In winter months this results in such spaces being at temperatures close to ambient, hence the need to Insulate to reduce heat losses down through the floor.

(d) Insulation of floor slates on ground

In passive solar building design it should not be necessary to insulate fully between a concrete slab and the ground except in extremely cold climates where in−floor central heating is being installed. The disadvantage of insulating the whole area under the floor slab Is that the house is isolated from the ground, which in winter is warmer and in summer is cooler than the external air conditions. The free heat storage benefits of the ground under the building is lost if full Insulation is used.

A considerable amount of the heat lost through a concrete slab floor flows out through the edges of the slab because it is in much closer contact with the cold outside air. An alternative is to insulate the edge and the perimeter strip of the floor for approximately 600mm. Such measures may only be necessary in cool temperate climates. Perimeter floor slab insulation is recommended in areas of 2000 degree days to base 18.3°C, or greater (a description of heating degree days is covered elsewhere). Such insulation will help to reduce the loss of heat stored in the floor slab. Details of the Installation of edge−of− slab insulation is illustrated in figure 53.

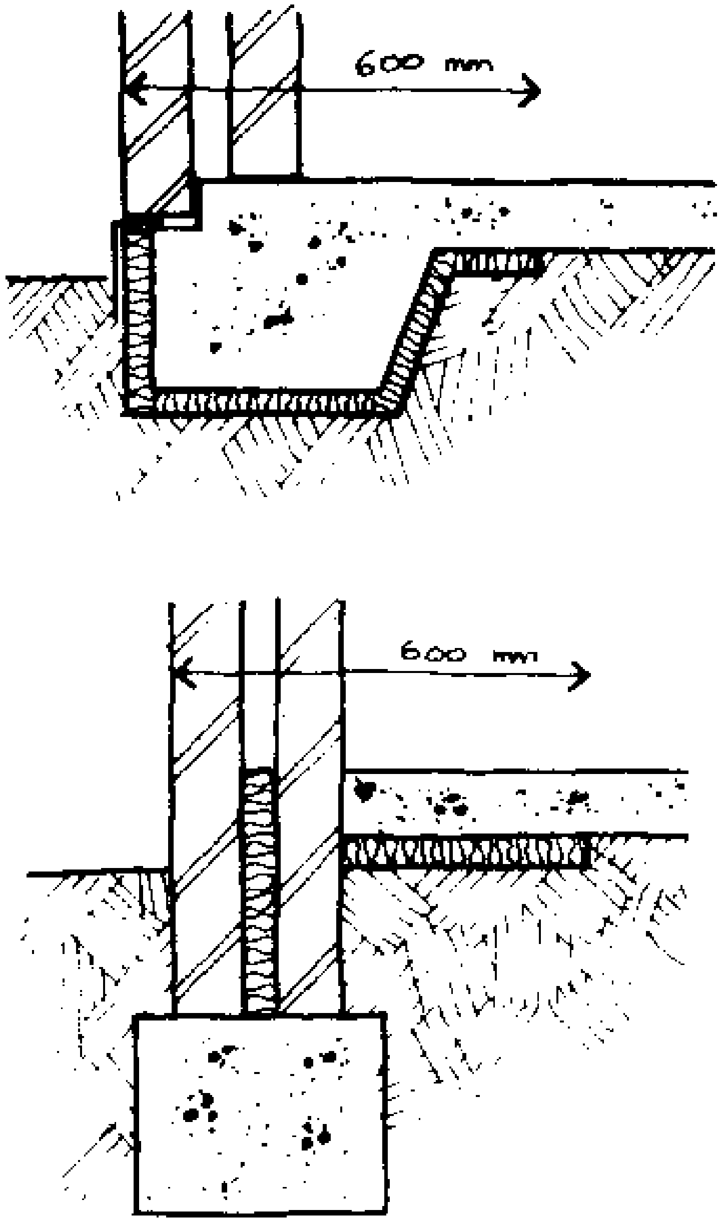


Figure 53. Edge Insulation of a concrete slab on ground

{e) Insulation materials

The minimum insulation levels desirable in roofs, walls and floors will be determined by building codes and regulations In most countries. Optimum levels will be higher and will depend on the installed cost of the products being considered, the local cost of energy for space heating or cooling and the accepted discount rate for finance in the particular country.

Thermal insulation to restrict heat flow into and out of buildings has been well demonstrated to be economically worthwhile. In most situations the optimum levels of insulation will repay their capital outlay in energy savings over a short time. The improvement in thermal comfort of an insulated building compared with an uninsulated dwelling is quite significant, although it can be difficult to evaluate In economic terms when the users are accustomed to lower than average comfort standards. This is often the case in the more temperate climates where it is possible to manage with lower comfort levels. The value of energy savings over time can be determined using conventional discounting techniques as adequately described by Markus and Morris.

Typically uninsulated walls have a U−value of approximately 2.0 W/m^2 .degC whereas correctly insulated walls have a U−value 0.6 W/m^2 .degC in temperate climates and lower in more severe climates. Roofs are typically 4.5 W/m^2 .degC when uninsulated and 0.5 W/m^2 .degC when insulated in temperate climates.

Thermal insulation generally available for building purposes can be classified into three groups:

(a) Bulk materials;
(b) Reflective foil laminates;
(c) Rigid lightweight boards.

(i) Bulk materials

Bulk materials are available in either flat batt form, blankets or loose fill. The materials most commonly used are rockwool or glass fibre (yellow batts and pink batts). Materials such as eel grass (fine sea weed), acrylic fibre and cellulose fibre (from waste paper) are sometimes used; the latter has been quite popular in recent years due to its lower installed cost.

Rockwool is usually irritating to the skin if handled (during installation) without protection. It withstands high temperatures and is used in boilers etc. It used to be used in buildings in past years but then it went out of favour. It now seems to be coming back. The conductivity of rockwool is 0.035 W/m.degC at the usual density of 48 kg/m .

Glass fibre is most commonly used for bulk insulation of buildings and is known to most people in Australia as either pink batts or yellow batts. It does not withstand such high temperatures as rockwool because glass fuses at about 600C. As a product, it tends to be most resilient and not fall to pieces on the building site if maltreated. It does tend to be irritating if not handled carefully. A popular concern is that it is carcinogenic although evidence seems to show that problems relate to manufacturing conditions only (large quantities of loose fibres) and not to site conditions. where the product is bound together with acrylic or epoxy binders. It is not used in hospitals because of these dangers (especially with regard to operating theatres). The conductivity of glass fibre is 0.042 W/m.degC at a density of 12 kg/m which is the usual value for building grade material. Material with a resistance of R1.2 is approximately 50mm thick whilst material with a resistance of R2.0 is about 90−mm thick, depending on the manufacturer.

Eelgrass, the botanical name for which is Zostera marina, is marketed as alpinete. It is not commonly used in New South Wales, but is more common in Victoria where the material is readily collected from the beaches. It used to be used in South Australia also before the Second World War. It is a fine grade long−strand seaweed and was used extensively in older buildings in Australia and overseas. Eelgrass is dried and treated with a chemical such as borax to make it fire−retardant and resistant to vermin. Its conductivity is 0.048 W/m.degC at a density of 20 kg/m^3. It may well be possible to collect it from some of beaches in New South Wales but it needs checking and treating for fire and vermin. It would seem to be an appropriate material for the appropriate technologist.

Cellulose fibre is marketed in Sydney by a number of companies. It has been in use for many years in both Melbourne and Sydney. It is made from waste paper and chemically treated with ground borax powder to make it fire−resistant and rot−resistant. The main difficulty in using it has been quality control when the material is made on site. The industry is working on this problem, which, if not already solved. will be solved soon. Cellulose fibre is non−allergic. Its advantage over batts and blankets is that it will fill crevices and can be blown into confined spaces. The problem is that it is very hard to ensure that there is sufficient material in the right place. Correctly manufactured and installed the conductivity of cellulose fibre is 0.035 W/m.degC. Its cost is competitive with glass fibre at about half to two thirds the price of the latter. It is made from recycled material which is a considerable attraction to some.

Vermiculite was formerly used as an insulator for bolters, hot− water tanks etc. It is too expensive to use as building insulation. It is a naturally−occurring material that expands into a loose flaky material in a kiln. It is generally used today for sprayed ceilings and fire insulation. Its conductivity is 0.067 W/m.degC at a density of 80 kg/m^3.

Acrylic fibre is marketed in Australia as Wonder Wool, among other names. It is made from 3 denier × 54−mm long acrylic fibres which have been fused into a matt. It Is treated with a frame retardant (ignitability 14, spread of flame 0, heat evolved 1, smoke developed 5). It resembles fluffy wool and is used industrially behind lining materials such as in railway carriages. It looks like orion pillow filling. It is supplied in various widths and thicknesses. Like cellulose fibre it is non− allergic. Its cost per value of resistance is competitive with other materials. Its conductivity is 0.023 W/m.degC which is better than rockwool (so that a thinner layer is required).

(ii) Reflective foil laminates (RFL) and composites

Aluminium foil is sold under various names such as Sizalation and Renfoil among others. It is a material made up in a sandwich construction as follows:

Aluminium foil
Polyethylene film
Kraft paper
Adhesive and fibre reinforcement grid
Kraft paper
Polyethylene film
Aluminium foil

(The old−style material was Jute and bitumen but today the core is a flame−retarded adhesive and glass−fibre reinforcement).

The aluminium foil sheet is bonded to the kraft paper and the polyethylene film before it is in turn bonded to a second set of the same materials with the reinforcement grid in between.

RFL sheet is available in double− or single−sided laminate, and supported or unsupported foil. It can be fire−resistant or non−fire−resistant, and anti−glare treated or untreated. Single−sided material should only be used in buildings where it is being laminated to another material. Single−sided material is not weather−resistant and so is not suitable for use in roofs where it may also have to be a sarking. Unsupported foils are only used when they are being laminated to another rigid material. Most building codes now require that all RFL laminate be of the fire− retarded quality.

Anti−glare coatings increase the emissivity and reduce the reflectivity of aluminium foil.

Material with an anti−glare coating should be used when the material is being applied in sunny conditions to protect the applicators' eyes from the sun's reflection during Installation. In roofs it should be placed with the anti−glare coating upwards as this side will soon be covered by a dust layer and so will be less effective anyway.

Some manufacturers also make a "vapour−stop" material with a heavier plastic film to ensure a high level of moisture stop. This material can be used in cool rooms and the like where a high level of moisture resistance is required.

The SAA standard for the installation of reflective foil is AS 1904 and it is manufactured to AS 1903.

Aluminium foil is only effective as an insulator when coupled with an air space (minimum 25mm air space). Sheets should overlap 150−mm or be sealed with tape.

RFL used in a ceiling with dust on the top surface has the same effect as 50−mm mineral fibre in summer and 12−mm mineral fibre in winter.

Aluminium foil is often bonded on to a number of products to form a sandwich. The core is usually glass fibre batts or urea formal−dehyde foam. This system provides the benefits of both materials in terms of summer reflectance and winter insulation against heat loss. When used in roofs over ceilings it is important to ensure that such products are placed over the top of joists so that there is an air space under the foil.

(iii) Rigid lightweight boards

Polystyrene (Isolite) is a white, (usually) rigid sheet which can be ordered to any thickness. It is the same material that many architectural students use for model making and from which cheap ESKYs are made. it can be obtained in either standard grade or fire−retarded grade (which is needed for building use). It is reasonably effective in moist situations but it will absorb some moisture (which increases its conductivity). It is commonly used as an edge insulation for concrete slabs and in slab form for wall insulation. When used in that way it can be ordered with a spring edge to assist with securing it between studs. Its conductivityis 0.036 W/m.degC at a density of 24 kg/m^3. It is difficult to use in oddshaped spaces because it has to be cut and fitted which is time−consuming. It is often used in bead form (bean−bag−chair filling) for hot−water cylinders and other cavity filling.

Polyurethane (Isothane) has a closed−cell structure. i.e., each bubble of gas is enclosed, unlike polystyrene where the many air pockets are only separated by a thin film that is not impervious. When new, polyurethane

Is filled with nitrogen and so has a lower conductivity than if it was filled with air. As it ages this gas leaches out and the conductivity increases gradually. After some years however it is still better than, say. glass fibre but it is more expensive. As a result of the closed−cell structure it tends to be more impervious to moisture. It is available in both standard grade and fire−retarded grade. Its conductivity when new is 0.016 W/m.degC, and 0.025 W/m.degC when aged. The flexible form of this material Is not generally used in building but rather in furniture and the like. Its conductivity is 0.035−0.039 W/m.degC. The rigid form is used In building but more often In cool room construction as it is generally more expensive than the other materials available on the market. It is also available as an in situ foam for use where access to a cavity space is difficult.

Woodwool is marketed in Australia by Stramit Industries as Woodtex, made from regular sized wood shavings or "wool" matted together with a Portland cement binder. The natural colour is grey but it can be supplied painted or coloured on the surface only to give various effects. Generally it is available as 25−mm and 50−mm thick sheets which are usually mounted in a patented steel suspension grid system. These slabs are quite heavy and are used mainly as acoustical absorber panels. Its conductivity is about 0.08 W/m.degC which is about half as good as the same thickness of glass−fibre thermal insulation.

Strawboards come in two principal forms. Solomit is manufactured in Adelaide and is often used as a ceiling material where a straw finish is desired. It is simply straw bound together with wire in such a way as to form a 50−mm thick bats. it is often seen as the ceiling in primary school buildings of the early 1970s period and in some child−care centres. Some architects have used it as a ceiling in domestic work where all the other materials are natural−finished.

Stramit is another of these products but has a paper covering to which various coatings are applied, including chopped straw. This material is also sold in 50−mm thick sheets. As a nonstructural ceiling it will span the width of the sheet which is 1.2m.

The conductivity of these materials is generally higher than glass fibre and so additional material is required to achieve an added resistance of R2.0 as required for Sydney. The conductivity of Solomit is 0.041 W/m.degC at a density of 213 kg/m^3 and of Stramit board it is 0.081 W/m.degC at a density of 320kg/m^3.

Fibreboard is marketed as Canite and is generally 12−mm or 20−mm thick. In some places such as Queensland It is available in thicker sheets. Sheets are usually 1200−mm wide and 1.8. 2.4 or 3.0−metres long. Fibre−board is often used as a ceiling but it must be well supported because it sags or settles with time. It is used in schools as pinboard material. Its conductivity varies with temperature and moisture, i.e., k = 0.062 at 23°C and 0.048 at 21°C. The density is usually about 215 kg/m and an average conductivity of 0.06 w/m.degC can be assumed.

Urea formaldehyde can be obtained in slab form formed between two sheets of foil but it is generally formed in situ It looks rather like pressure pack shaving cream or mock dessert cream when first made. It is marketed in New South Wales by two main suppliers through a number of outlets − HEIMAX and ICI. The foam is made on site by adding a foaming agent (liquid) to the ureaformaldehyde resin in very carefully measured quantities. The mixing occurs in the dispensing gun and must be tested on site for the correct mix (springy lump on the ground, not limp). As the chemical reaction takes place some water is liberated which is normally absorbed by the surrounding materials. There is some shrinkage on setting which should not exceed about 3 per cent by volume; although the installation standard states 5 per cent. After it is placed from a hose it takes 4 to 5 minutes to set, and 24 hours for a complete set and cure. It has been in use In industry for about 25 years although its use in the building industry is quite recent (since about 1975). Its cost is competitive with glass fibre but it should be used in places where it is not subject to mechanical damage. as it crushes to a powder after curing. It is ideal for use where the cavity is too inaccessible to place other batt type materials as it can be pumped through a long 12−mm hose over quite a distance. There has been some concern about the safety of the product as it does release a small amount of formaldahyde gas during the curing. The amount released is very small when compared with particle−board flooring and furniture. There is no evidence that it acts as a bridge for water to cross a brick cavity. Experience with seven houses has revealed no problem. Due to the bad press publicity it has received in the past it tends to be used more as a pre−cured slab material.

3. Draught control

The infiltration of cold air in winter can result in considerable discomfort for the occupants and a large additional energy consumption if they try to combat the problem with heating. Research has shown that on many occasions the most cost− effective strategy to reduce heating loads is to reduce unwanted infiltration. During hot summer days when outdoor temperatures exceed indoor comfort temperatures substantially, unwanted infiltration will also cause discomfort and drain the interior of stored coolness.

The calculation of heat flow due to infiltration has been explained fully in chapter III under "Air infiltration".

The flow of air into and out of a building should be at the discretion of the occupants who can choose the conditions they desire. Fixed ventilation does not allow that choice and can too often be a source of discomfort for the occupants. Often a lack of ventilation is blamed for condensation problems caused by chilled surfaces. Such problems are considerably reduced in correctly insulated buildings. In such rooms as bathrooms and kitchens, where condensation is a problem, it is better to provide positive ventilation (exhaust fans) at the time the moisture is generated than to build in fixed ventilation which cannot be controlled.

Unintentional infiltration can be the result of choice of construction details and building design. The following points are provided as a design and detailing checklist.

(a) Major entrances and commonly used doorways from outside should be isolated by lobbies or vestibules. Such lobbies should have doors to isolate them from living areas and other habitable rooms;

(b) Fireplaces should be fitted with dampers to close off the flue when not in use;

(c) Exhaust fans should be fitted with positive action shutters to close when off;

(d) Windows should be selected or detailed to allow locking in the partially open position in preference to fixed ventilation;

(e) Care should be taken to ensure the junction of different materials is sealed. Common areas of difficulty are windows installed into face brickwork inside and out, junctions of walls and exposed−beam roof structures and Junction details where open joint shadow line detailing is used. Exposed timber floors should be sealed at the perimeter with a flexible sealant.

The amount of fresh air required in a space depends on the concentration of pollutants and the number of occupants. In houses, about 20−30 m^3 /hour of fresh air per person is sufficient for most activities. In terms of the volume of an average dwelling of 100 m of habitable space with an average of four occupants, one air change every two hours is quite adequate in cold weather. Research has found that in older dwellings with fixed ventilators in each room and exposed timber floors, the air change rate can be as high as 10−15 air changes per hour. In modern dwellings with concrete slab floors the figure is more commonly 1−2 air changes per hour.

H. Heat distribution

7. Thermo−circulation

As air is heated it becomes less dense and floats upward to be replaced by cooler air. Research by Balcomb and others has demonstrated that this effect can generate considerable energy flows from a double height sunspace into a two−storey building behind. This heat distribution effect is due to the relatively high temperatures achieved at the lower levels of a well−designed sunspace. In taller buildings the flow will be even greater. The flow due to the vertical distance between openings can be calculated and is described later in chapter VII.

2. Mechanical circulation

Whilst natural air movement Is desirable it is often more effective to use mechanical means to circulate warm air (air + energy) from one place of collection to the place needed. When used to move air at low flow rates, fans can be very effective and economical to operate.

Simple exhaust fans (with or without ducting depending on the application) can be used to move warm air that collects at the top of high volumes to occupied spaces at lower levels. They can be used to move warmed air from a sunspace to a cooler non−sunlit space behind.

The rate at which air moves with mechanical devices depends primarily on the fan design and the power of the motor. Such information can be found in design guides for air handling equipment or sometimes In the manufacturers literature.

Worked example No.2

To calculate the daily heat gains or losses through 1 m of north−facing window In Sydney during July, select the following information from the climate section:

Mean daily ambient temperature

T_o = 11.7°C

Assume mean internal temperature = 21°C

Solar heat gain (SHGF) = 1 2.2MJ/m² (from Sydney insolation tables)

To calculate or select the U−value for glass = 6 W/m².degC: assume glass 3mm clear shading coefficient A = 1.00

To calculate daily heat loss by conduction:

H	$= A.U\ (T_i - T_a) \times 24 \times 3.6 \times 10^{-3}$
	$= 1 \times 6 \times (2.72) \times 24 \times 3.6 \times 10^{-3}$
	= 4.8 MJ/m².day

To calculate daily heat gain by radiation:

H	= SHGFx SC
	= 12.2x 1.00
	= 12.2 MJ/m².day

The total daily heat gain as a result of conduction and radiation exchanges is 12.2MJ radiant gain less 4.8 MJ conductive loss/m².day

= 7.4 MJ gain per m of window per day.

If curtains are drawn at night then it is possible to use a modified U−value (Um). Assume curtains to be lightweight with restricted air circulation. Refer to section H.1 above. The modifier for light drapes with restricted air circulation is M = 0.6. Assume also that curtains are closed for 13 hours per day (say 6 p.m. to 7 a.m.).

Therefore:

Um	$= U/24 \times ((M \times H_d) + 24 - H_d)$
	= 6/24 × ((Q.6 × 13) + 24 − 13)
	= 4.7 W/m².degC.

The revised daily heat loss by conduction is therefore:

H;	$= A.U_m\ (Ti - T_a) \times 24 \times 3.6 \times 10^{-3}$
	$= 1 \times 4.7 \times 9.3 \times 24 \times 3.6 \times 10^{-3}$
	= 3.8 MJ/m².day

The revised total daily heat gain is now (12.2 − 3.8)

= 8.4 MJ per m² of window per day.

Now consider windows on other orientations and see why the north windows are so important for winter heating.

I. Passive solar heating strategies

The three systems for passive solar heating generally accepted today are direct gain, thermal storage walls (masonry or water), and the attached sunspace. These are described below. Further Information and design details can be found in the literature on passive solar design listed in the bibliography. The reader will also find that opinions about precise details will vary from author to author in much the same way that opinions vary about construction details. Passive solar design does not have just one correct solution. Correct solutions are as varied as the designer's imagination.

1. Direct gain

Direct–gain systems are those where the solar radiation enters the habitable spaces via equator–facing windows and is absorbed by the materials inside the space for later dissipation when the ambient temperature falls. This is by far the most commonly used system and in spatial design terms the most flexible because it can accommodate daylighting and views to the exterior as well as providing a source of heat. Whilst it is the easiest for the designer to work with, it does have far more limitations than some of the other systems.

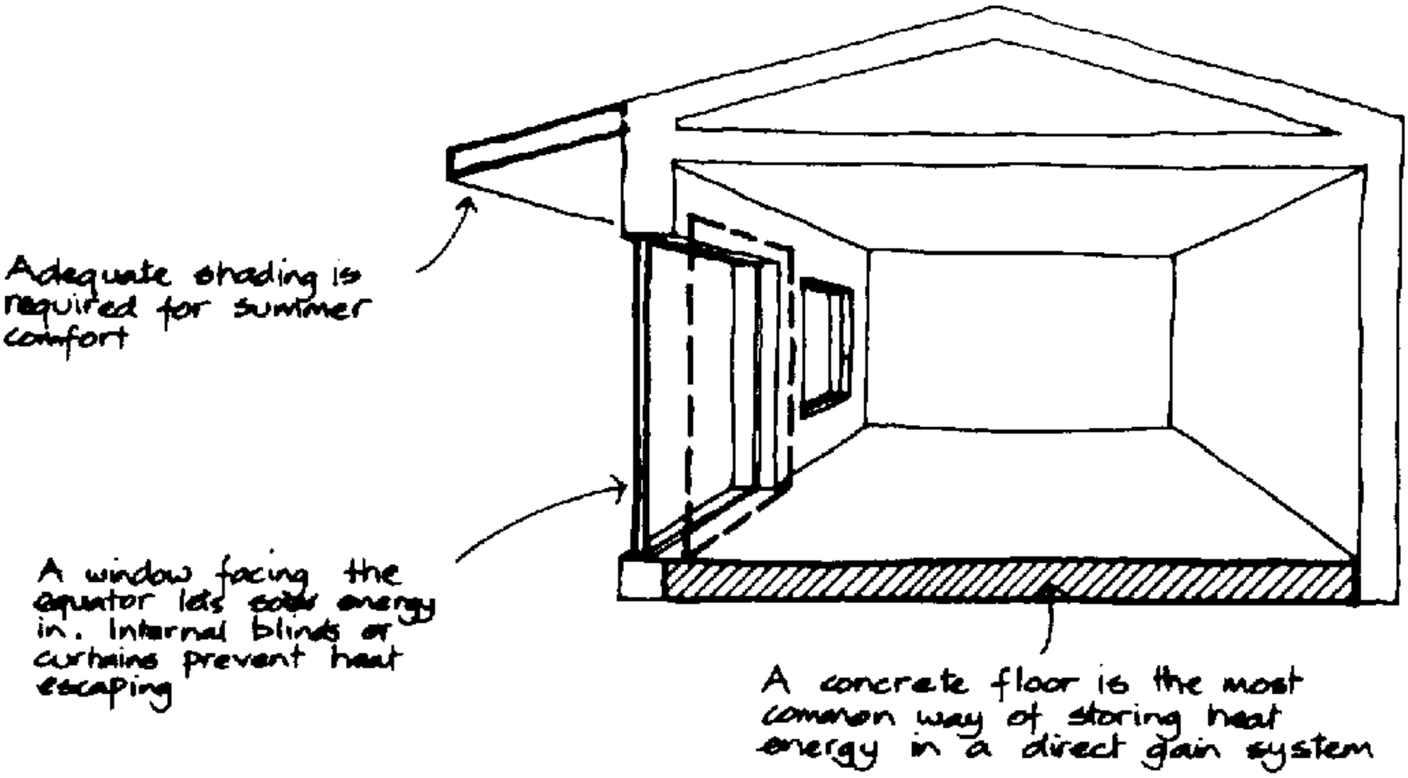


Figure 54. An example of direct gain

To operate effectively, the area of the equator–facing direct–gain window is closely related to the area of thermal–storage materials within the space and the climate characteristics of the particular location. The thermal–storage area must be matched to the incoming solar radiation to maintain the diurnal temperature swing in the range of 5–6C for acceptable thermal comfort. Insufficient thermal storage could result in daytime overheating even in quite cold climates. In temperate climates, where heating loads are modest. this system should provide high levels of thermal comfort without any significant auxiliary heating. In very cold climates there is likely to be insufficient solar contribution due to the limitations of glass area and it may be more appropriate to use a combination of systems. Manual techniques for the design of appropriate window size and area of thermal–storage material are given in many publications such as the SLR–method. A computer–based calculation method, CHEETAH, is also available.

The equator–facing windows must be designed with appropriate shading and means of minimizing conductive heat loss as described earlier. Direct sunlight entering the space can be a problem in terms of fading of interior finishes and also glare for the occupants. The latter can be countered in most domestic situations by appropriate selection of surface finishes. Direct sunlight inside a room has many psychologically beneficial qualities which have been recognized down through the ages and so this should not be overlooked.

Roof−level glazing can provide a useful contribution to the equator−facing glass area provided its thermal resistance is adequate to minimize heat losses. In temperate climates and those locations where the summers are quite hot, it is important to avoid sloping glass. In any event, all glass must be well shaded to stop the entry of summer sun as discussed in more detail later.

The floor is most commonly the main termal storage medium in direct−gain systems because so often it is the most economical place to locate heavy masonry materials. Unless there is an adequate amount of thermal storage in the walls of the space (perhaps at least half the walls) the floor should be of a material with a high thermal admittance (see chapter 111) and have the least amount of thermally−resistive covering (i.e., carpets or cork tile). The surface should have a low reflectance to absorb as much of the incoming energy as possible. Where there is a significant thermal storage component in the walls. the floor may be more reflective the better too distribute the sun's energy to the other heat storage surfaces.

2. Thermal storage walls (Trombe wolfs)

Thermal storage wall systems usually comprise a dark−coloured heavy wall (masonry, concrete, mud brick etc.) erected in the solar aperture with a double−glass system mounted approximately 1 " (20−30mm) in front of the wall surface. The sun's radiation passes through the glass and is mostly absorbed by the dark surface of the wall (preferably of high absorbency and low emissivity). The amount of energy that is lost back through the glazing depends on the insulating properties of the glazing and the surface properties of the wall. Special surface coatings for thermal storage walls with low emissivity and high absorbency are manufactured In North America specifically for this application.

The solar energy absorbed into the wall raises its temperature slowly throughout the day. By night−time the heat has penetrated to the inside surface where it can radiate Into the room raising the environmental temperature so providing warmth to the occupants. The time taken for the heat to reach the inner surface depends on the thermal properties and the thickness of the wall material, typically about 10 hours per foot of thickness for masonry. The same design guidelines and computer−based design tools listed for direct−gain systems also provide for thermal storage walls.

In early examples a range of movable night insulation systems were employed but Balcomb now reports that experience has shown double−glazing and selective surface coatings on the outer face of the thermal storage wall to be more reliable and cost−effective. Current recommendations are that the air space between the glass and the wall surface should be well sealed. The earlier examples had various systems of venting either to the room being heated for winter or the outside to reject heat in summer.

Protection from solar radiation in the summer is best provided by some form of cover over the glazing. The protection that is appropriate for direct−gain windows may not be sufficient to keep out the diffuse− and ground−reflected forms of radiation. Unwanted solar heat in direct−gain heated spaces can be dissipated by natural ventilation whereas in thermal storage walls it will be absorbed into the walls to heat the room when not wanted.

In some cases water has been used as the thermal storage material. This technique of passive solar heating is similar to the thermal storage wall except for a number of key points. The thermal storage capacity of water Is approximately three times that of brickwork by volume (see table 8). Whilst it is inexpensive as a material it is both difficult and relatively expensive to store securely. The time−lag effect of water in containers is shorter than in masonry because it is a fluid: the transfer of energy is part by conduction and part by convection. Many examples built so far use water in vertical cylinders painted a dark colour or finished with a selective coating as described for the thermal storage walls. The cylinders can be placed with spaces between them to allow some solar radiation and daylight to penetrate directly into the space. The water−storage walls generally perform better than thermal storage walls because the convection mixing of the water results in lower surface temperatures and a more even distribution of energy. Most of the design tools that have been developed for use with thermal storage walls are also suitable for the design of water−based heat−storage systems.

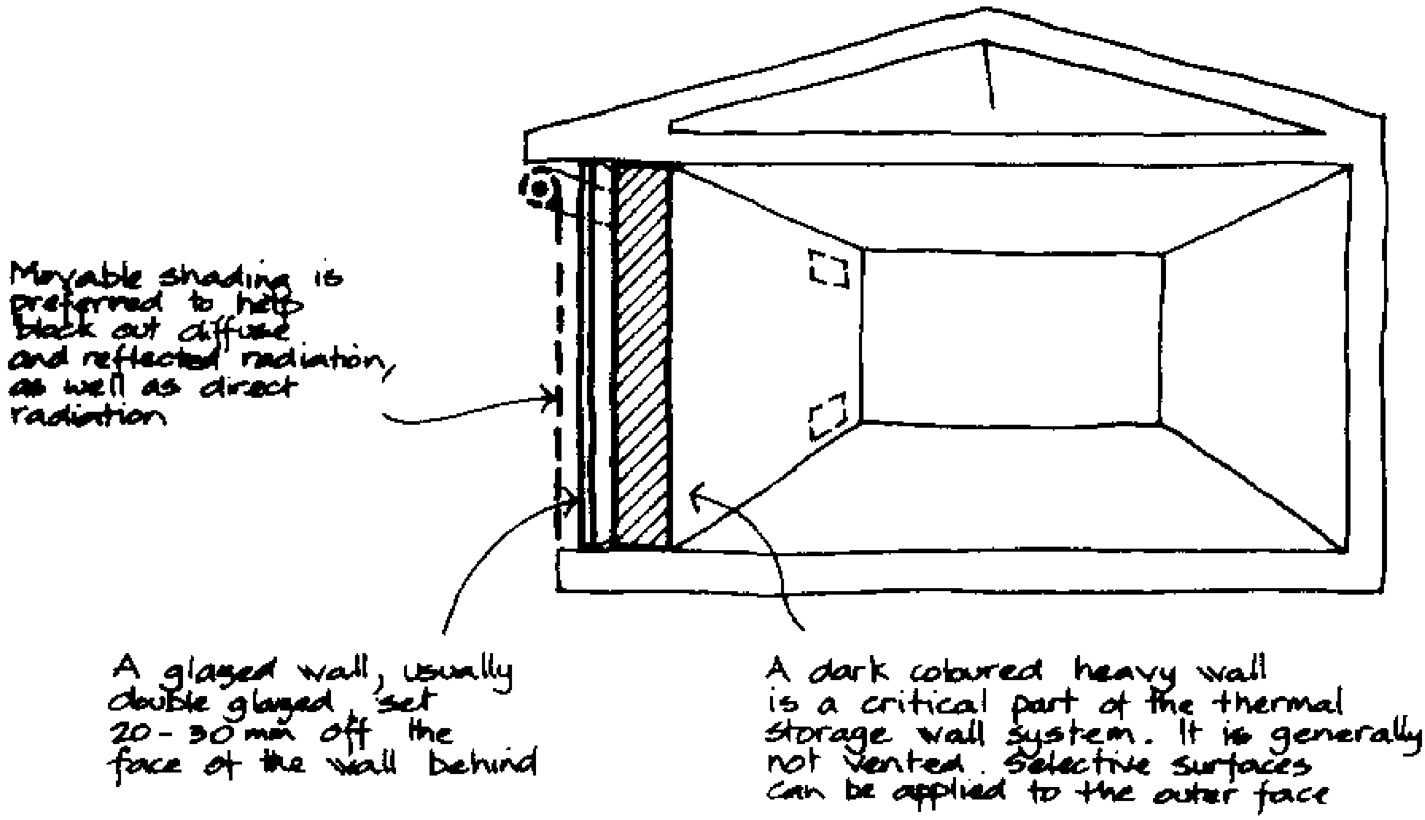


Figure 55. A thermal–storage wall system

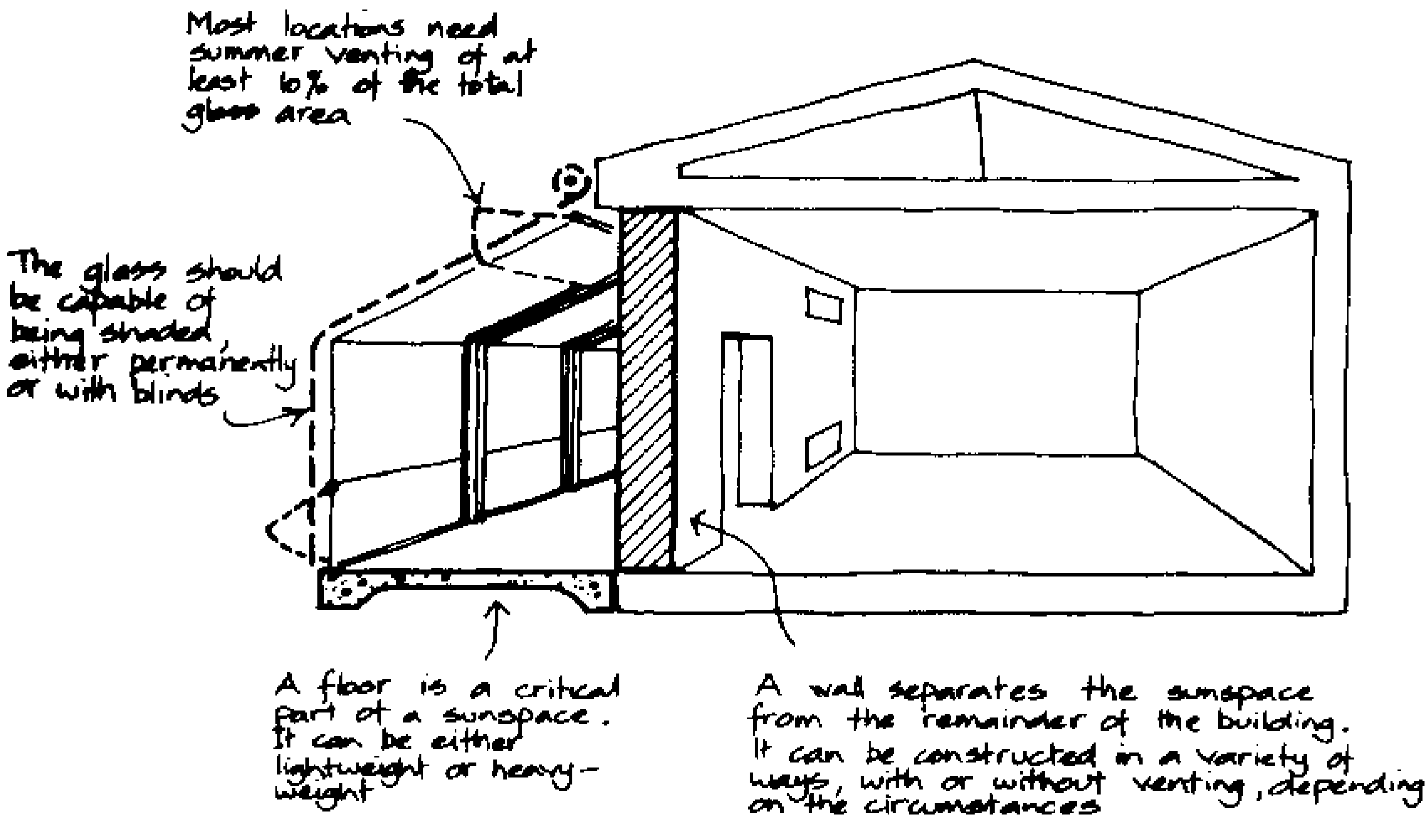


Figure 56. Sunspace enclosures

3. Sunspace enclosures

An attached sunspace system comprises an additional enclosure, usually with all surfaces glazed, attached to the equator–facing side of the building to be solar heated. The additional space so created can be used for various purposes that are suited to exposure to high levels of sunlight and a wider temperature range than aimed for inside the rest of the building. The built form of the sunspace may range from simple attachment to the face of the building to full integration into the building envelope. A number of sunspace configurations have been defined in the literature. for use in design tool analysis. They are essentially variations on a theme that have been defined for computer–modelling purposes. In reality, an attached sunspace is a room on the equator–facing side of a building with a significantly high glass area compared to the floor area (glass/floor ratio > 1).

The critical components of a sunspace solar–heating system are the floor (usually ground connected), the wall separating the sunspace from the remainder of the building to be heated and the area and nature of the glazing. The wall dividing the sunspace from the rest of the building is similar to the thermal storage wall described before. In this case the glass has been moved out to form an accessible space for other purposes. thus making the overall system more economically viable. The dividing wall can be either a solid mass, uninsulated, insulated on the inside, insulated on the outside or simply light–weight heavily insulated. If the wall is of uninsulated heavy materials then the same rules apply as with the thermal storage wall. If it is insulated then a venting system is required to transport the collected heat to the interior of the building. The use of thermal mass materials inside the sunspace will help to modify the diurnal temperature swing.

In all locations except where summers are very cool, it is important to provide adequate through ventilation to remove summer heat build–up (minimum vent area should be 10 per cent of the total glass area for mild summer climates and more for warm to hot summer climates). In most areas where summers are warm (mean temperatures within the comfort range) it will be necessary to shade the glass area fully to avoid overheating and degradation of the interior surfaces and fitments. The preferred design for such areas is with a fixed opaque roof and only the vertical surfaces glazed. Even in colder slimates there is likely to be problems with overheating in autumn as the sun is passing low in the sky and yet the temperatures are not commensurately lower. This can be overcome to some extent with suitable shading of the roof glass and the east and west glass, if any. The current trend is to build such enclosures as a visual element in an otherwise conventional building. Unfortunately, too often little thought is given to the protection of the glass areas from solar gain in summer and, as a result, many unsatisfactory buildings are being built.

In many applications an attached sunspace is used as a multi– level connecting space (lower floor with mezzanines above to the upper floors). In such cases the designer must be aware of the chimney effect of the must be aware of the chimney effect of the tall space as the air in the sunspace will be much warmer than the remainder of the house. The design should allow for the cooler air inside to flow down to the lower area and out to the sunspace. With large glass areas, overheating can be quite a serious problem without correct shading.

J. Natural cooling strategies

This section considers strategies that can be adopted to regulate overheating. Whilst some strategies can be quantified using reasonably accurate design methods such as the admittance method to predict peak Indoor temperatures or computer–simulation techniques, others are more elusive although well known in use. One of the main difficulties is that most cooling strategies rely on user action and accurate knowledge of their behaviour and such climatic information as detailed wind patterns. If these were really known to the designer then the quantifying process would be simpler.

In many cases of poor design, the internal thermal climate Is more severe than the external climate due to uncontrolled external environmental gains (windows not adequately shaded and external walls and roof not adequately Insulated) or unnecessarily large internal energy gains. A good design solution will provide an indoor thermal climate that starts from the position of being better than the outdoor environment.

In much of the year overheating the inside of buildings is the result of excess solar heating and internally–generated heat reaching the interior spaces. This is certainly the case where the ambient air temperatures are no greater than about 27 °C. In such cases, it is usually practicable to maintain comfort conditions with appropriate control of those heat gains (such as shading of windows and exhausting internal heat) and stood ventilation and air movement patterns.

Where air temperatures are above reasonable comfort levels it is necessary to apply other strategies which will collect or soak up the excess heat for disposal into the cooler earth or to the cooler night air. In these cases the design approach should be as follows:

(a) Reduce solar gains to the interior by correctly designed shading;

(b) Minimize conductive gains by shading walls and other surfaces as appropriate and Insulating the external fabric of the building:

(c) Minimize the effects of internal gains (lights and other appliances) by exhausting the heat;

(d) Design night ventilation openings to optimize the cooling of thermal sinks (thermal mass):

(e) Allow for appropriate air movement (ceiling fans and the like) to raise the occupants' comfort threshold;

(f) Design for minimum air infiltration during the day when external air is 3C greater than the upper comfort limit.

1. Control of heat gain through external fabric

Discomfort from overheating is the result of the body not being able to dispose of the heat generated at an appropriate rate. This state in turn may be the result of external heating influences or a person's activity rate. In the design of buildings the aim Is to cater for people whose activity rate is appropriate to the situation, i.e., when designing a gymnasium allowance is made for the increased activity rate of the occupants by providing more ventilation than might be the case in another situation. In this section the primary concern is with excess heat from the sun or from appliances being used within the building enclosure.

The unwanted heat generated by appliances (cooking stoves in houses or computers and the like in an office environment) can usually be dealt with by ventilation in temperate or cool climates. This technique will at least bring the surrounding conditions to that of the incoming ventilating air. In excessive cases other techniques are applied using heat pumps and the like to remove the excess generated heat.

In most cases for the building designer, the major source of excess heat is the sun in two forms; incident solar radiation and ambient air temperature above an acceptable comfort level. In both cases, the first strategy should be to provide some form of barrier or filter to reduce this overheating effect. The second is to provide positive means of effective natural cooling. The strategies chosen for a project should suit the specific characteristics of the climate and also enhance the architectural design solution.

The reduction of overheating is best achieved by exclusion of the unwanted heat rather than its later removal (often by air conditioning). Therefore the external fabric should be insulated as discussed earlier (including the appropriate use of RFL insulation in summer driven climates). Appropriate shading of opaque external elements is desirable especially where the sol− air temperature effect is significant. The solutions available to the designer range from suitable landscaping to shelter the walls and roof from solar gains (unfortunately these solutions are slow to establish unless already existing) to more sophisticated screens and vented wall linings built as an integral part of the building structure. Transparent elements of the external fabric such as windows and skylights are usually the main source of concern and so will usually require shading from direct sun in the non−heating seasons. The design of shading is discussed separately in this book as it is both a key factor in the reduction of overheating and in visual design of the building. Unwanted solar energy can be excluded by various techniques that can all be grouped into the following general categories.

(a) External devices or systems that deflect the sun's rays (either fixed or adjustable, natural or man−made, to suit the particular application). This is the most positive and effective approach with the least chance of failure;

(b) Specific treatment of the transparent element to change its transmission properties. Generally such solutions are fixed and so will also minimize sun penetration at times when it may be desirable, i.e., winter. A number of variable transmission glasses are being developed such as electrochromic glass, where an electrical force is used to alter the transmission properties of the glass. These should be available in the next few years;

(c) Internal devices that reflect some energy back out and convert other energy from radiant to sensible heat by heating up the air around the shading device. These devices, such as reflective blinds and curtains. are less effective than external barriers but are easier to operate and maintain;

(d) Each of these has its place in the designers "palette" and the successful designer will choose the best one for the job.

2. Passive cooling

In many locations it is necessary to apply some positive cooling strategies to overcome overheating resulting from climatic factors, even after reducing direct solar heat gain to a minimum. This situation usually occurs where the ambient air temperature is either close to the upper limit of the comfort zone or above it and is, sometimes, exacerbated by high humidity levels.

Where the ambient air temperature is within the comfort zone and humidity levels are low it may be possible to satisfy comfort needs with the heat control strategies discussed above. If these limits are exceeded in one way or another the following approaches may be appropriate. either individually or in combination. Some are more climate–dependent than others, such as evaporative cooling which is only applicable where the wet bulb temperature is in the range of 12°C to 24.5°C and relative humidity is less than 80 per cent.

Varying degrees of cooling in a building can be achieved using natural sources such as:

(a) The night air: night–time convective cooling of a thermal mass or heat sink within the building fabric;

(b) The upper atmosphere: radiant nocturnal cooling of the building fabric to the night sky, causing a chilling of the roof structure which can then take up heat the next day;

(c) Water evaporation: evaporative cooling of the air and/or the building structure;

(d) Earth cooling: storage and recovery of energy from the sub– surface soil.

Cooling systems using these sources have been in existence for a long time but in some cases little is known about how to quantify their effectiveness. Water evaporation for cooling is well understood when used in a defined environment of cool air within a mechanical systems. Little is known about how to define the evaporative cooling effect of water sprayed into the surrounding landscape or the free use of water in semi–enclosed spaces such as an atrium or centrally–located courtyard. Some work has been done on this by authors such as Givoni and Lesuek but there is still a long way to go. Many designers have their own knowledge of specific cases from personal experience: they have tried ideas built on the available knowledge and their own developed sense of logic. The young designer can learn from studying the natural and the built environment, noting the cases where a space is comfortable in an otherwise unpleasant environment and observing what makes it better; the use of sprayed water. a large shaded mass that soaks up the heat of the day etc.

Night–time convective cooling used to cool the structural mass of a building can be most effective where the vapour pressure is generally below 2.27 kPa and the diurnal temperature range is large (above about 10 deg.C.) and night time temperatures fall below about 20°C. In areas where the vapour pressure is between 2.27. kPa and 2.67 kPa, nighttime convective cooling is still workable but it may be necessary to use air circulation techniques whilst the building is closed to maintain comfortable conditions. These limits are discussed in detail in chapter VI – Bioclimatic analysis. Almost all places in Australia that require cooling. except for the warm–humid areas, can achieve a useful cooling contribution from this technique. Usually natural ventilation during the day is undesirable under such conditions and so indoor air movement must be created using fans until the day cools sufficiently to open the building to the outside air. The night–time cooling of the structural mass of a building by convection will lower the daytime temperatures by about 2–4C compared with the same building not ventilated at night. The external fabric of such a building should be well insulated to minimize daytime conductive and solar heat gains to the interior and the structural mass in particular.

Radiant nocturnal cooling can be achieved in areas where the night sky tends to be clear during hot weather, generally in all Australian climates except the warm–humid areas. The power of such systems is limited to about 70 W/m^2, which is minimal for most purposes. In most areas of Australia where there are clear night skies sufficient for such a system there is also a large diurnal temperature swing which will provide cool night air as discussed above, which can be used more simply and at less capital expense.

Evaporative cooling has been used extensively throughout the hot–arid areas of Australia for many years. Mechanical systems that force evaporatively cooled air through the building in much the same way as an air–conditioning system are most effective and economical to run. The main energy requirement is to drive the ventilating fan. In many of the places in Australia where evaporative cooling is most needed there tends to be a shortage of clean water suitable for such equipment. As a result the dirty or brackish water that is often used tends to clog the evaporator pads and increase the maintenance costs. In the more temperate areas of

Australia, when on certain occasions the wet bulb temperature is below about 17°C, it is possible to use evaporative cooling but more often the humidity levels are too high resulting in unpleasant warm humid conditions inside.

Passive uses of evaporative cooling such as open water in roof ponds and courtyards have been effectively used throughout history, but as stated before it is difficult to quantify their benefits. Even today most of the design details are based on anecdotal experiences. The water in a pond will follow about 1C above the wet bulb temperature with diurnal swings dependent on the depth of the pond. If water is used in a concrete roof pond then the ceiling below can be expected to reduce the indoor temperature by up to 3C below the average outdoor dry bulb air temperature.

Earth cooling can be utilized in many climatic areas and its effectiveness has been demonstrated by those who have constructed their whole building underground. It is possible to draw air through tubes or passages beneath ground that has been cooled by water evaporation and then into a building for cooling. This technique was used in Alice Springs in a dwelling built for the Flying Doctor Service earlier this century. There have been other examples tried but generally the capital cost is quite high and the passages difficult to maintain free of harmful bacteria.

3. Ventilation and air movement

Natural ventilation of a building will initiate passive cooling during the summer. The exhaustion of excess warm air and the intake of cool air help to lower interior temperatures. To facilitate the exit of warm air, dampered vents should be located at high points in a building.

Natural thermal pressure differentials provide airflow in domestic dwellings. In still conditions ventilation occurs due to this effect. In windy conditions thermal pressure differentials are insignificant compared with the effects of the wind. Ventilation due to temperature differences can be increased by extra storey heights or by providing heat to the upper end of a chimney which is the principle of the solar chimney. If natural thermal pressure differentials do not produce sufficient flow velocities, fans, turbines, or plenums can be used to accelerate them. Attic fans will, if needed, more quickly remove hot air that accumulates during the day. Operable vents, connecting the building space with the attic, provide a pathway for the upward flow of hot air. The motion of outside air can often be used to induce interior air movement without the aid of fans. Wind can be used to power a turbine or can be directed in such a way that pressure changes result which move inside air.

Buildings themselves act as large–scale ducts and should be designed with options for unobstructed movement of air.

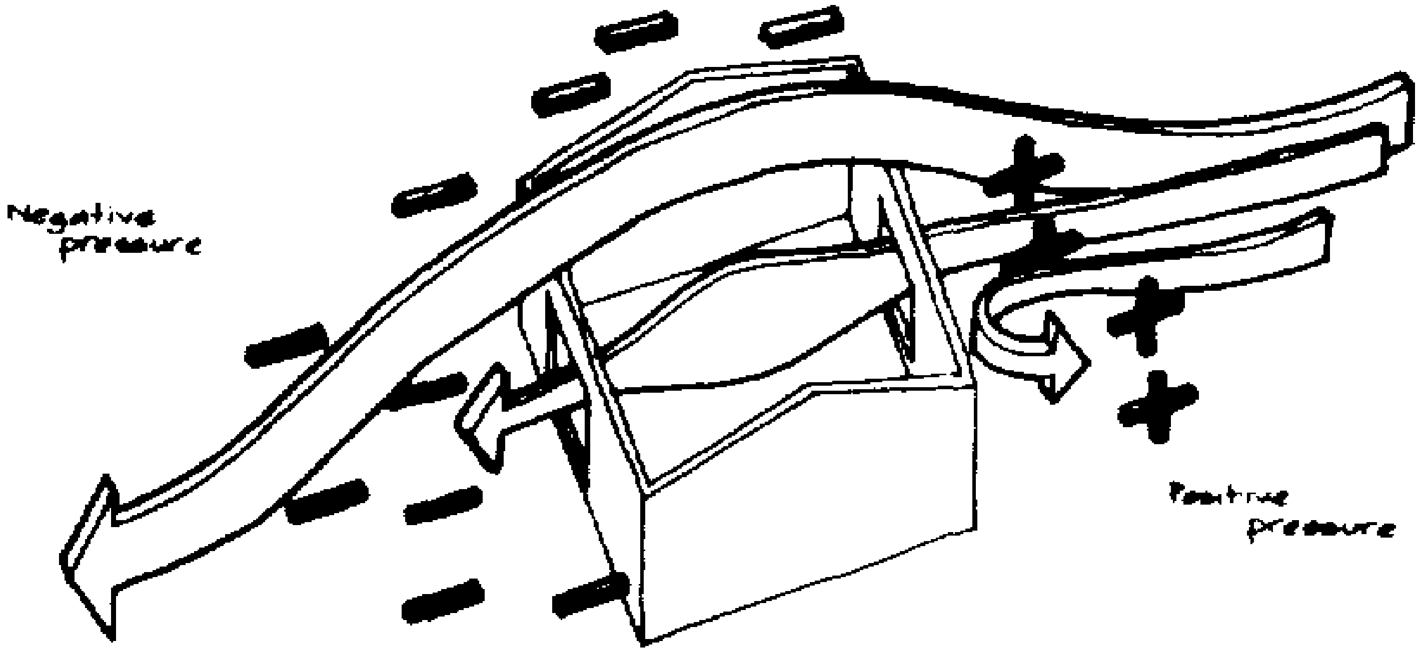


Figure 57. Air flow over a building to induce air flow

Ventilation will generally occur if a pressure differential exists across a building. This differential may be enhanced by the shape and orientation of the building with regard to the prevailing wind direction and openings placed to utilize those pressure differences.

Openings in opposite walls produce a different interior air movement than openings on adjacent walls. Similarly the position of the opening in each wall will influence the path of the interior air stream. The area of openings may be varied for different effects. However, maximum ventilation occurs by having equal size of inlet and outlet openings.

Internal air flow may be further affected by roof overhangs, awnings and fenestration. The main air stream can be directed towards the ceiling for winter ventilation and towards the occupied zone for summer comfort.

Internal walls, partitions and floor−to−ceiling furniture will affect the air flow pattern. Whether the air flow is perpendicular to or parallel to the direction of the main stream flow will modify the air flow. The number of internal openings that the air must flow through to reach the outlet opening will further modify the ventilation produced within the building by reducing the volume of flow.

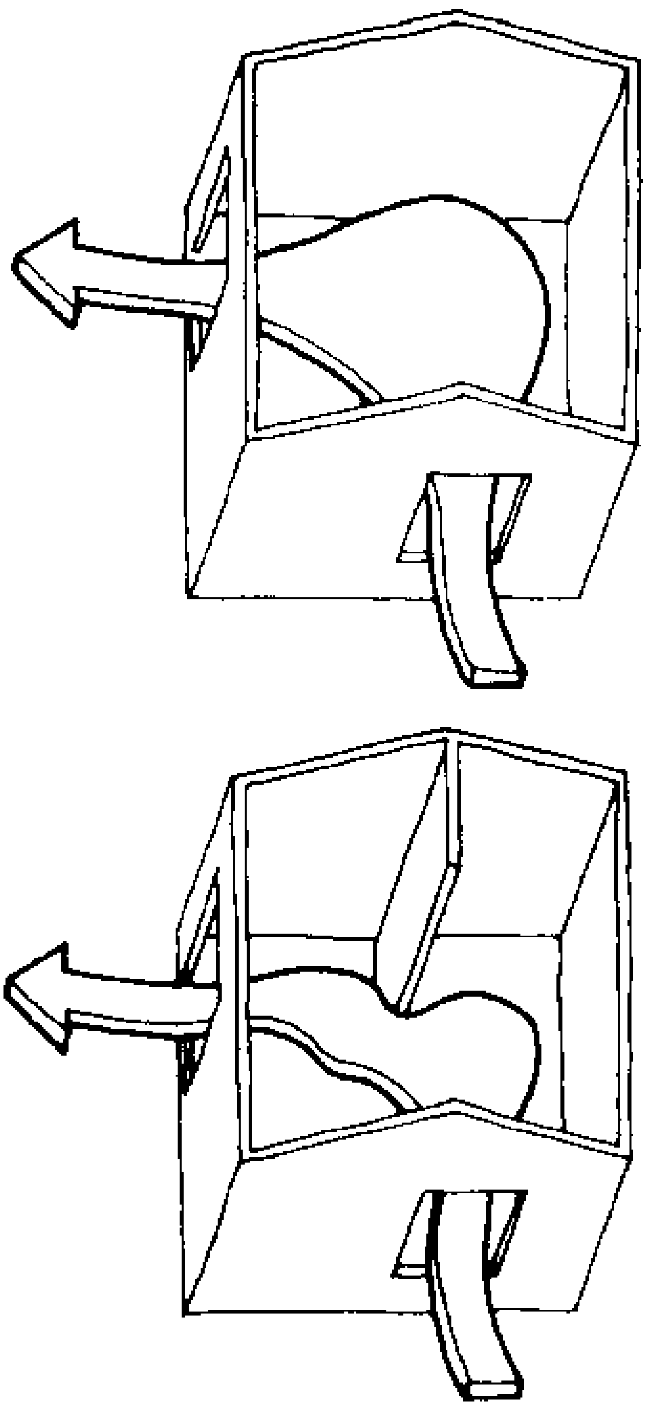


Figure 58. Effects of the position of openings in a room on ventilation and cross air−flow

4. Circulating fans for air movement

Where natural wind patterns are not available or buildings have to be closed to keep out an overheated environment. it may be desirable to use mechanical aids to induce air movement throughout the space or building. The advantage of using a fan for air movement compared with natural ventilation is that its effect is more controllable and so can be directed as needed away from work areas where papers or other materials can be disturbed.

Personal low level fans can be used close to the occupant and directed in such a manner that others are not affected by H. Ceiling fans are economical to operate and provide a broad area of air movement. Generally the blades move slowly creating a gentle movement which need not be disturbing. This type of fan is ideal in cases where air movement is needed for comfort in an otherwise closed space such as a massive building in a hot−arid climate. This fan type can effectively mix the air in the space bringing it in contact with the structural mass cooled the night before. The values in figure 59 illustrate how air movement at comfortable rates can be provided over a reasonable area from one ceilingmounted fan. The distribution covers a much wider area than does the vertical type fan. The only disadvantage being that for safety the units should be mounted at about 2.5−m necessitating ceiling heights of 3−m (regulations in Australia require that the blades be mounted at not less than 2.2 m above floor level.

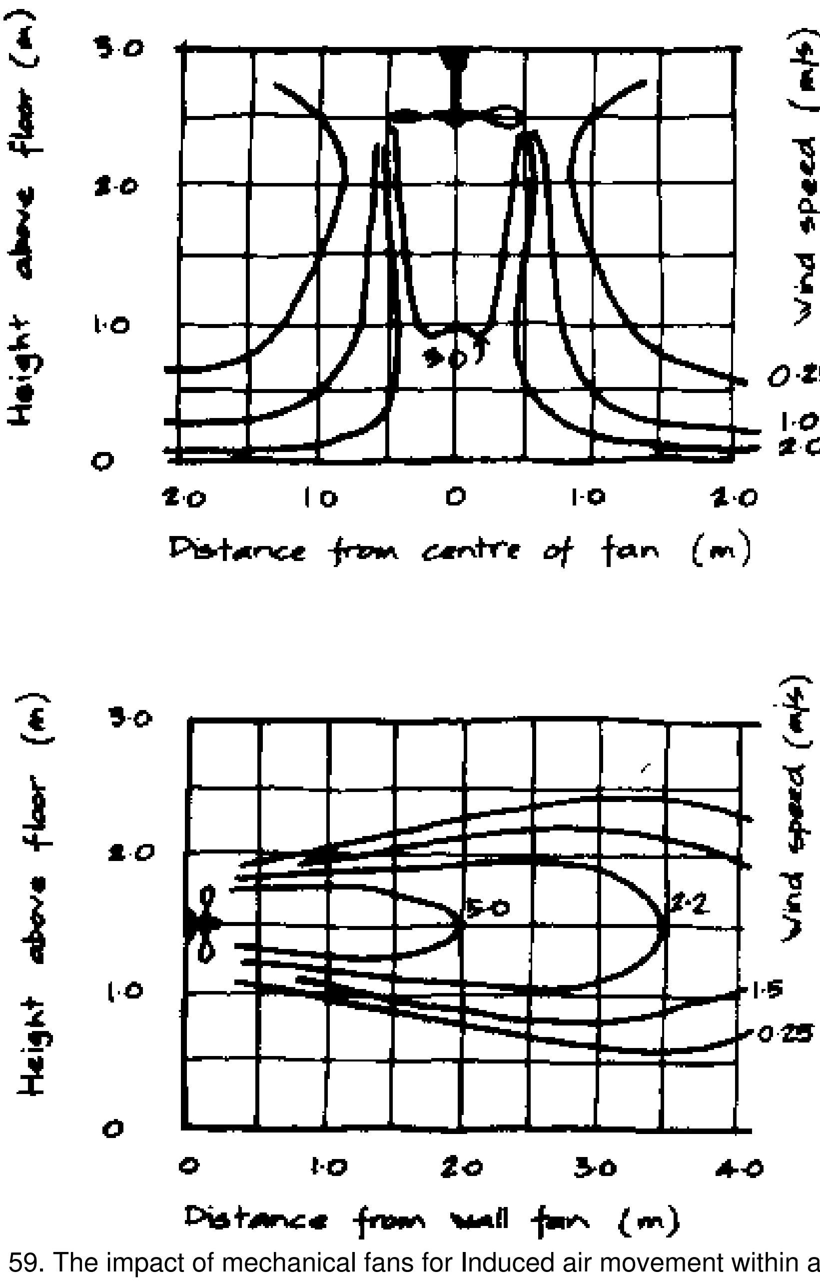


Figure 59. The impact of mechanical fans for Induced air movement within a space

5. Daylighting

Daylight is important for more than just vision. Studies have shown that daylight is important to satisfy many human physiological reactions. It is most important that designers consider both daylight quality as well as daylight quantity. In this section it is intended only to highlight the need to incorporate good daylighting design with passive solar and natural cooling technologies. A brief summary of sources of daylight are given for general guidance. Designers should refer to other more detailed texts for design guidelines.

Function	**1** **Minimum ventilation for odour removal etc.**	**2** **Ventilation for structural cooling**	**3** **Air movement for cooling the body**
Required	In all buildings	Mainly in hot dry conditions	Mainly in warm humid conditions
Conditions	All conditions of external temperature	Outside air cooler than inside air by more than 2 deg C	Outside air the same or cooler than inside air
Suitable building	All buildings	High internal heat capacity building	Single banked building
Methods			
Stack effect	Adequate for ventilation under most conditions	Adequate for cooling	Not adequate
- Openings	No special requirement	High outlet and low inlet, each 5% of floor area	
Wind pressure	Adequate for ventilation	Adequate, but may not be available at night	Good if available
- Openings	No special requirement	Follow the requirements for stack effect	Large inlet and outlet on opposite sides of building, each 20% of wall area minimum
Mechanical	Not usually necessary, but fans may be used in kitchens. Internal WCs also require extract fans	Not necessary as stack effect will work automatically if outside air is cooler than inside air	May be desirable; fans are needed to move the air in the room not to provide air change
Typical requirement	1 air change per hour	10 air changes per hour	1 - 1.5 m/sec air speed (equivalent to 100 air changes per hour or more)

Table 9. Summary of ventilation functions

Sources of daylight include direct sunlight, (high intensity), diffuse skylight and diffuse reflected light from buildings. ground. objects

Direct daylight is the result of allowing direct solar radiation into a space, and so in hot times of the year it will be more often excluded or at least filtered to reduce the heating effect of the sun. Direct sunlight often be a serious source of glare unless internal surface colours and textures are chosen to avoid the problem. Direct daylight/sunilght is a valuable design modelling tool as it is always on the move and changes in intensity as the day passes. The designer should not lose sight of this magnificent component of a designers vocabulary.

Diffuse light comes from the sky hemisphere (that component reflected and refracted through the Earth's atmosphere) or is reflected from the surfaces of other objects and if too bright it can cause glare. Diffuse

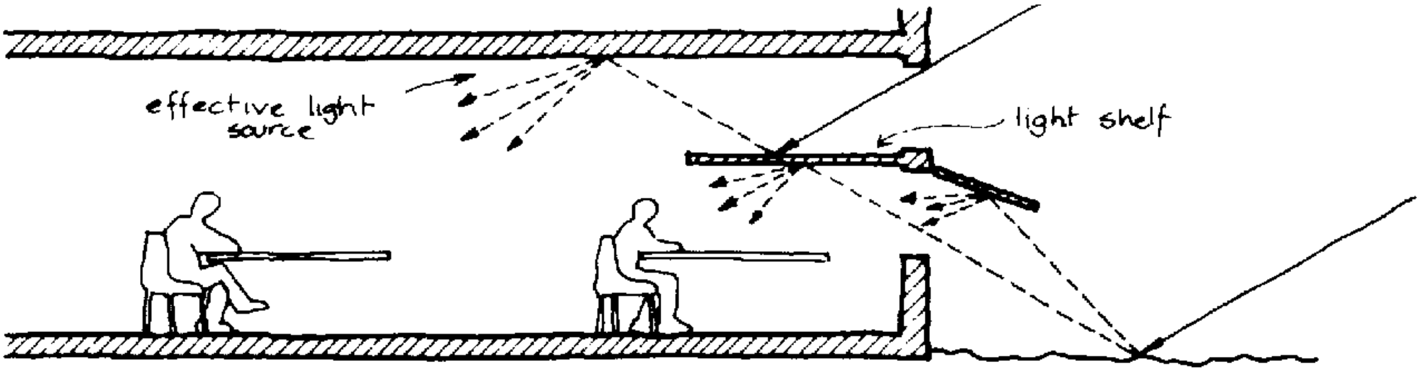


Figure 60. Use of light shelves or other reflective surfaces to direct sunlight Into a space without glare

Good daylighting design is to do with the quality of light rather than just quantity. Glare from daylight can be a serious source of discomfort especially when direct sunlight is reflected off another object either inside or outside the building. In a residential situation, occupants are more able to adjust their position to avoid glare, whereas in other spaces where people are working in a fixed pattern it is more difficult to move and so potential glare sources must be considered in the basic design.

Direct sunlight may be necessary for heating and as a source of light and so it may be better to direct it away from work surfaces and other potential glare−producing surfaces. The use of reflective surfaces outside the viewing range such as light shelves and louvres are an excellent way to overcome this problem. Many designers have utilized these techniques, as Is shown below, to produce glare−free interiors with good natural daylighting levels and a dynamic visual quality that exploits the changing nature of natural light.

VI. Bio−climatic analysis and comfort strategies

A. Climatic factors

In the chapter on thermal comfort it was noted that the main climatic factors that influence comfort are air temperature (DBT, humidity, radiant energy received by the body (or emitted from the body to a colder body) and the relative air velocity.

The concept of bioclimatic design was first proposed by Victor Olgyay. The effect that the above−mentioned four elements have on comfort can be demonstrated for a given climate by a simple chart. Techniques such as this are very useful for assessing the overall characteristics of a particular climate relative to one with which an individual is familiar.

A detailed description of Australia's climates can be found in many publications such as those produced by the Bureau of Meteorology. Many of the descriptions from world−wide climate books tend to simplify the climates of Australia to such an extent that they are of little help to the building designer. The map of Australia showing climate zones by Drysdale for example (see figure 12) classifies New South Wales as largely temperate, or dry−warm−temperate and hot−arid in a rather crude manner (this is a problem of scale on maps which show very large land areas). Only a small area in the Australian Alps is shown as being "cool'. Anyone who has studied the geography of New South Wales will be aware that such a classification is too broad and in some ways misleading. The area around Tamworth and Armidale where the winters are very cold is ignored.

An inspection of the heating degree day tables at the end of this publication will show how much the climate varies even around the Sydney region. The data for Sydney are collected in the city and so reflect the tempering influences of the built−up area. Yet how much colder It is in the winter at Liverpool, Richmond and Campbell town. This Is where the major new housing developments of Sydney are located. The building designer needs detailed information relative to the particular site under consideration.

Relative to the climates of the United States and of Europe, the Australian climate Is certainly temperate. Designers must realize, however, that in much of the populated part of Australia it gets cold in winter as well as getting hot in summer. This is why the overseas examples one sees in the literature must be viewed with caution. Large north−facing glass areas will usually rake the indoor temperatures of a room in winter but with the penalty of severe overheating during the summer months unless adequate precautions are taken to reduce summer heat gains.

B. Bioclimatic design strategies

Bioclimatic analysis is a systematic procedure for the assessment of thermal comfort in relation to external climate. It has the purpose of identifying desirable adaptations of structure to meet human comfort needs under specific climatological conditions.

The various design strategy templates shown on the following pages, can be used in conjunction with local climatic data to determine appropriate thermal design strategies. Figure 61 defines the comfort zones considered appropriate for various Australian cities overlaid on a psychrometric chart, similar to those used by mechanical engineers. The comfort boundaries for specific cities is defined by the first letter of that city, i.e.. "H" for Hobart. The limits are defined by absolute humidity levels and dry bulb temperature (DBT) levels. Whilst the limits of absolute humidity are fixed at 12g/kg and 4g/kg, the upper limits of DBT vary for each city in accordance with the concept of thermal neutrality, proposed by Auliciems (see Szokolay for descriptive text). In addition, figure 61 also illustrates diagrammatically how the limits of thermal comfort inside can be extended by different design strategies such as cooling by ventilation and air movement.

The designer first chooses the bioclimatic chart for the project location from those in figures 61 to 70, or prepares a new chart with appropriate weather data for the specific location. The graph is prepared by plotting on a conventional psychrometric chart a straight line for each month of the year between the following points: monthly mean minimum DBT with 9 a.m. relative humidity (RH) joined to mean maximum DBT with minimum RH (the 9 a.m. data for maximum RH and 3 p.m. data for minimum RH are the most commonly available data).

The 12 lines so plotted are representative of the major proportion of the weather for the particular location. The appropriate design strategies which will be useful in achieving a thermally comfortable building are those in which the climate lines fall. Based on the data used to represent Adelaide it can be seen that passive solar heating design will be most effective for the winter months. while a number of strategies are useful for summer. Thermal mass would seem to be most important as the boundaries of its "comfort patch' are well away from the limits of January and February. In the case of Alice Springs in figure 63 it can be seen that again thermal mass is effective but evaporative cooling is also most effective. Considering the relative position of the climate lines for both Adelaide and Alice Springs it can be said that evaporative cooling is going to be useful more often in Alice Springs.

It is important to realise that the temperatures used in these bioclimatic charts are mean maximums and mean minimums and not the absolute minimums or maximums. With regard to ventilation cooling, on many of the very hot days the outside air will be too hot to let inside and so this strategy only applies to night ventilation to drain daytime heat from the thermal mass and lower the night−time temperatures. Additional data such as absolute maximum and minimum and 86 percentile temperatures can also be included if available. The monthly lines should be considered more as fuzzy zones rather than hard edged data. The usefulness of these charts is extended as more data are included.

The bioclimatic approach is especially useful for the designer who is not completely familiar with the climate of the project site. It assists in developing a holistic understanding of any climate and its influence on thermal comfort.

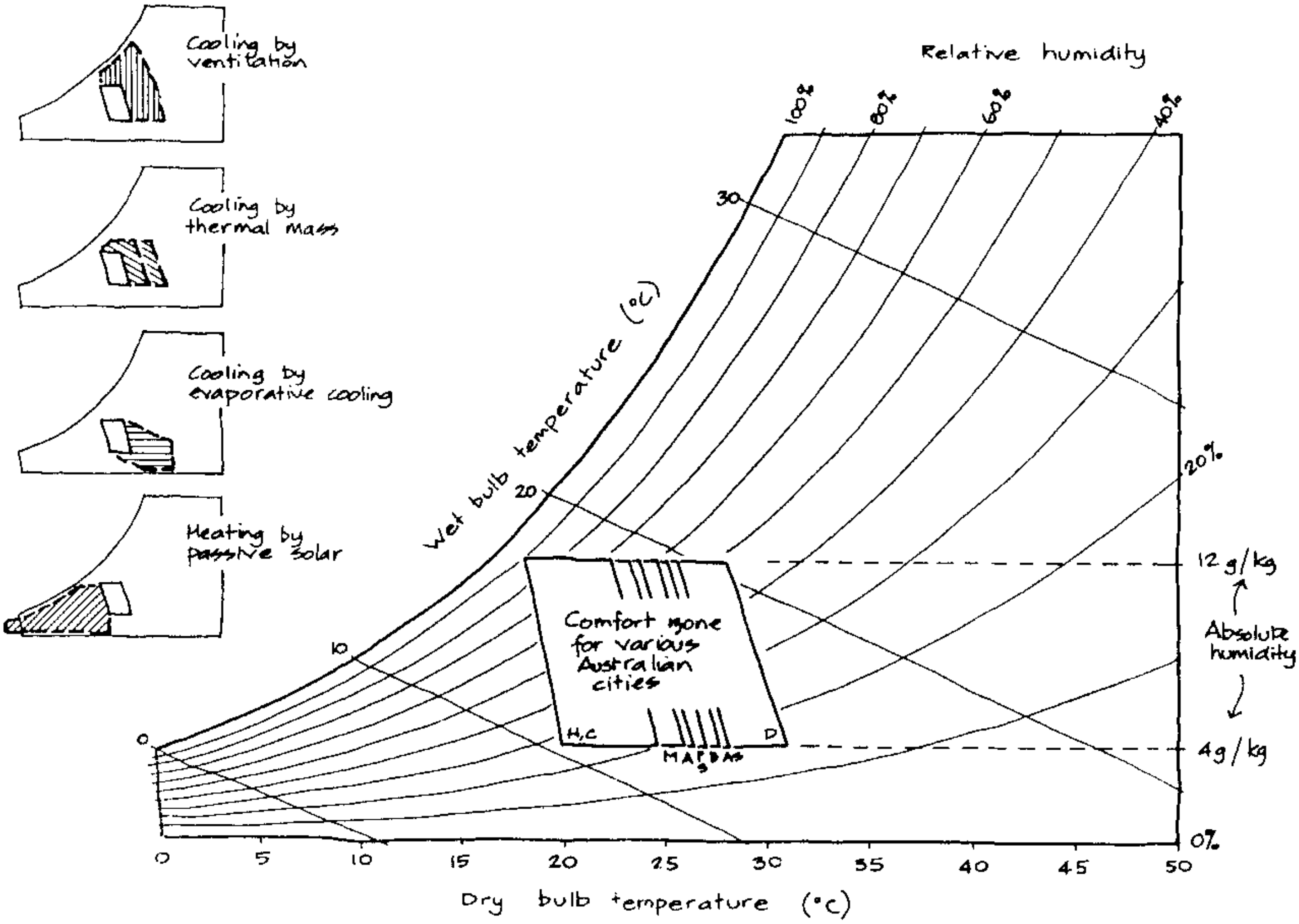


Figure 61. Bioclimatic chart – comfort zones and design strategies

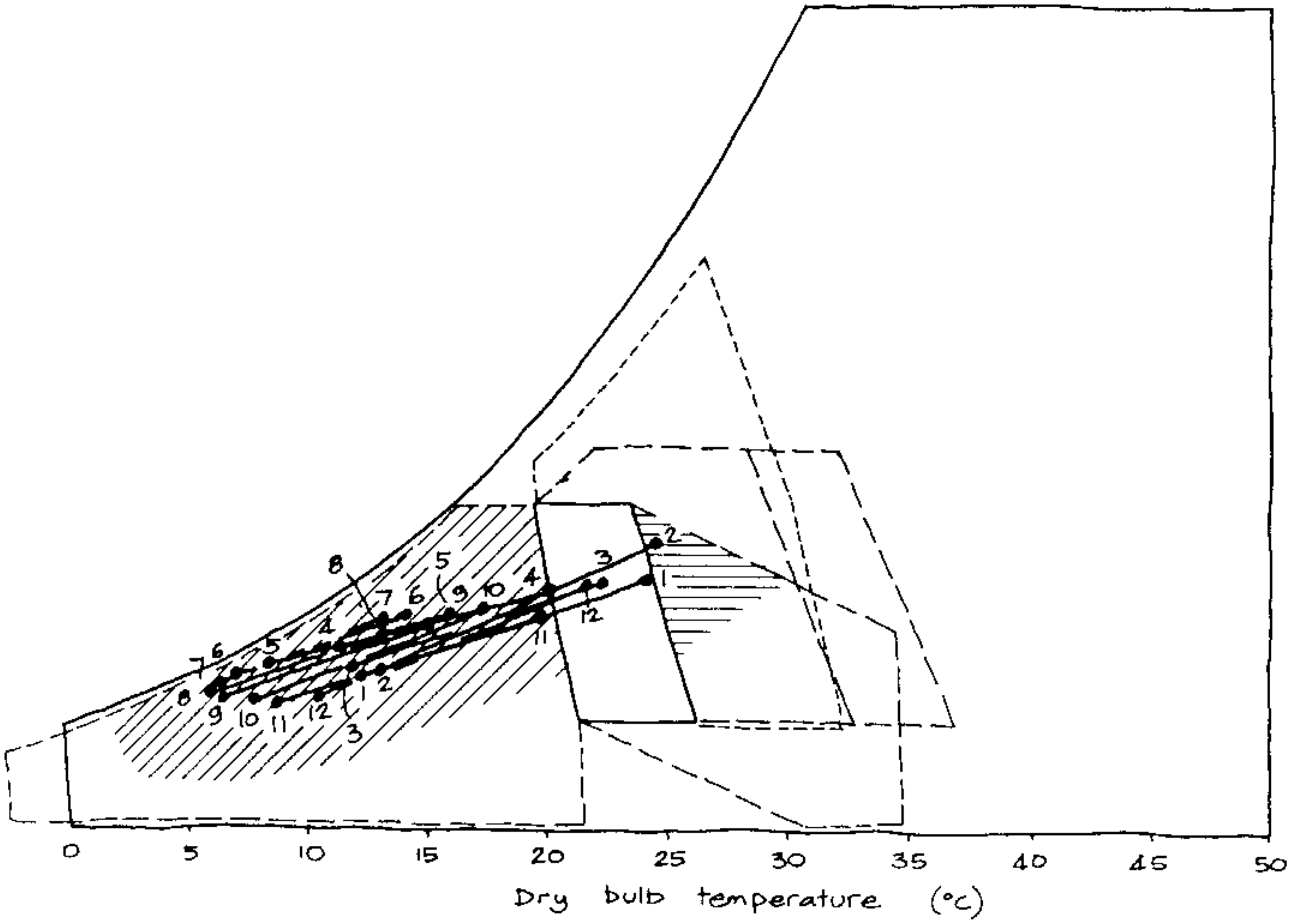


Figure 62. Bioclimatic chart for Adelaide. South Australia

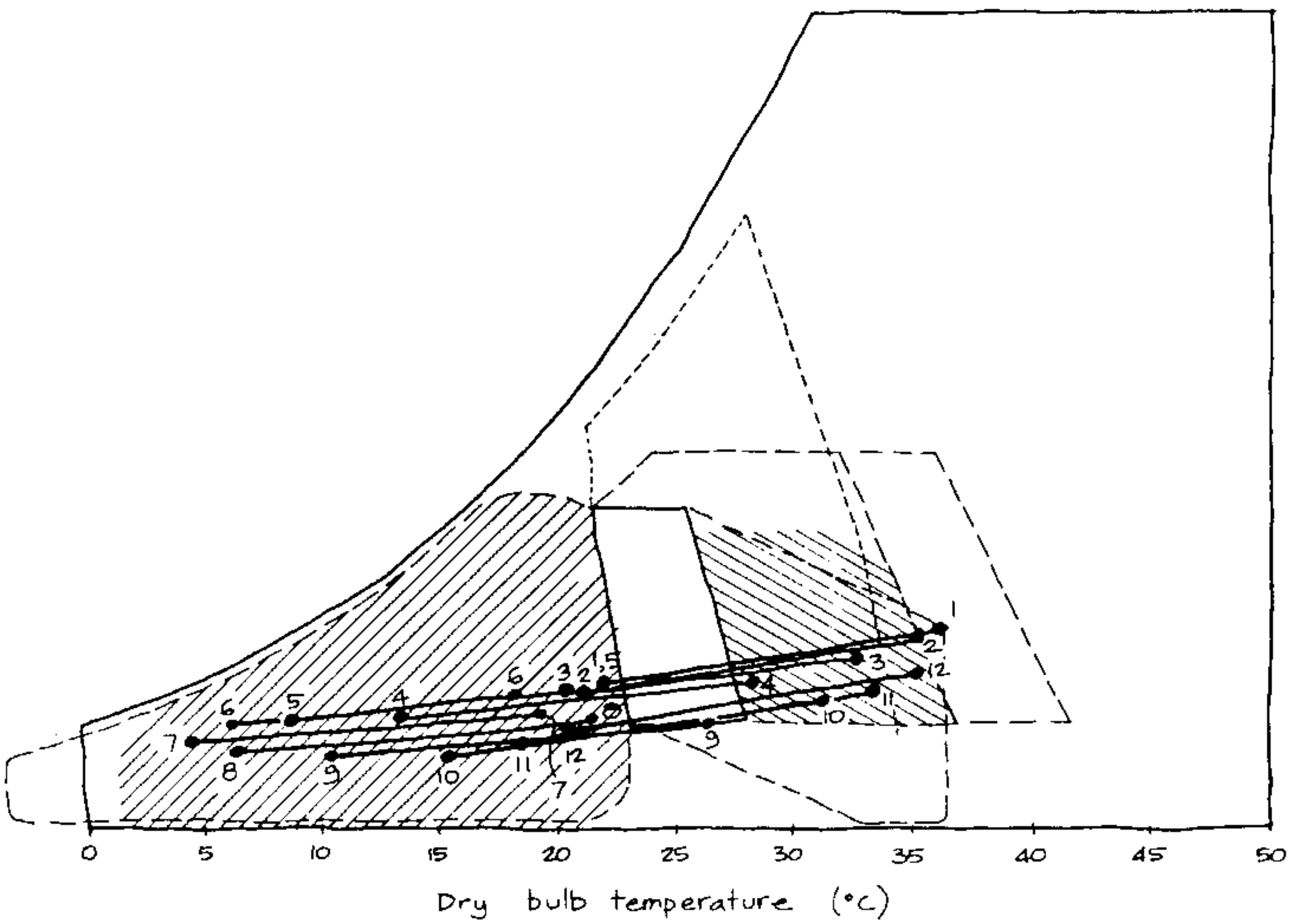


Figure 63. Bioclimatic chart for Alice Springs. Northern Territory

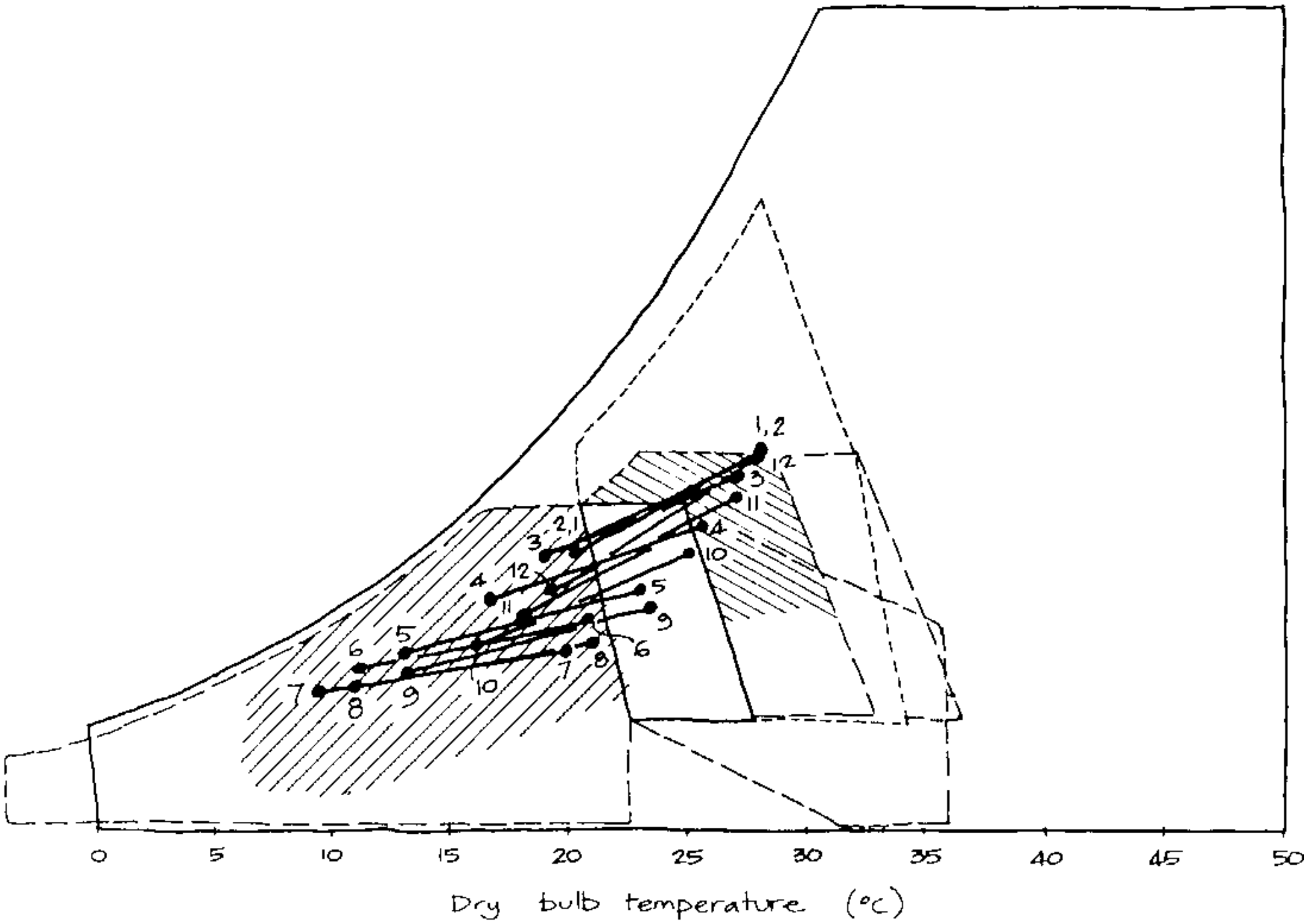


Figure 64. Bioclimatic chart for Brisbane. Queensland

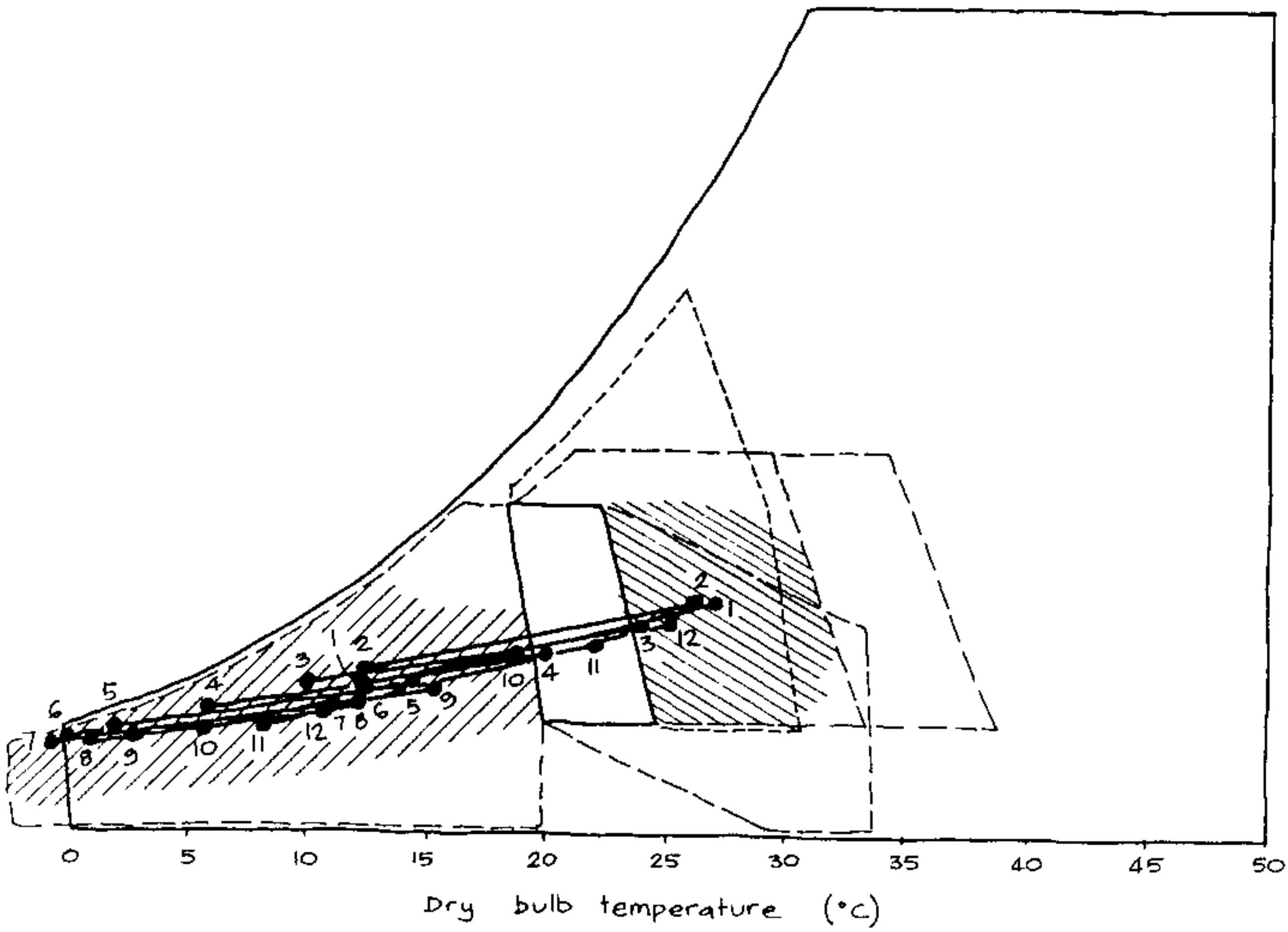


Figure 65. Bioclimatic chart for Canberra. Australian Capital Territory

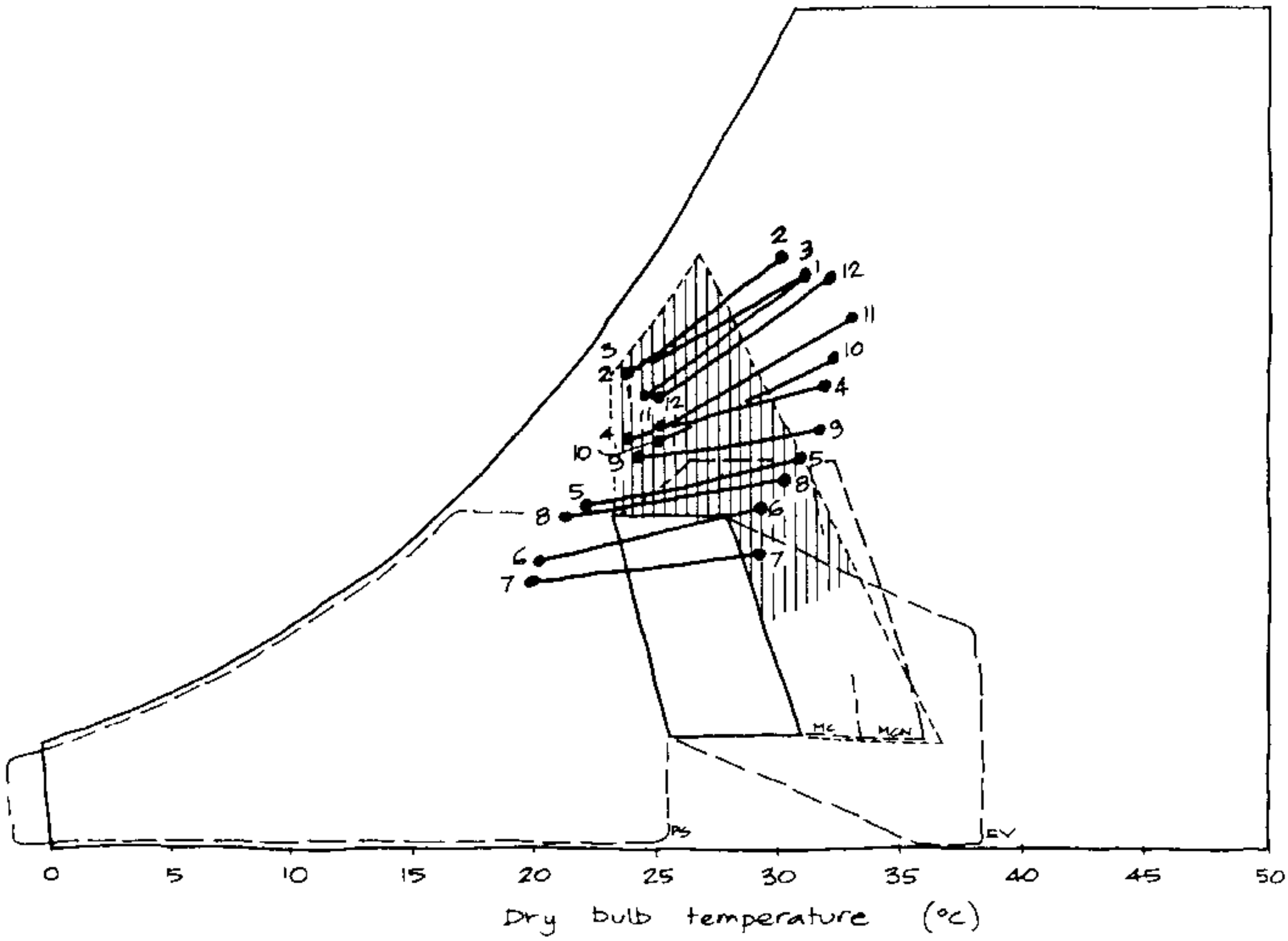


Figure 66. Bioclimatic chart for Darwin. Northern Territory

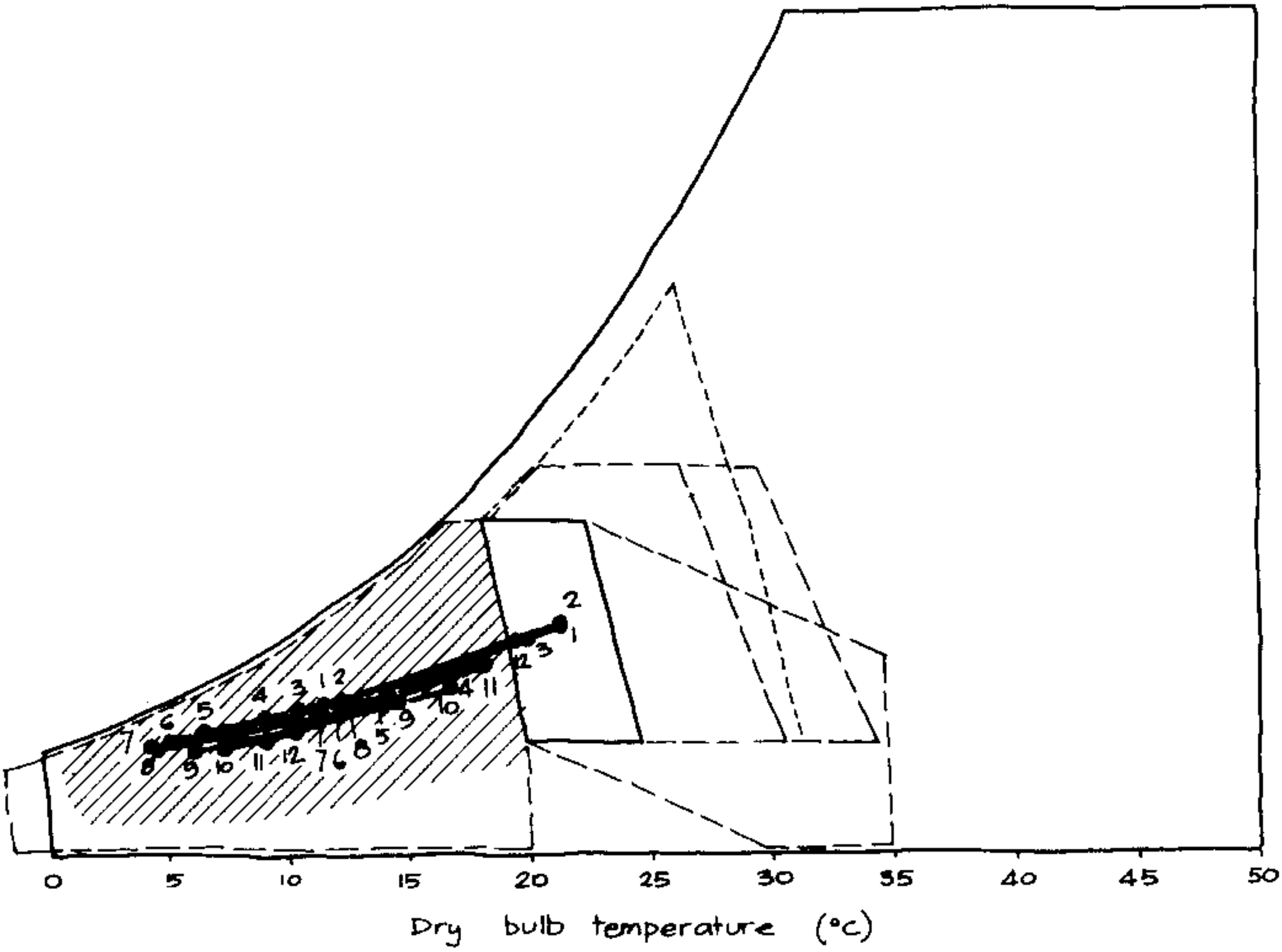


Figure 67. Bioclimatic chart for Hobart. Tasmania

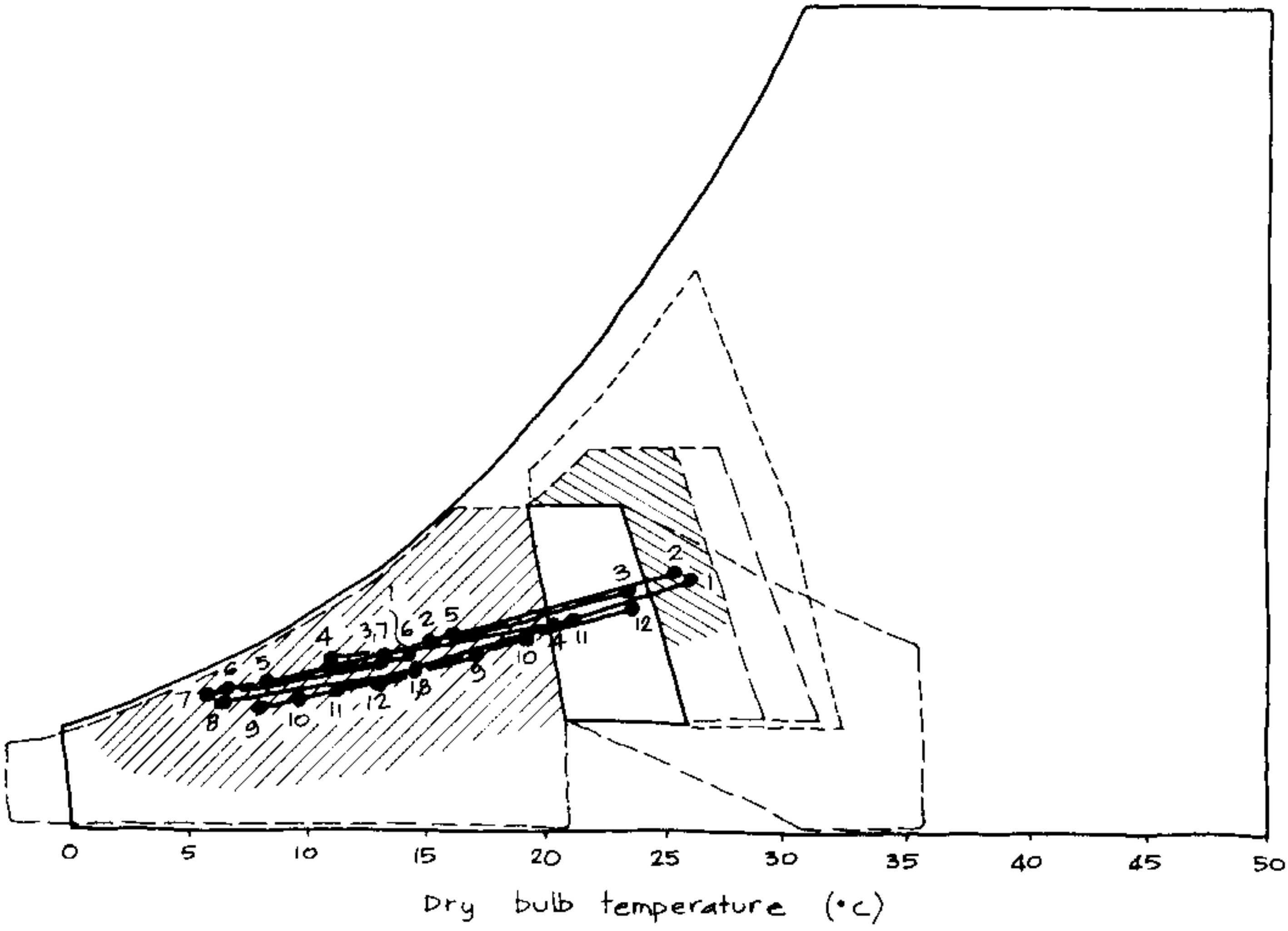


Figure 68. Bioclimatic chart for Melbourne, Victoria

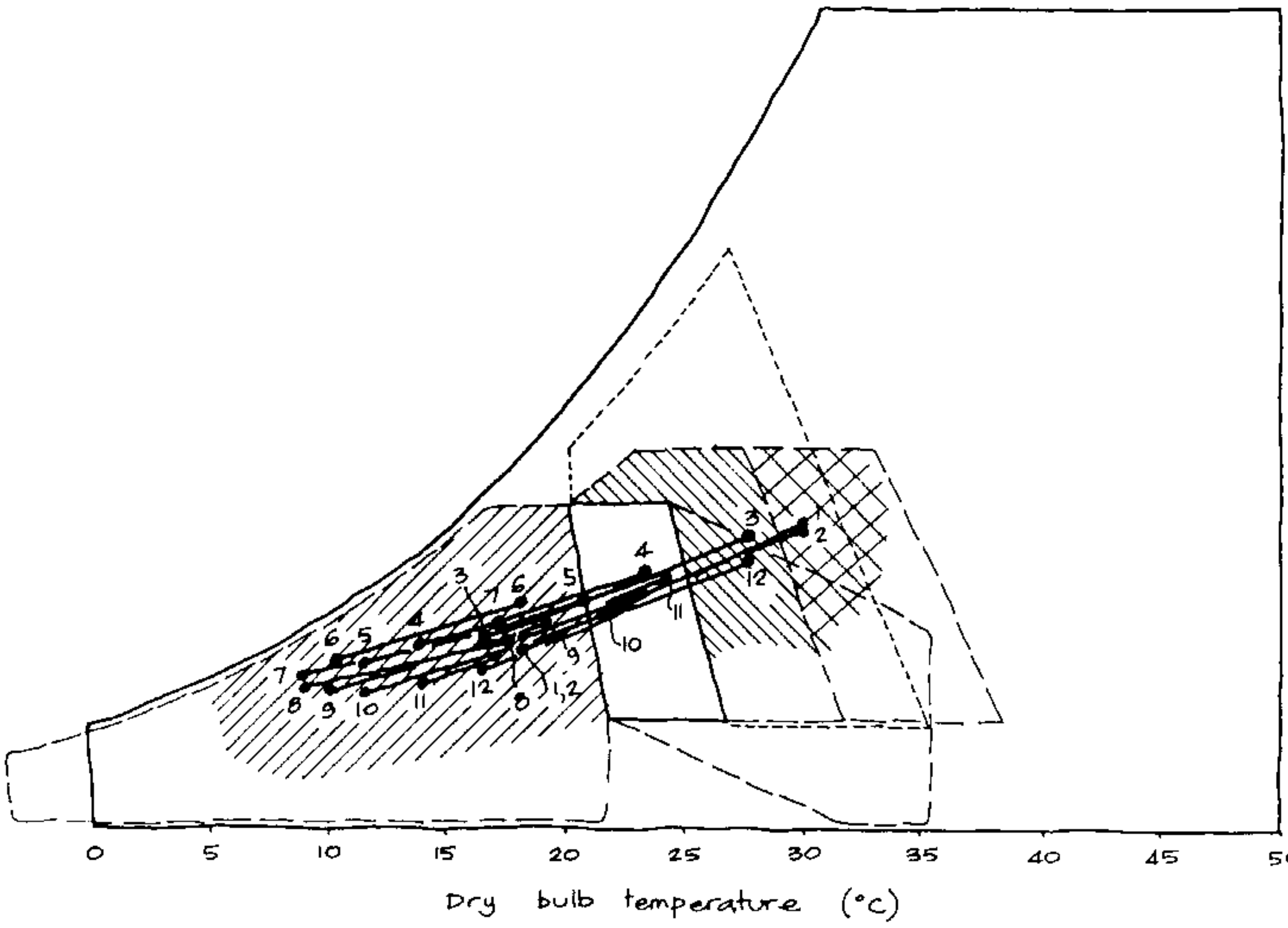


Figure 69. Bioclimatic chart for Perth. Western Australia

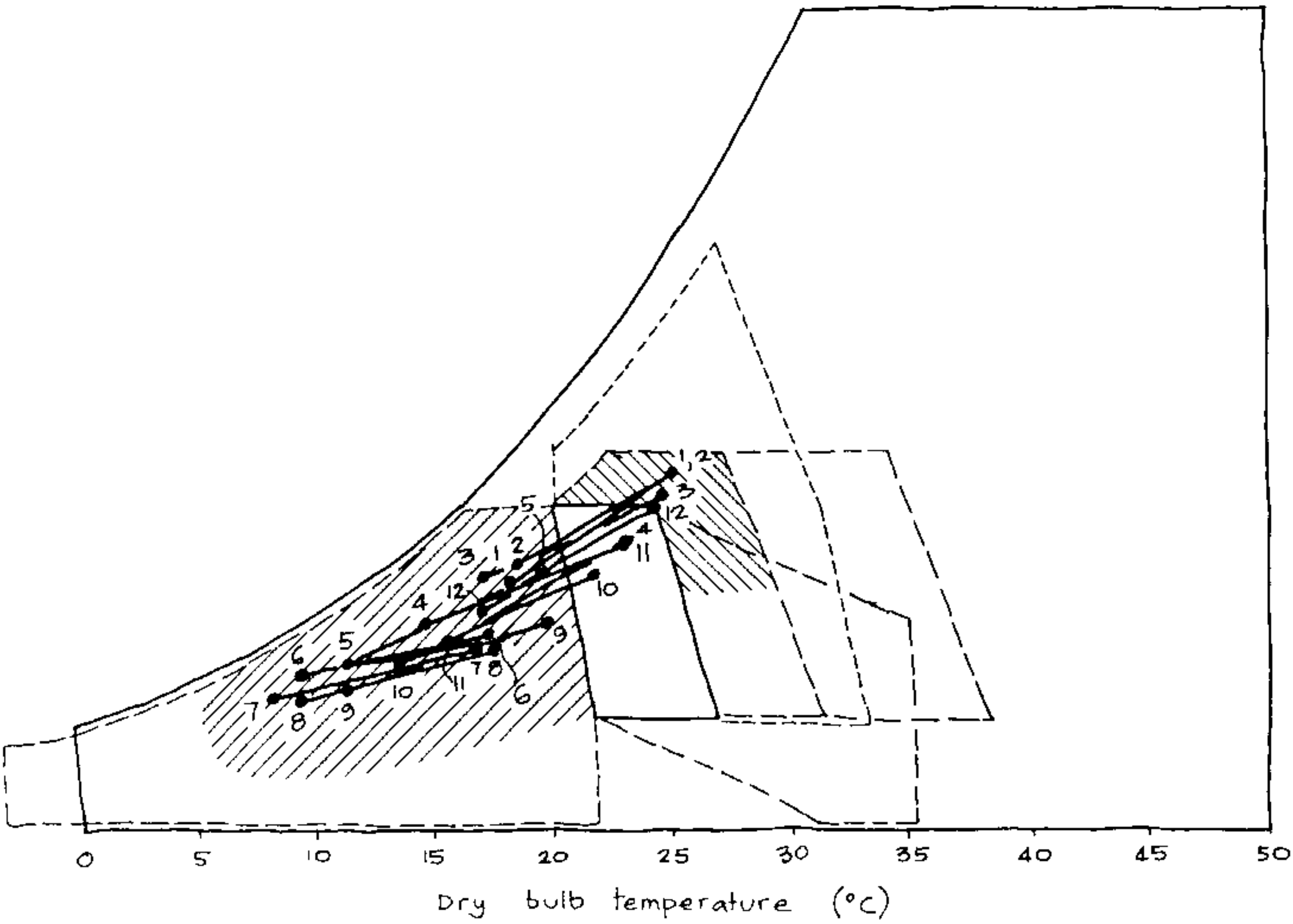


Figure 70. Bioclimatic chart for Sydney. New South Wales

VII. Detail design

A. General

The detail design for passive solar heating and natural cooling involves the careful checking and selection of the various elements of the building. Some design issues are important to both passive solar heating and natural cooling principles such as the control of conductive heat flow (control of heat out in winter and in during summer) whilst the design or selection of shading is important for its summer control and important in its absence in winter to let the sun in.

It has been found in recent studies undertaken for the 5−star design rating system that thermal−storage materials inside a house influence comfort levels in both summer and winter. The mass has little effect however on the heating loads of an intermittently heated house (the more common pattern of heating in most of Australia except in the very cold areas).

1. Passive solar heating

In both the cool−temperate and the hot−arid zones, passive solar heating is necessary in winter. The detailed design procedure should be as follows:

(a) Locate as many habitable rooms as possible with a northerly outlook to receive winter sun and buffer spaces to the south as natural insulation to habitable rooms. Provide adequate air−lock protection to main entrances for draft control;

(b) Determine the desirable glass−mass relationship for specific location and building use;

(c) Select or adapt the desired construction system to achieve the appropriate glass−mass relationship;

(d) Develop construction details to facilitate the economic installation of appropriate insulation levels in all external fabric;

(e) Select and specify glazing and window treatments for optimum daytime solar gains and minimum conductive losses:

(f) Develop construction details to minimize heat loss due to infiltration.

2. Natural cooling and summer comfort

In much of the year overheating inside buildings is the result of excess solar heating and internally generated heat reaching the interior spaces. This is certainly the case where the ambient air temperatures are no greater than about 27C. In such cases it is usually practicable to maintain comfort conditions with appropriate control of those heat gains (such as shading of windows and exhausting internal heat) and good ventilation and air movement patterns.

Where air temperatures are above reasonable comfort levels it is necessary to apply other strategies that will collect or soak up the excess heat for disposal into the cooler earth or to the cooler night air. In these cases the design approach should be as follows:

(a) Reduce solar gains to the interior by correctly designed shading;

(b) Minimize conductive gains by shading wall and other surfaces as appropriate and insulating the external fabric of the building;

(c) Minimize the effects of internal gains (lights and other appliances) by exhausting the heat:

(d) Design night ventilation openings to optimize the cooling of thermal sinks (thermal mass):

(e) Allow for appropriate air movement (ceiling fans and the like) to raise the occupants' comfort threshold;

(f) Design for minimum air infiltration during the day when external air is 3 deg.C greater than the upper comfort limit.

The overall goal is to be warm in winter and cool in summer. The sections that follow will assist the designer to achieve these goals by design, not by accident.

B. Solar access, shading and window protection

This section deals with two aspects of detail design. Access to solar radiation and protection of buildings and their interiors from solar radiation. They have been grouped together because they deal primarily with the geometry of the sun's movement.

1. Solar access

There are two fairly well documented ways of protecting solar access: solar envelopes and shadow masks used in conjunction with a solar access butterfly.

The solar envelope concept has been studied extensively by Knowles at the University of Southern California. He defines it as "the volumetric limits of building that will not shadow surroundings at specified times. (usually between 9 a.m. and 3 p.m.)

The aim of the envelope is to protect solar access for the future.

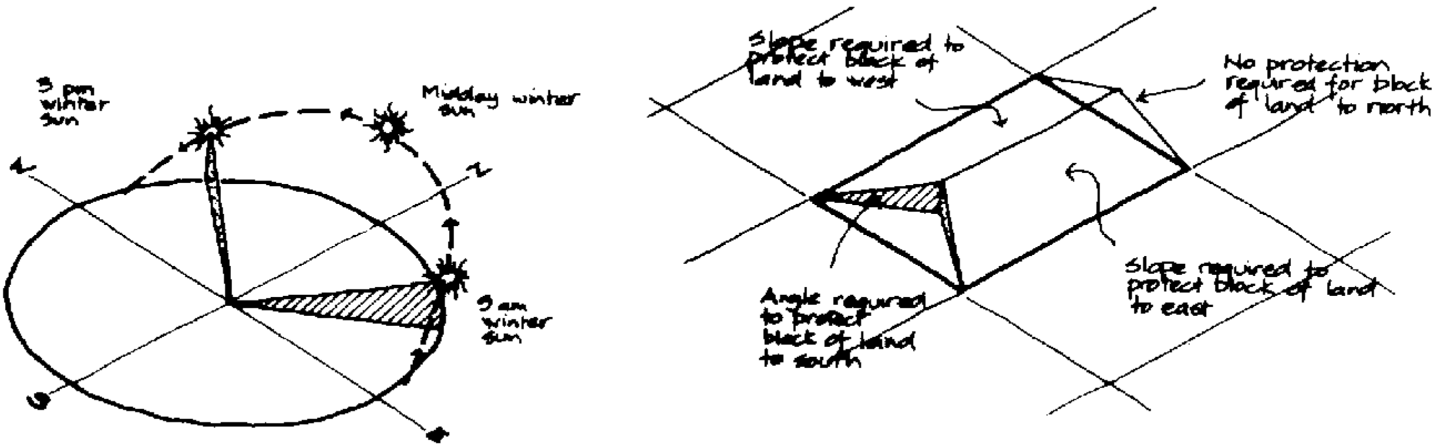


Figure 71. Solar envelopes

Ralph Knowles' envelope is designed for whole−site solar access, which involves increased allotment size and therefore decreased density. which has development cost implications.

All solar access protection techniques require some trade−off between density and solar access. The Knowles' envelope is generated using the altitude angles of the sun, at nominated times. to establish imaginary planes sloping inwards from their base on the boundaries of the site. as illustrated in figure 72.

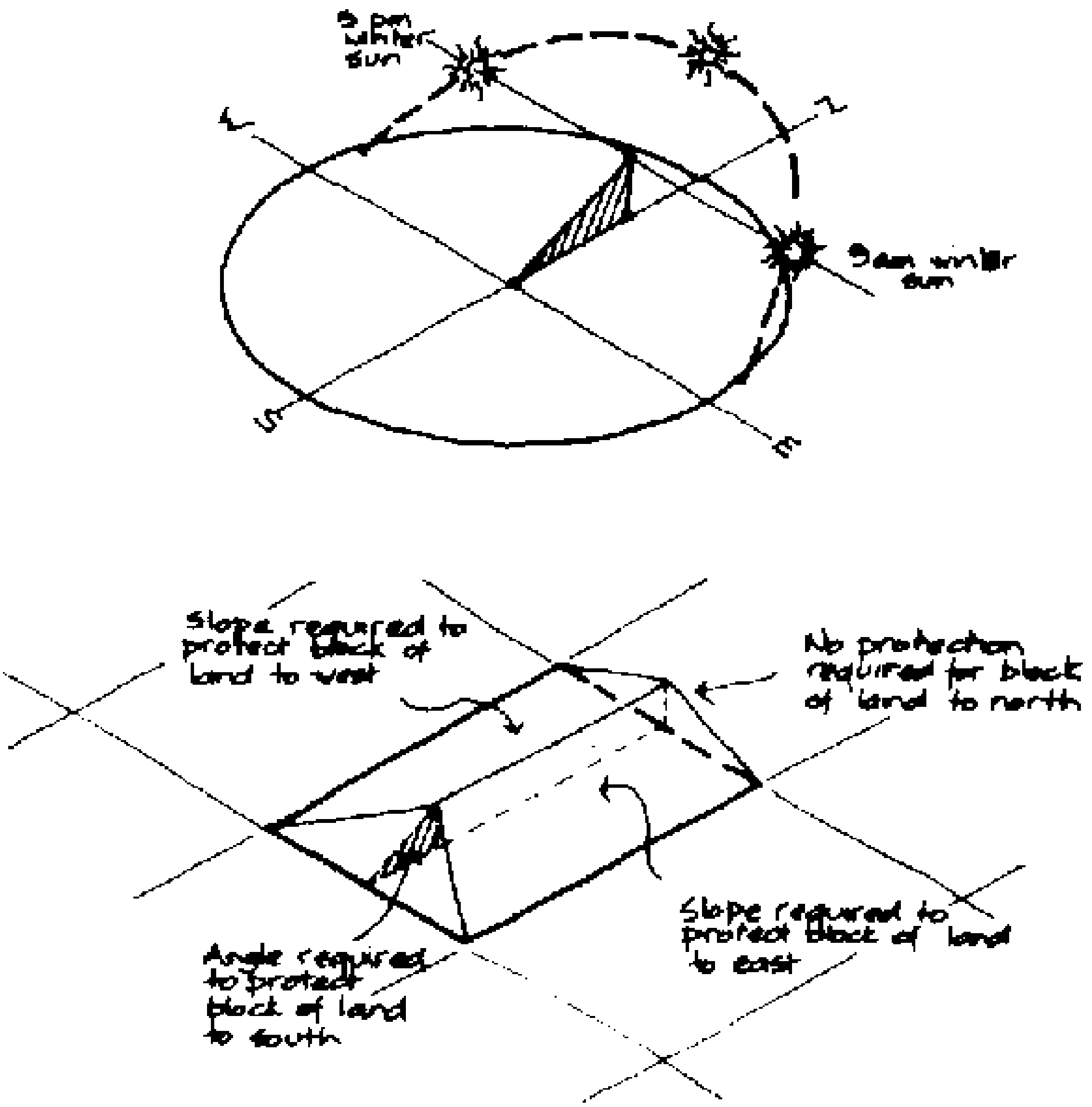


Figure 72. Knowles' envelope

Differing levels of solar access can be achieved by raising or lowering the height from which sloping planes are generated (the base plan height).

2. Shadow masks and the solar access butterfly

In order to consider topography and house orientation simultaneously. shadow masks and the access butterfly can be used. because the solar envelope is a form established in space and as such is difficult to visualize and to use in large−scale planning. The solar envelope is more appropriate in existing built−up situations.

The shadow mask principle takes into account factors such as gradient and orientation of slope and building orientation more easily than the solar envelope principle. The solar access butterfly is a method which enables vegetation to be located to the north of a house without shading the north wall in winter.

Using the shadow mask and butterfly principles, large housing estates can be designed in plan to ensure solar access to each dwelling. It is established for each dwelling for the position in which it is to be located. The composite mask that is formed is that of the shadow cast by a given building with a given orientation on a known slope and slope orientation. The shadow is a composite of the shadows cast at 9 a.m.. 12 noon and 3 p.m. at the winter solstice (22 June). It is during this time period that overshadowing of the north wall is unfavourable. If no overshadowing occurs at this time of the year then active systems, such as rooftop hot−water heaters, would not be shaded at any time of the year.

The composite shadow mask is established by:

(a) Presenting the building. tree or other object as a series of poles;
(b) Finding the shadow length and direction cast by those poles;
(c) Connecting the pole shadows into a composite shadow mask.

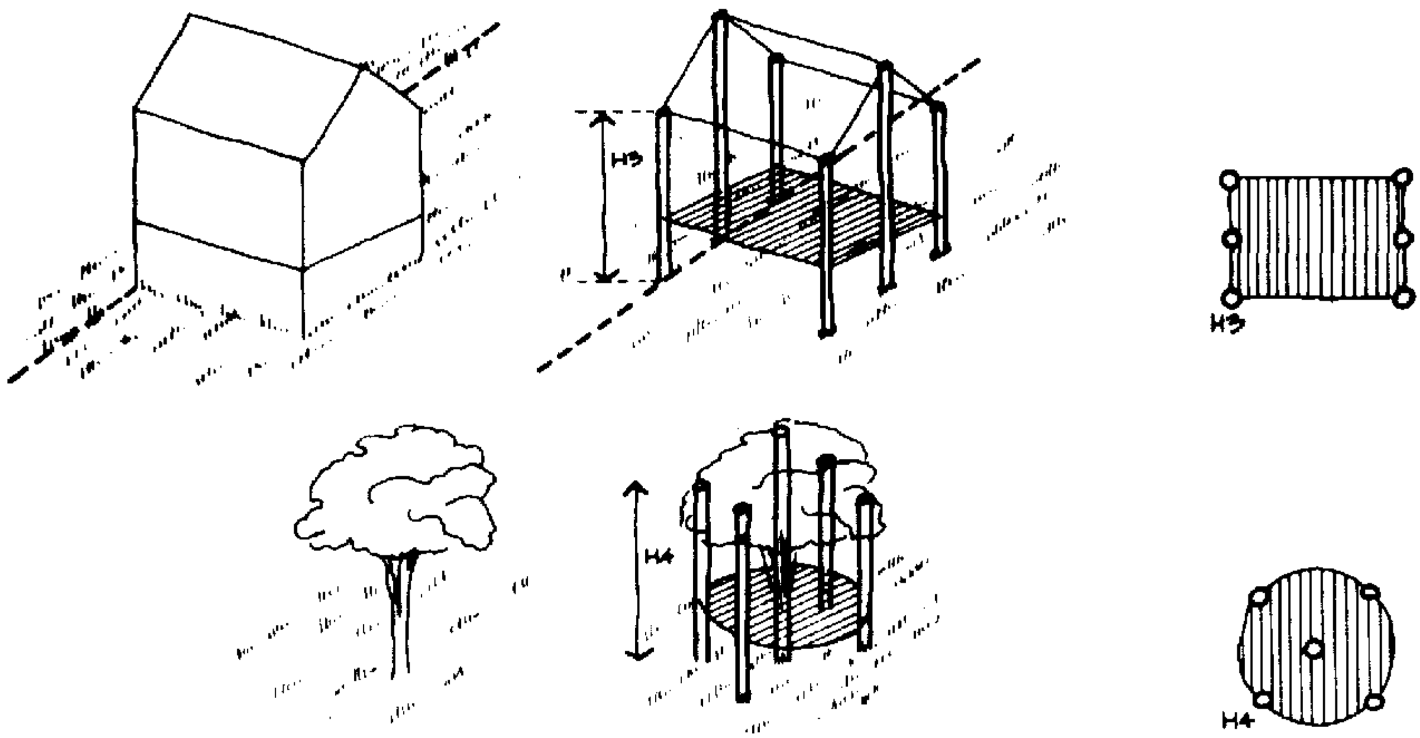


Figure 73. Presenting the object as a series of poles

(a) Presenting the object as a series of poles

The pole height is the distance between the gutterline, ridgeline or top of the object. and natural ground level. and can be measured from the elevation drawings of the building.

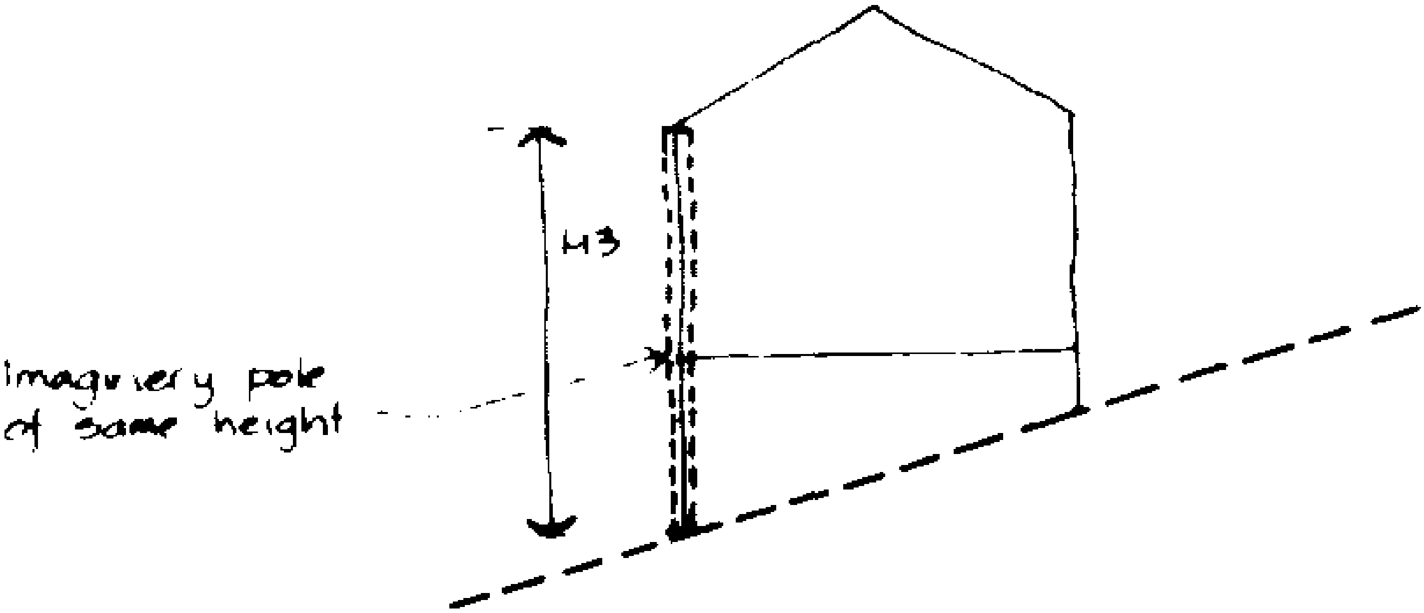
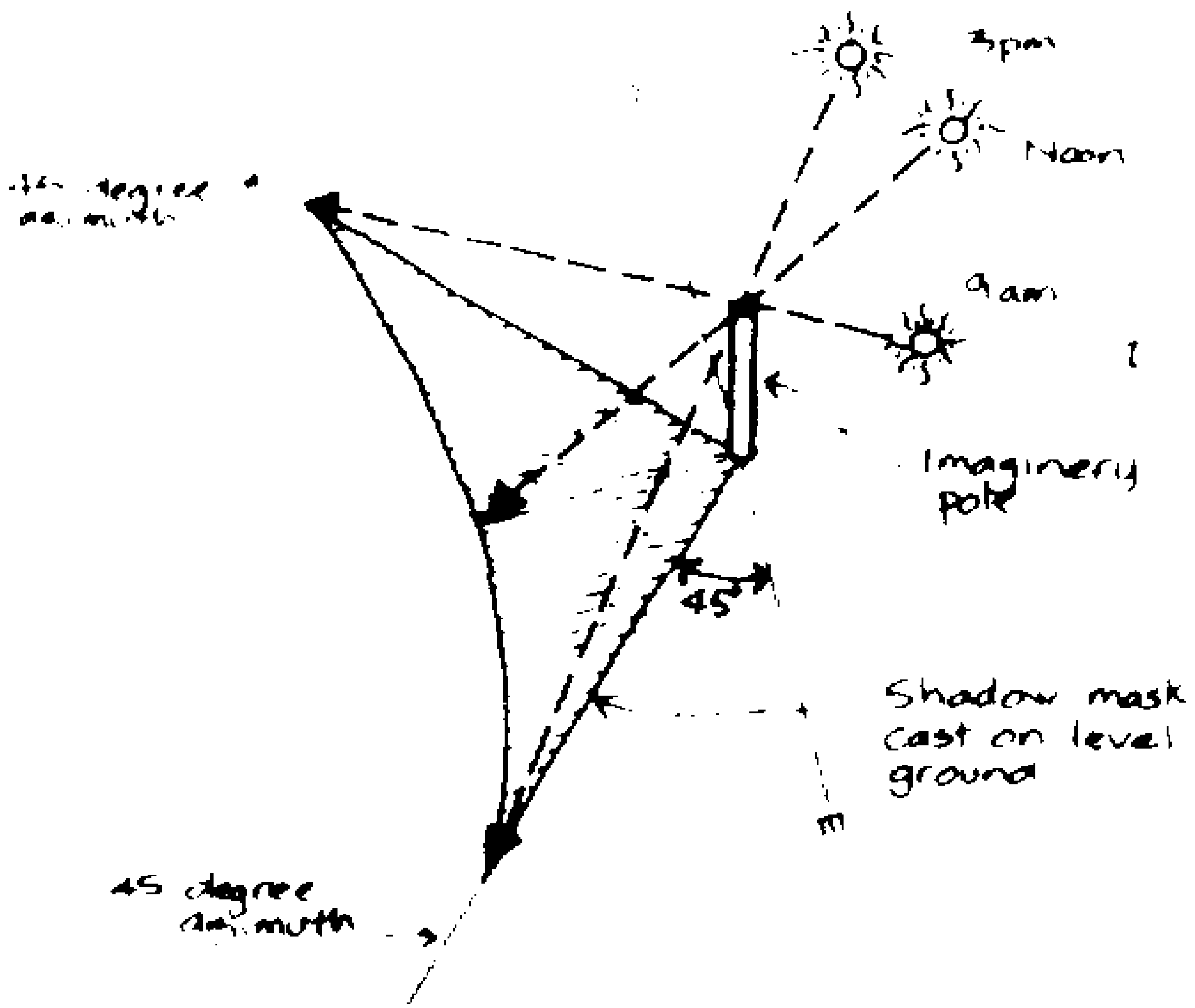


Figure 74 Measuring pole height from elevation

(b) Finding the shadow length and direction cast by each pole

This is done using table 10 to get shadow length factors established for the winter solstice. It gives the shadow length of a 1 unit length pole for various slopes of different gradients and orientations. The a.m. and p.m. values give the shadow length for approximately 9 a.m. and 3 p.m. and correspond to the 45 degree azimuth for Sydney (34 degrees South). (The 45 degree azimuth is adopted for ease of application and means that the a.m. shadow falls on a line 45 degrees west of north and the p.m. shadow falls on a line 45 degrees east of north) as shown in figure 75.


3pm
Noon
9 am
Imaginery pole
45°
Shadow mask cast on level ground
45 degree azimuth

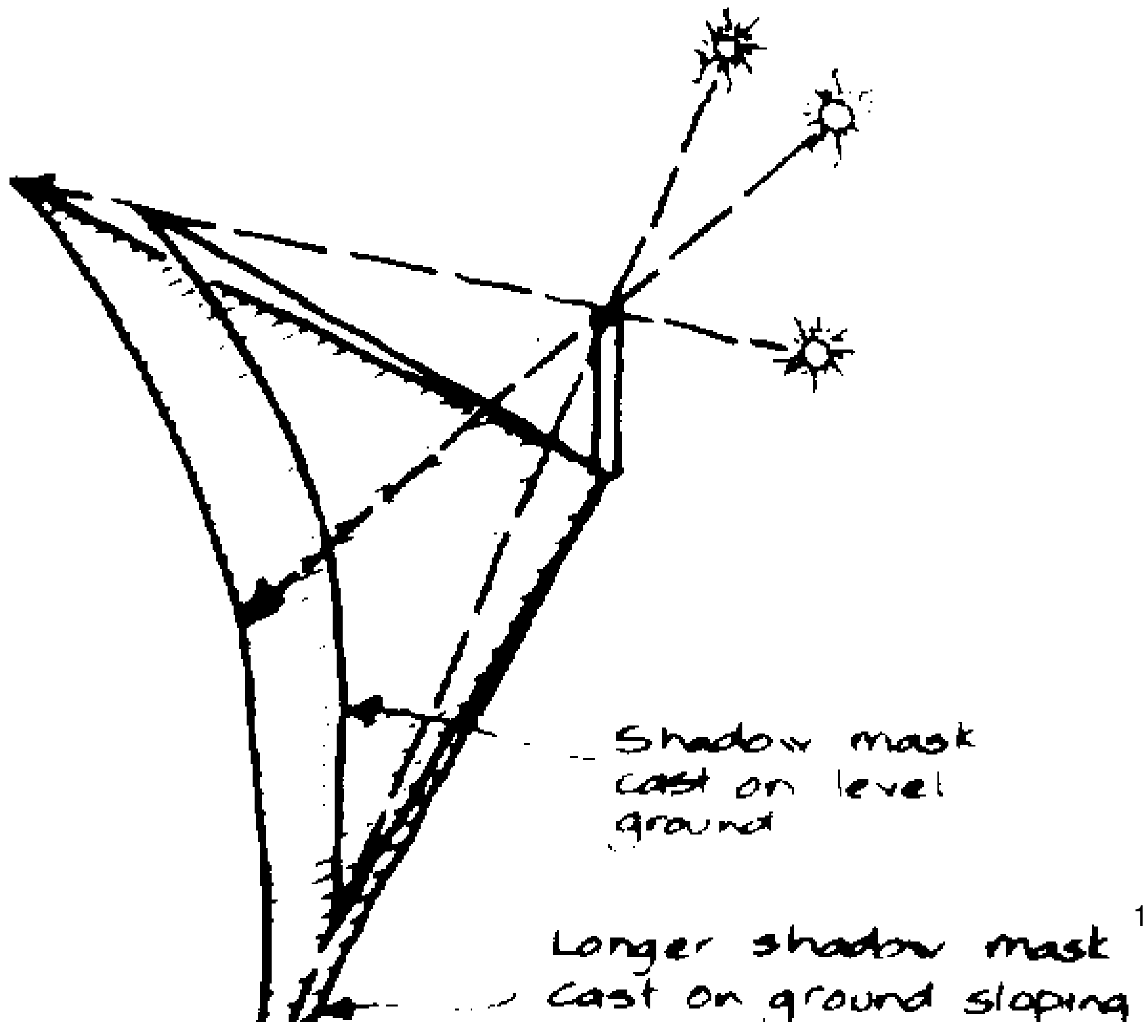

Shadow mask cast on level ground
Longer shadow mask cast on ground sloping

Figure 75. Shadows falling on a 45 degree line

Orientation:S					SW				
Slope		a.m	noon	p.m.	Slope		a.m	noon	p.m.
%					%	deg			
0	0	3.3	1.6	3.3	0	0	3.3	1.6	3.3
3	2	3.6	1.6	3.6	3	2	3.7	1.6	3.3
7	4	3.9	1.7	3.9	7	4	4.2	1.7	3.3
11	6	4.3	1.9	4.3	11	6	5.0	1.8	3.3
14	8	4.8	2.0	4.8	14	8	6.1	1.8	3.3
18	10	5.5	2.1	5.5	18	10	7.7	1.1	3.3
21	12	6.4	2.3	6.5	21	12	10.7	2.0	3.3
25	14	7.7	2.5	7.7	25	14	17.7	2.1	3.3
29	16	9.7	2.8	9.7	29	16	52.7	2.3	3.3
32	18	13.2	3.2	13.2	32	18	-	2.4	3.3
36	20	20.7	3.6	20.7	36	20	-	2.6	3.3
Orientation: W					**NW**				
0	0	3.3	1.6	3.3	0	0	3.3	1.6	3.3
3	2	3.6	1.6	3.0	3	2	3.3	1.5	2.9
7	4	3.9	1.6	2.8	7	4	3.3	1.4	2.7
11	6	4.3	1.6	2.6	11	6	3.3	1.4	2.4
14	8	4.8	1.6	2.5	14	8	3.3	1.3	2.2
18	10	5.5	1.6	2.3	18	10	3.3	1.3	2.1
21	12	6.4	1.6	2.2	21	12	3.3	1.3	1.9
25	14	7.7	1.6	2.1	25	14	3.3	1.2	1.8
29	16	9.7	1.6	2.0	29	16	3.3	1.2	1.7
32	18	13.2	1.6	1.9	32	18	3.3	1.1	1.6
Orientation: N					**NE**				
0	0	3.3	1.6	3.3	0	0	3.3	1.6	3.3
3	2	3.0	1.5	3.0	3	2	2.9	1.5	3.3
7	4	2.8	1.4	2.8	7	4	2.7	1.4	3.3
11	6	2.6	1.3	2.6	11	6	2.4	1.4	3.3
14	8	2.5	1.3	2.5	14	8	2.2	1.3	3.3
18	10	2.3	1.2	2.3	18	10	2.1	1.3	3.3
21	12	2.2	1.2	2.2	21	12	1.9	1.3	3.3
25	14	2.1	1.1	2.1	25	14	1.8	1.2	3.3
29	16	2.0	1.1	2.0	29	16	1.7	1.2	3.3
32	18	1.9	1.0	1.9	32	18	1.6	1.1	3.3
36	20	1.8	1.0	1.8	36	20	1.5	1.1	3.3
Orientation: E									**SE**
0	0	3.3	1.6	3.3	0	0	3.3	1.6	3.3
3	2	3.0	1.6	3.6	3	2	3.3	1.6	3.7
7	4	2.8	1.6	3.9	7	4	3.3	1.7	4.2
11	6	2.6	1.6	4.3	11	6	3.3	1.8	5.0
14	8	2.5	1.6	4.8	14	8	3.3	1.8	6.1
18	10	2.3	1.6	5.5	18	10	3.3	1.9	7.7
21	12	2.2	1.6	6.4	21	12	3.3	2.0	10.7
25	14	2.1	1.6	7.7	25	14	3.3	2.1	17.7
29	16	2.0	1.6	9.7	29	16	3.3	2.3	52.7
32	18	1.9	1.6	13.2	32	18	3.3	2.4	-
36	20	1.8	1.6	20.7	36	20	3.3	2.6	-

Table 10. Midwinter shadow length factors for Sydney (Sydney altitude = 17°) (Azimuth = 45 ° (approximately 9 a.m. and 3 p.m.))

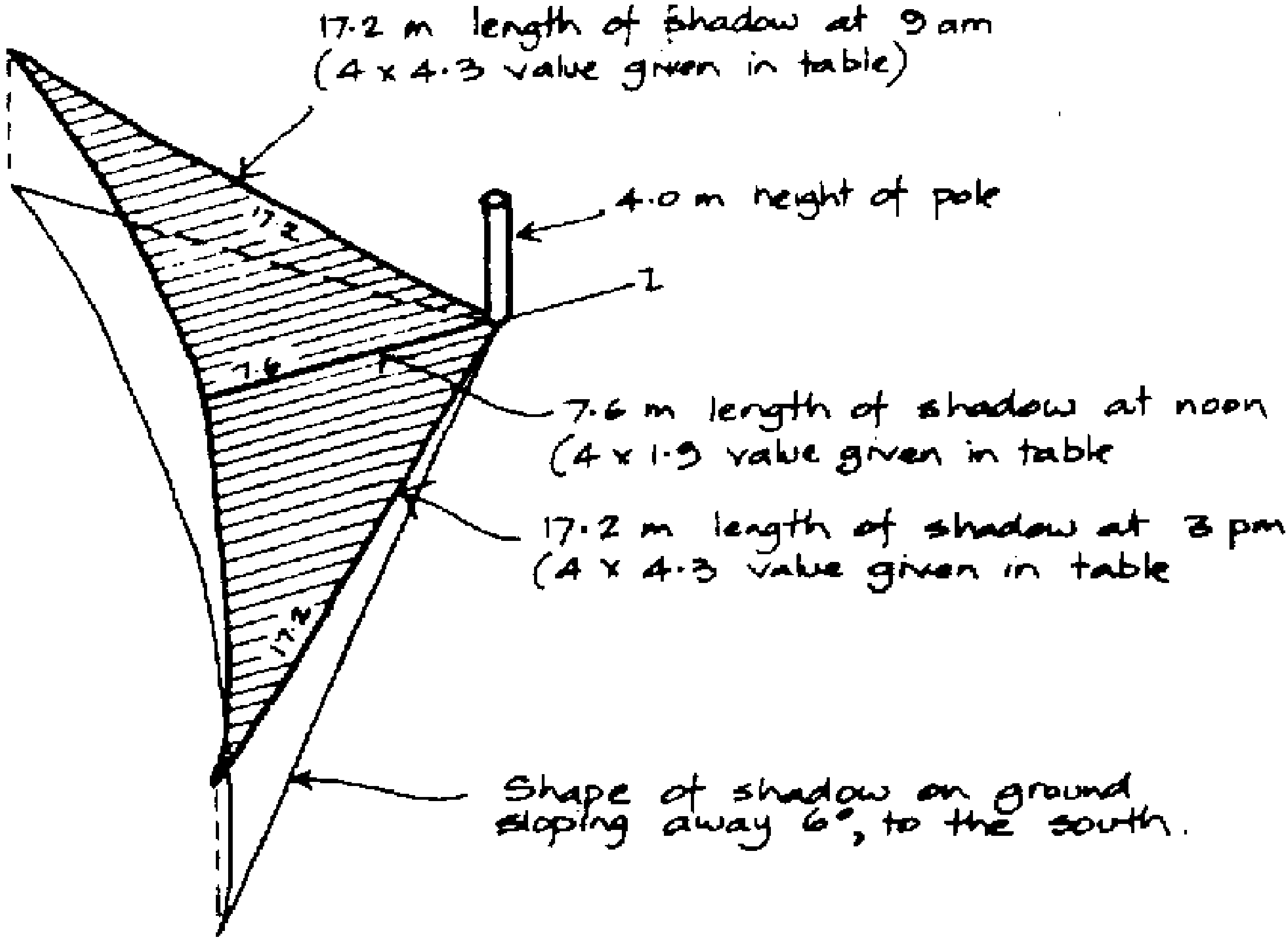


Figure 76. Shadow lengths

The length of shadows for a given slope are multiplied by the height of the pole to give the length of the shadow for that pole on that slope (see figure 76).

(c) Connecting the pole shadows into a composite shadow mask

The shadows for each pole are connected to give the composite shadow mask for the building, as shown figure 77.

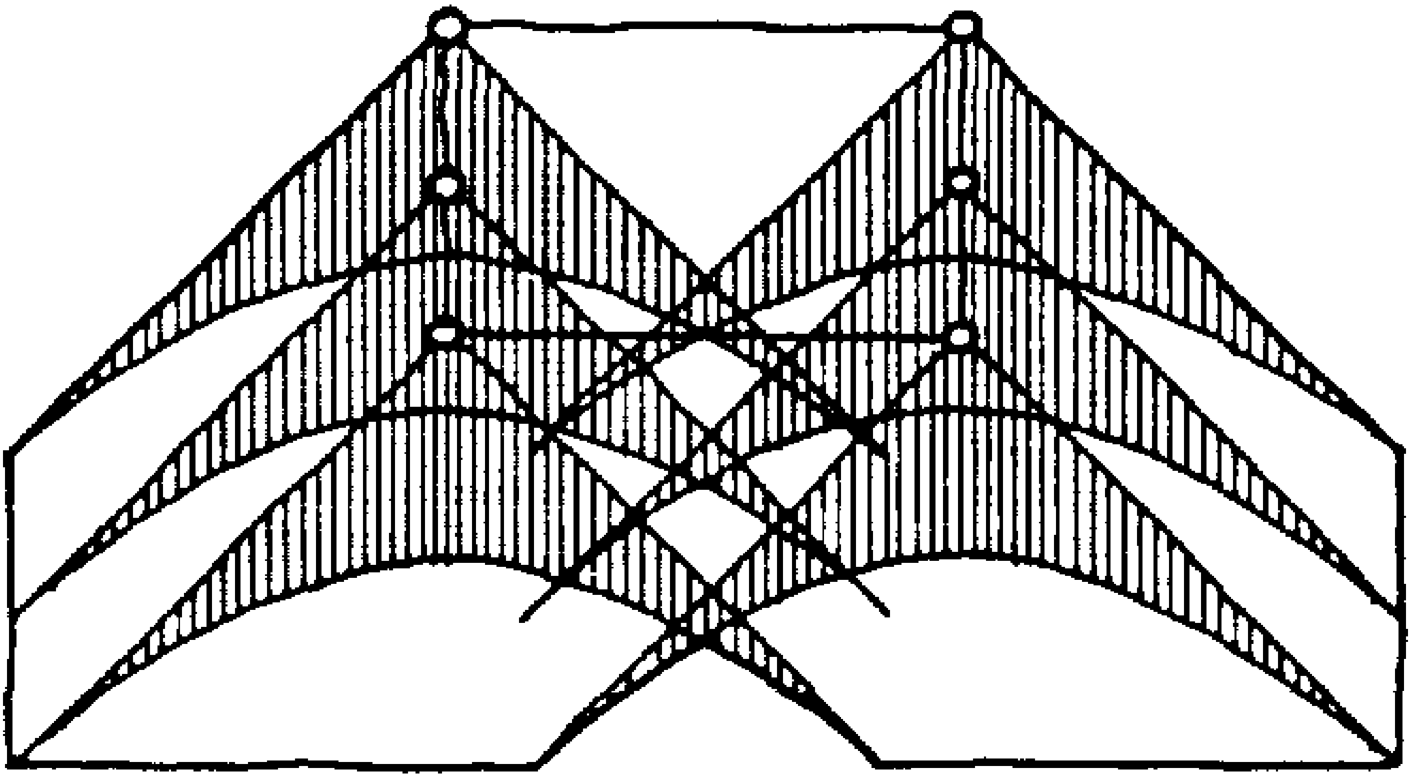


Figure 77. Connection of pole shadows Into a composite mask

Where a large number of houses are being planned, a computer program has been developed which will draw the composite shadow mask for a given building of any orientation on any slope, to a scale specified.

3. The shadow mask program

A complete listing of the program to run on a HP−85 desk top computer is contained in appendix 2 of Energy Efficient Site Planning Handbook by Kay, Ballinger, Hora and Harris. The program develops the shadow mask for a house of given dimensions on a slope of known gradient and orientation.

The shadow mask shows the maximum shadow that a building will cast and the limits of this shadow determine how close buildings may be placed together on any given slope.

The solar access butterfly can be used once the buildings have been located to determine where vegetation or other structures may be placed north of the house where shading may or may not be desirable. For example, shading of the north wall (bun not the rooftop hotwater collector) may be desirable in summer. Therefore deciduous trees may be placed at appropriate distances from the north wall according to their height. Similarly, evergreen trees must be placed to prevent shading in winter. This is the reverse of the shadow mask principle. The shadow mask and butterfly may overlap.

The butterfly specifies zones where obstructions may not be higher than a nominated height for that distance from the north wall.

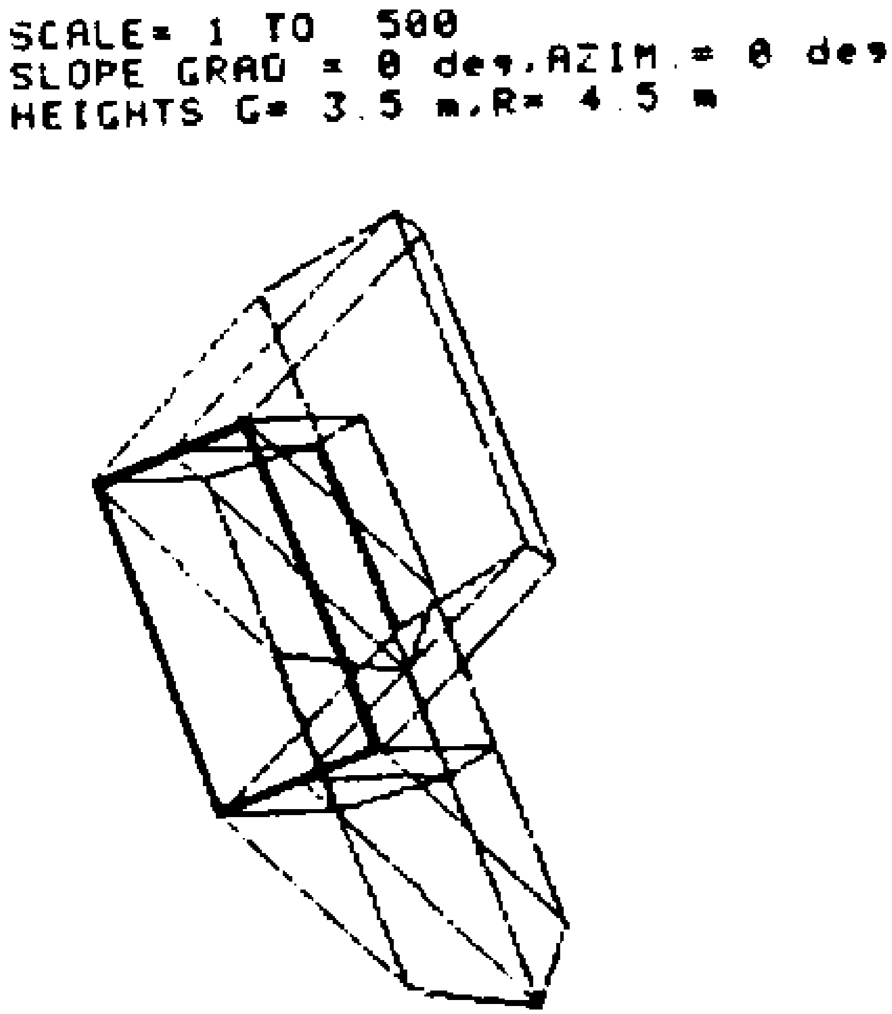


Figure 78. Computer drawn shadow mask

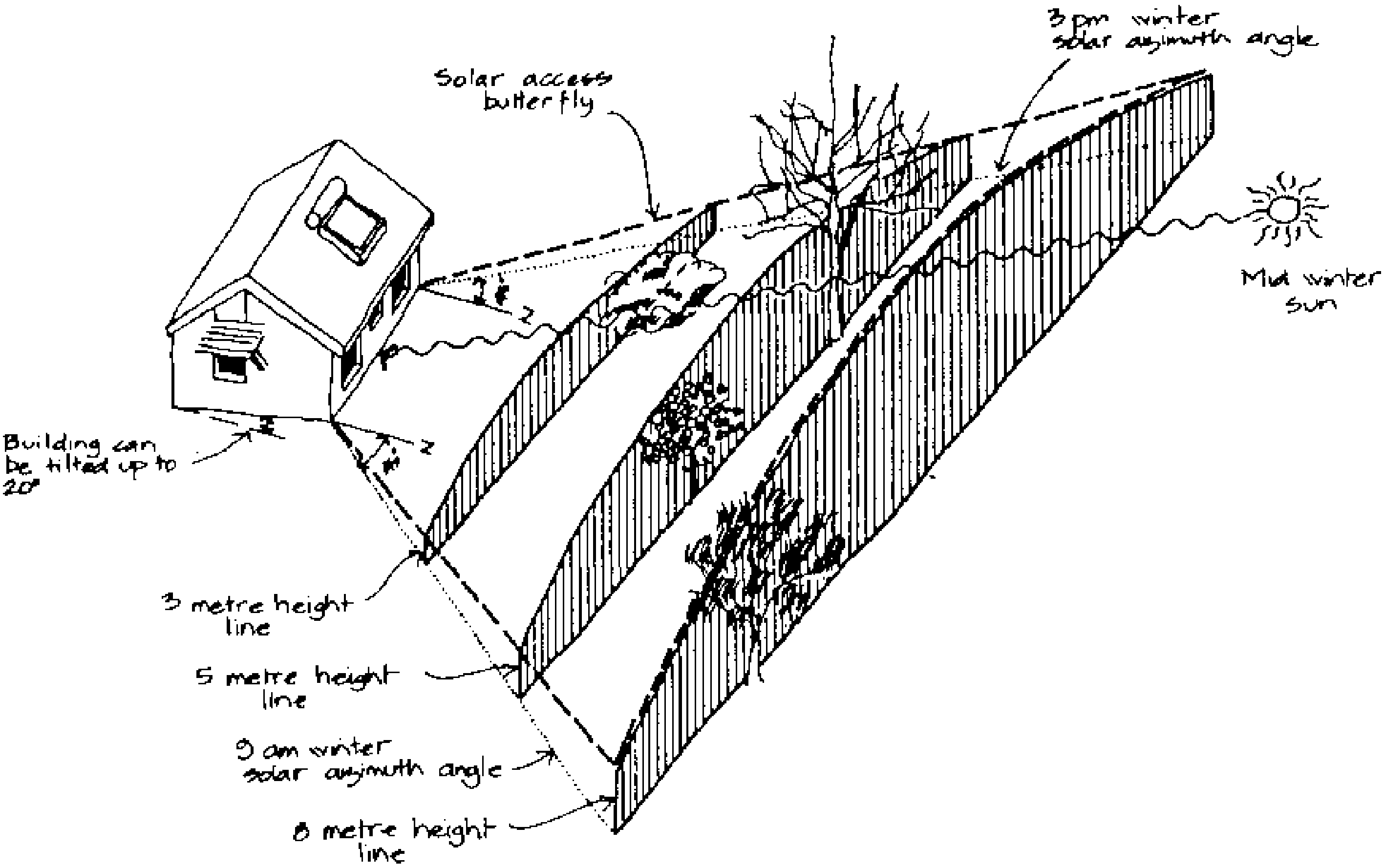


Figure 79. Solar access butterfly−section

4. Solar access butterfly

The solar access butterfly saves having to draw a shadow mask for each tree or other object located to the north of the house. The butterfly is made up of a series of height restriction lines at specified distances from the north wall of the house, depending on topography. For example, no object 3−metres high can be placed closer to the north wall than the 3 metre height line (unless it is a deciduous tree). The east and west extremities of the butterfly fall along the 9 a.m. and 3 p.m. winter solar azimuth angles drawn from the north façade of the house.

For example, in figures 79 and 80 all objects 3−m high can be placed on the 3−m height line, those of 5−m high on the 5−m height line etc. These height lines can be established knowing the shadow−length of that object on the relevant slope using the shadow length factor table (see table 10). The shadow length is based on the altitude angle of the sun at different azimuths. Deciduous trees can be placed closer to the north facade than the height line indicates if the branches are not too dense to cause shading in winter. Care must be taken, however, to prevent shading of the rooftop collector by the deciduous trees in summer.

The shadow mask principle can also be used to determine how trees shade solar collectors. The shadow of the tree can be drawn using the bottom of the solar collector as the base height. Slope and orientation are still considered.

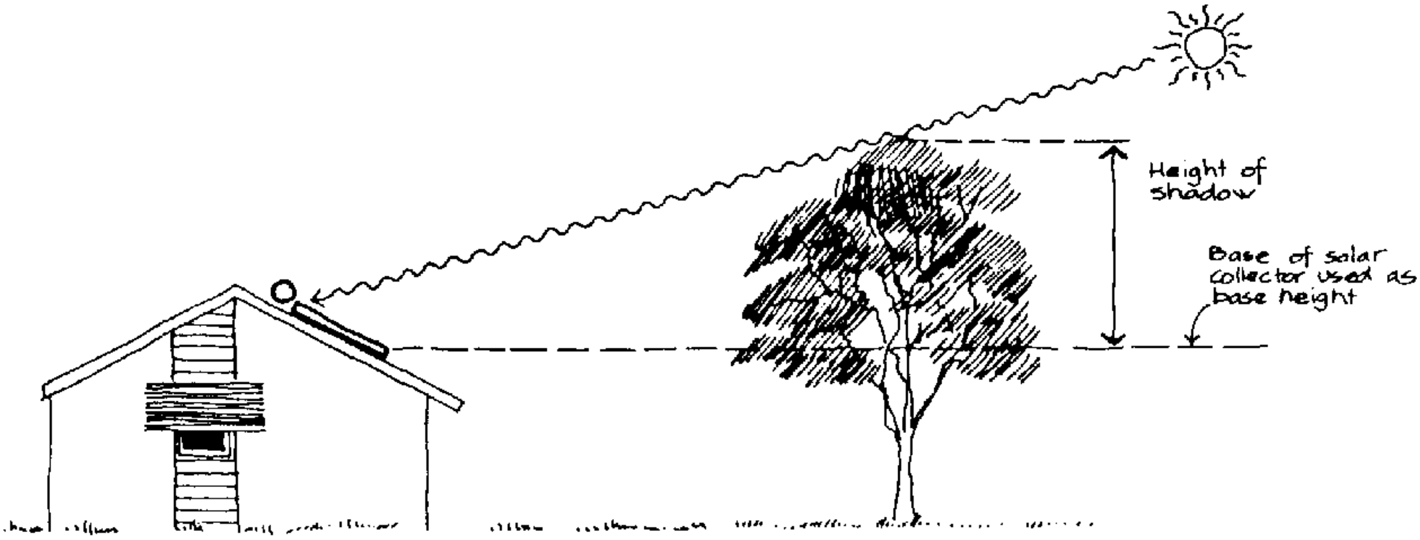


Figure 80. Shading of solar collectors

5. Site planning for solar access

Protecting the solar access of houses has some important implications for overall site design.

In order to achieve good orientation of passive solar houses. house design needs to relate to the block on which It is located. Broadly speaking. there are four types of house blocks which require different house types.

(a) Entry from north side (N)

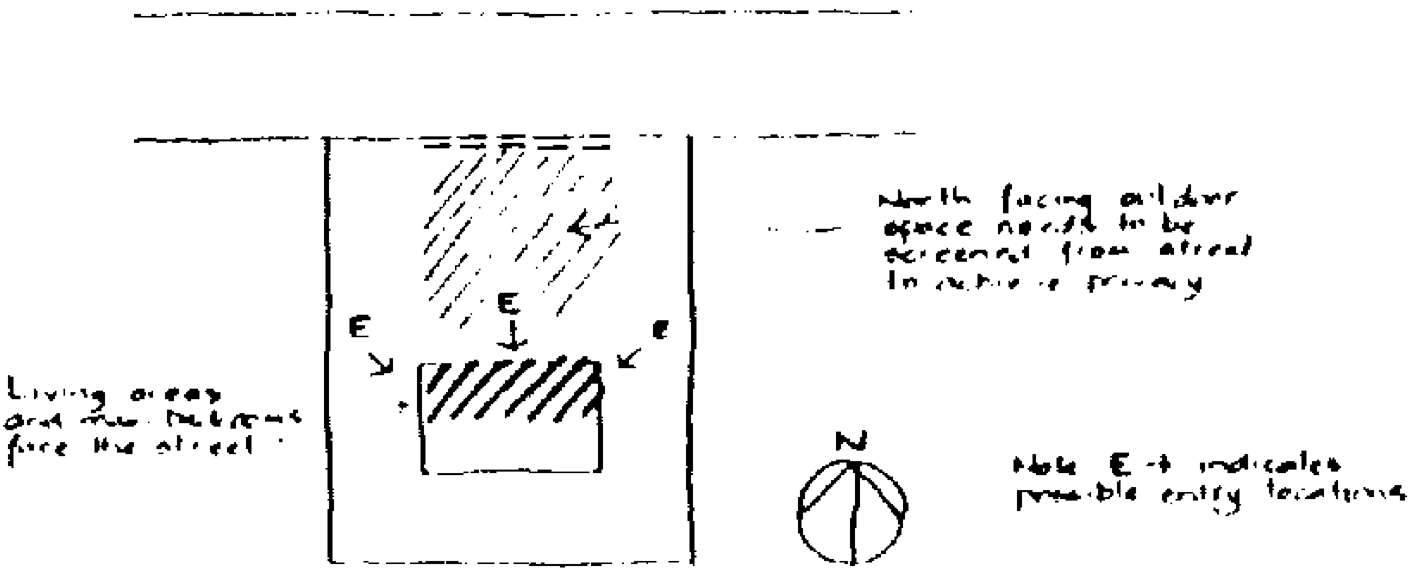


Figure 81. North side entry

In this house type:

(a) Living areas and mayor bedrooms face the street;
(b) North−facing outdoor space will need to be screened from the street for privacy.

(b) Entry on south side (S)

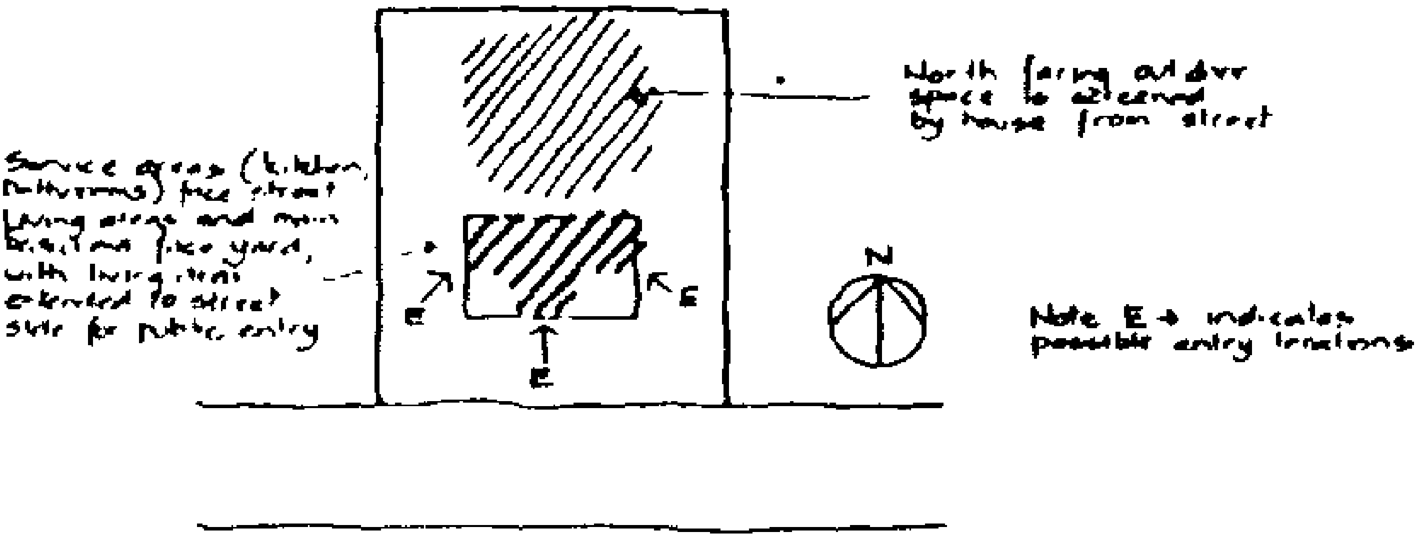


Figure 82. South side entry

In this house type:

(a) Living areas and major bedrooms face the private yard;
(b) North−facing yard is screened from the street by the house:
(c) Service areas (kitchen. bathrooms) face the street;
(d) Living area is extended to the street for public entry.
(e) Entry on east side (E)

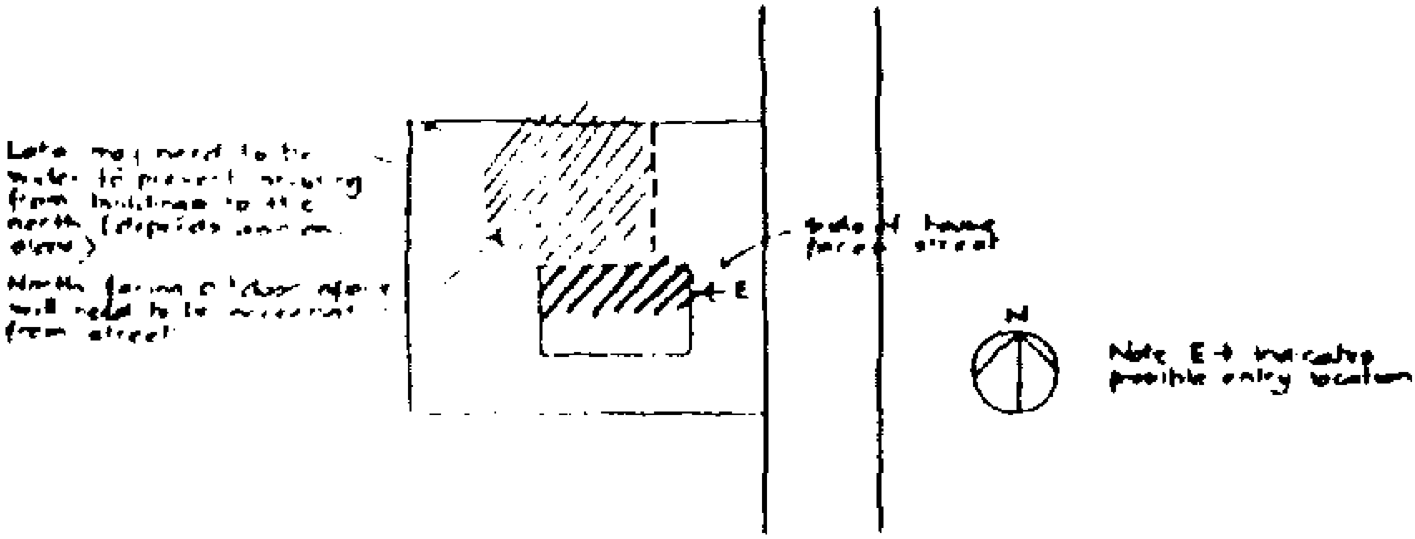


Figure 83. East side entry

In this house type:

(a) Side of the house faces the street:

(b) North−facing outdoor space will need to be screened to the side and north of the house. This also creates a sense of entry:

(c) Lots may need to be wider to prevent shading from a building to the north (this depends on slope).

(d) Entry on west side

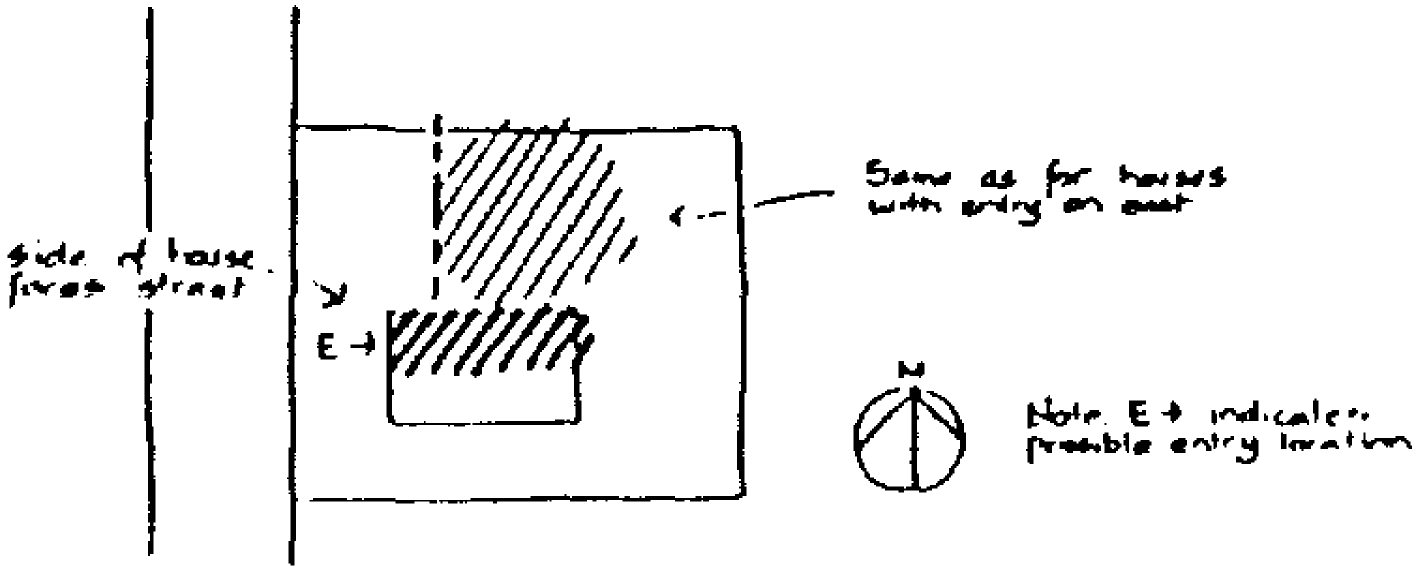


Figure 84. West side entry

In this house type conditions are the same as for east–side houses.

(e) Entry from other directions

For other blocks. where the road runs. for example. north–east southwest, one of the above house types can be used.

In most situations, existing setback regulations can be adapted to meet the solar access criteria. A standard setback from the street (building line) is the easiest means of protecting solar access. provided the slope is constant. This, however. creates a monotonous streetscape–and does not allow houses to be sited on the lot according to how outdoor spaces are to be used.

For a detailed discussion of this area reference should be made to Energy Efficient Site Planning Handbook.

Trees, shrubs and other plants can have a beneficial effect on the microclimate as well as on the energy requirements of a house. Trees can block unfavourable winter winds and hence reduce heat loss, and funnel cooling breezes and hence reduce the cooling energy load. They also block unwanted summer solar radiation and improve the microclimate. Deciduous trees and vines can be used to allow winter sun penetration and block summer sun. Methods of landscaping for energy efficiency are detailed in the guidelines.

6. Shade, shading devices and window treatments

In general terms the purpose of shading is to protect the building and its occupants from the heating effect of solar radiation and in specific cases from visual glare. Solar radiation absorbed by the building fabric will cause a rise in temperature which may be undesirable when the air temperature is within or above the accepted comfort zone. In such circumstances direct sun on the occupants (radiant energy) may also cause discomfort or at least contribute to it. Direct sunlight reflected off surfaces in the field of view will probably cause glare discomfort. The function of shading then is to control or eliminate these conditions whilst the function of windows is to allow air flow through openings, maintaining views and admitting adequate daylight.

Shading can be categorized as follows:

(a) External projections, i.e., overhangs and projecting blade walls;

(b) Systems integral with the window frame or attached to the building face, i.e., Louvre and screens;

(c) Specially treated glasses, i.e heat absorbing and reflective glass;

(d) Internal treatments either opaque or semi–opaque, i.e., curtains and blinds.

The first two can be addressed generally as geometric shading.

7. Geometric shading devices

Shading can be used on buildings to protect either the windows or the walls or both from solar radiation. The aesthetic value of shading systems and the shadows which result is also important in the overall building design as it allows the designer to define volumes and model the building surface. The dynamic qualities of shading provides the opportunity for the designer to present an ever changing image.

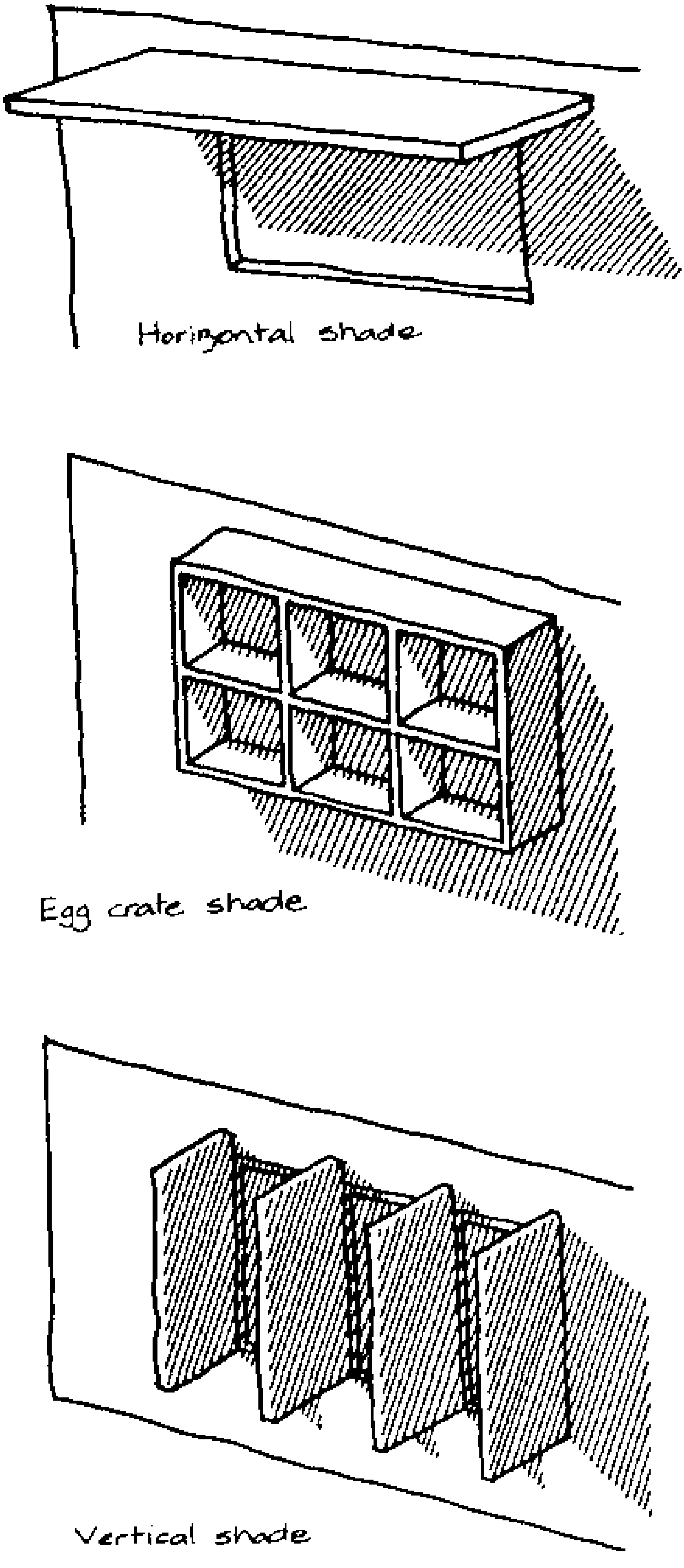


Figure 85. Examples of geometric shading forms

For the convenience of detail design, external shading for buildings can be classified as being vertical, horizontal or a combination of the two. The range of possible designs is limited only by imagination and appropriate materials.

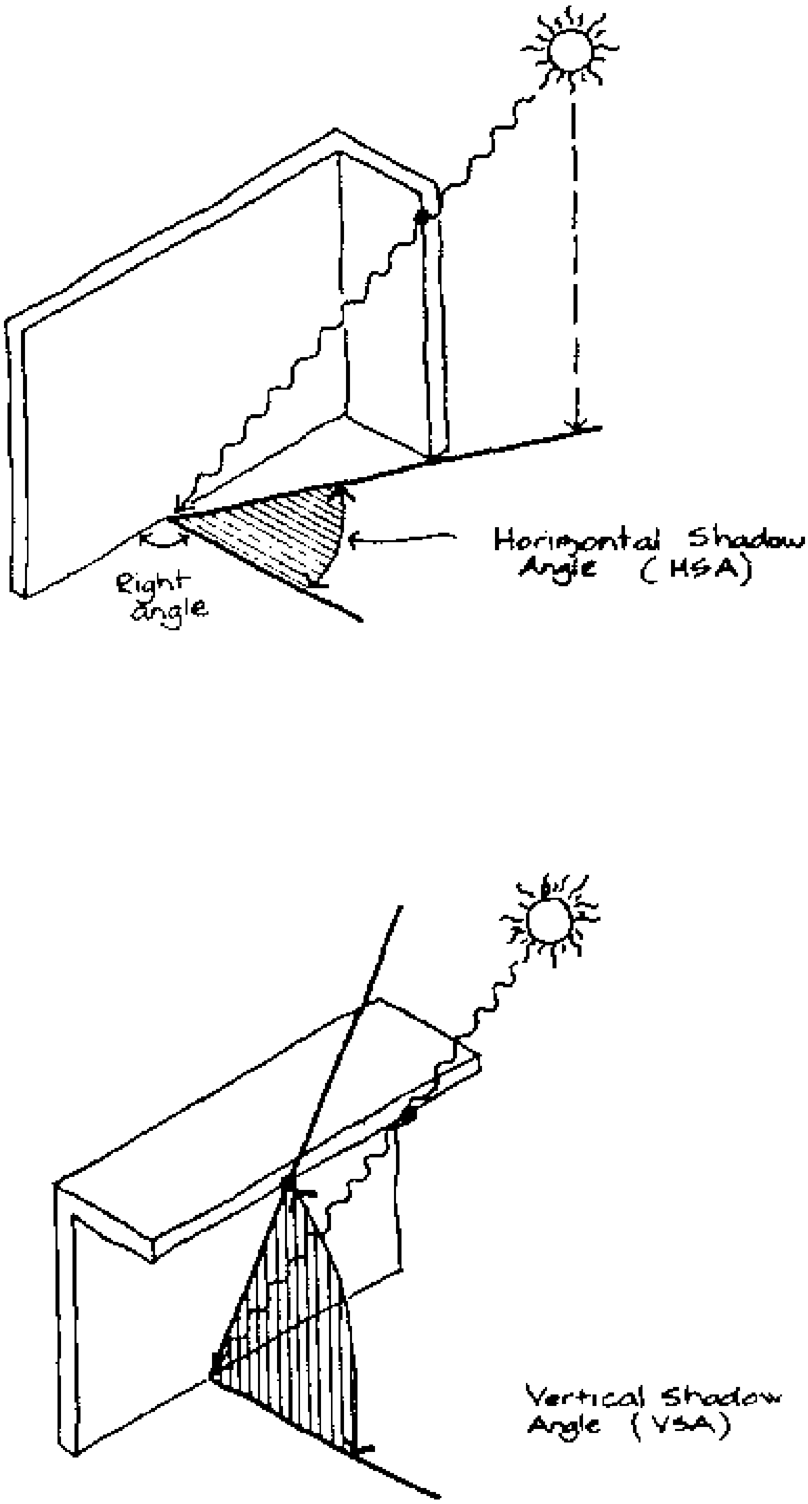


Figure 86. Horizontal and vertical shadow angles

The colour and heat storage capacity such devices will also contribute to the control of the environment adjacent to the windows. In theory shading devices of heavy materials will store heat during the day and help maintain a warmer environment near the windows when the air temperature drops. Whilst this may be desirable in cool winter areas it may not be desirable in hot arid areas. Light−coloured surfaces may cause more radiant energy to be reflected into the openings; with this will come daylight and perhaps unwanted glare.

The calculation of the cut−off lines for any shading device is important in the detailed design and so one must first determine the horizontal shadow angle (HSA) and the vertical shadow angle (VSA). This information is available from many sources including available computer programs. Using the shadow mask provided with most sun position charts it is a simple matter to read off the appropriate values.

In most locations in Australia, except for the cool−temperate areas, it is desirable to be able to exclude summer sun at all times. During the cooler periods of summer a little early morning sun may be acceptable and to some people even desirable. Consider carefully the use of the building being designed and especially the spaces associated with the shading under consideration. For example, some early morning sun may be desirable in bedrooms and bathrooms provided it is excluded for the rest of the day. Such sun in hot weather would be most undesirable in living areas which will be used late into the evening.

Buildings facing true north are easiest to shade as the sun path across them is symmetrical and seasonally manageable with simple horizontal projections. Such projections do not generally hamper views and the psychological connection with the outside. If the projection distance is correct there is effective blocking of sun in summer and minimum obstruction in winter.

The further the façade faces towards the east or the west, the more difficult it will be to provide fixed seasonally−effective shading. The workable solutions require a combination of horizontal and vertical elements. If the façade faces north−east then, unlike a north−facing facade, it is extremely difficult to obtain an optimum solution with a fixed shading system.

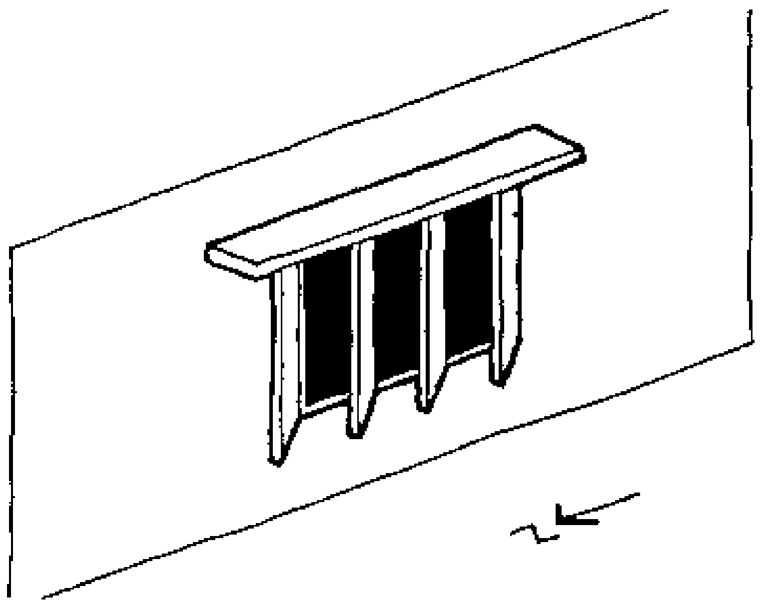


Figure 87. Vertical blade shading for east or west facades

The east−facing facade requires a vertical style of shade to block low altitude radiation. The sun around the middle of the day is high in the sky and so easier to block. Unfortunately appropriate vertical shading for east− and west−facing fact aces tends to defeat the purpose of the window as the view out is disrupted and restricted by such devices. Adjustable devices are therefore more attractive except that maintenance becomes an important issue.

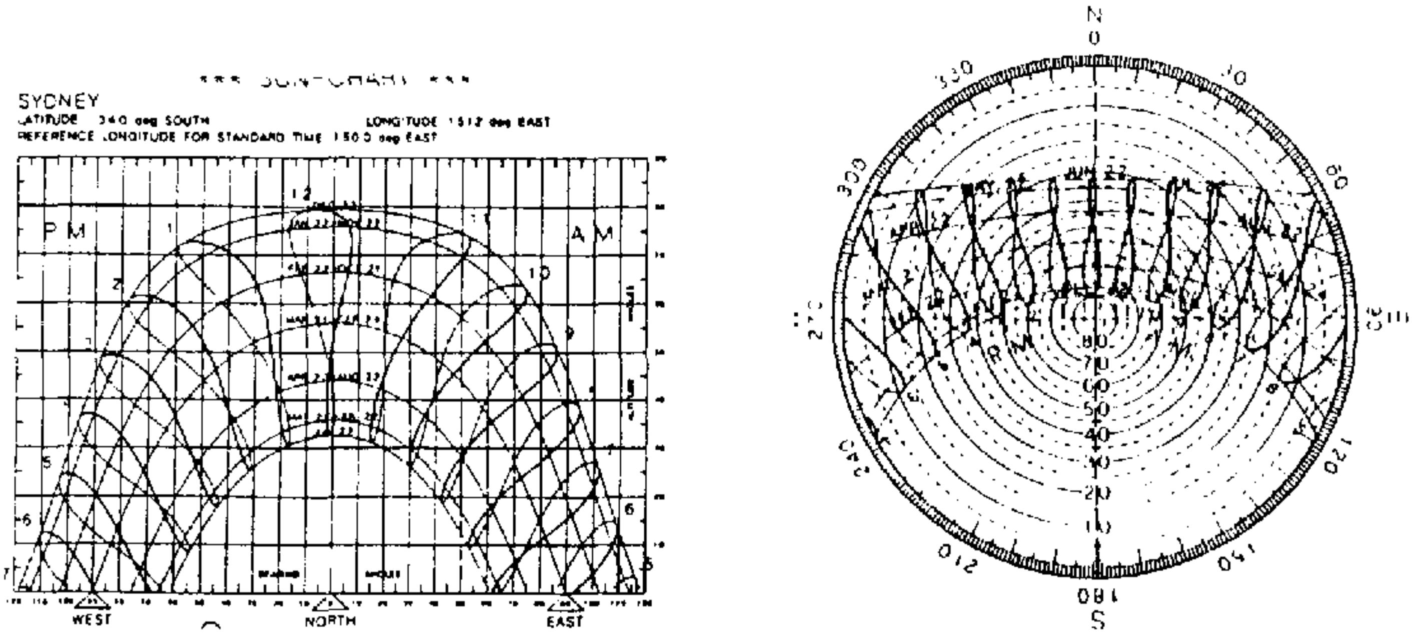


Figure 88. Two types of sun charts available for use in Sydney

Suitable adjustable shading devices for non−north−facing shading devices include canvas or aluminium lath roll−down awnings, retractable timber or metal external−quality venetian blinds, and metal roller−shutter type units especially designed for external window use. Where fixed awnings are acceptable the most satisfactory solution is to use vertical blades turned towards the north and capped at the top as shown in figure 87.

Selected solar charts for use in Australia are provided in the annexes at the end of this book. More extensive information is provided by Phillips and also by Hassall.

In some situations where it is appropriate, a suitably designed shading system can also double as a security screen, thus helping to offset the expenditure against other purposes. The commercially available roller−shutter units fulfil this role as would a suitably designed louvre system.

When designing or selecting a shading system, it is important to consider the sources of energy to be blocked and the projected purpose of the rooms or internal spaces being shaded. As discussed in an earlier section, the sun's energy reaches the window mostly by direct radiation which is easily blocked. In addition to this there may also be heat and glare (from visible wavelength energy) from solar energy reflected off surrounding surfaces including the ground outside the window, especially if it is light in colour. Where the windows being treated face in a northerly direction. it is relatively easy to shield the ground and the windows by extending the horizontal overhang in some form. This extension should be designed to be removed or otherwise made ineffective in winter (deciduous vegetation, adjustable louvres or removable fabric would achieve this goal).

The studies conducted by researchers in Europe where sun intensities are not as high as in Australia indicate that even grass surfaces in direct sunlight all day reach as much as 10C higher than shade air temperature. If the surfaces were paved with either concrete or bitumen then they could easily rise to 20C above shade air temperature.

The fixed shade element should be large enough to provide the protection needed to surfaces below whilst allowing maximum penetration of the sun in midwinter. The choice of materials and the exact dimensions must be appropriate to the building design. Table 11 gives some suitable permanent and summer−only projection factors for north−facing facades. Such values can be applied without modification to façades facing up to 15 either side of true north. They can be applied to facades a little outside this range where there are tall external obstructions to the east or west as appropriate, such as trees or neighbouring buildings. Facades outside this range should be dealt with individually by calculating the shading effect of the treatment proposed. As the larger shade elements covering external surfaces will also provide more suitable outdoor living spaces. it is important to consider whether such shade protection should also give rain protection to the covered outdoor space.

8. Climate−specific recommendations (a) Cool−temperate

Shading must be designed to allow maximum winter sun penetration and partial sun penetration at other times except during hot summer spells. To achieve this there must be flexibility in the design. as certain times of the year both options may be required depending on the specific weather conditions at the time. As a guide the shading should totally exclude the sun in the warm to hot months (beginning of October to mid–March). The overheated days outside that time will have a reduced effect on the interior as the shading is still partially effective.

Glazing type	Visible light		Solar heat gain coefficient (SHG)			Total heat transfer	Shading coefficient
	Transfer	Reflected	Reflected	Absolute	Transfer	(percentage)	
Single clear glass (6mm)	88	8	7	13	80	83	0.95
Double-glazing (6mm + 6mm) (clear glass) 12.5mm air space	76	14	11	25	64	72	0.83
Single-glass grey-tinted heat-absorbing 6mm	43	5	5	48	47	61	0.69
Single-glass bronze-tinted heat-absorbing 6mm	51	5	5	46	49	62	0.71
Double-glass grey-tinted (one sheet tinted) 6mm + 6mm	37	6	7	56	38	49	0.56
Single-glass blue on clear heat-reflecting 6mm	21	20	20	65	15	30	0.35
Single-glass silver on grey heat-reflecting 6mm	15	8	10	76	14	34	0.39

Table 11. Values of solar heal transmission (infra–red) and visible light for various glass types

(b) Hot–arid

Shading is more clear–cut in this climate zone. It is vital to maintain maximum shade from late spring through summer to early autumn. As the winter Is usually colder than In the cooltemperate areas (due to longer periods of clear skies and cold driving winds) it is most desirable to maximize winter sun penetration. The use of removable shade extensions is possibly more appropriate as the change from one season to another is more clear–cut. In this climate zone it is beneficial to shade the walls of the building, especially where the outer skin has a heat–storage capacity. such as brick or concrete (external walls must be insulated).

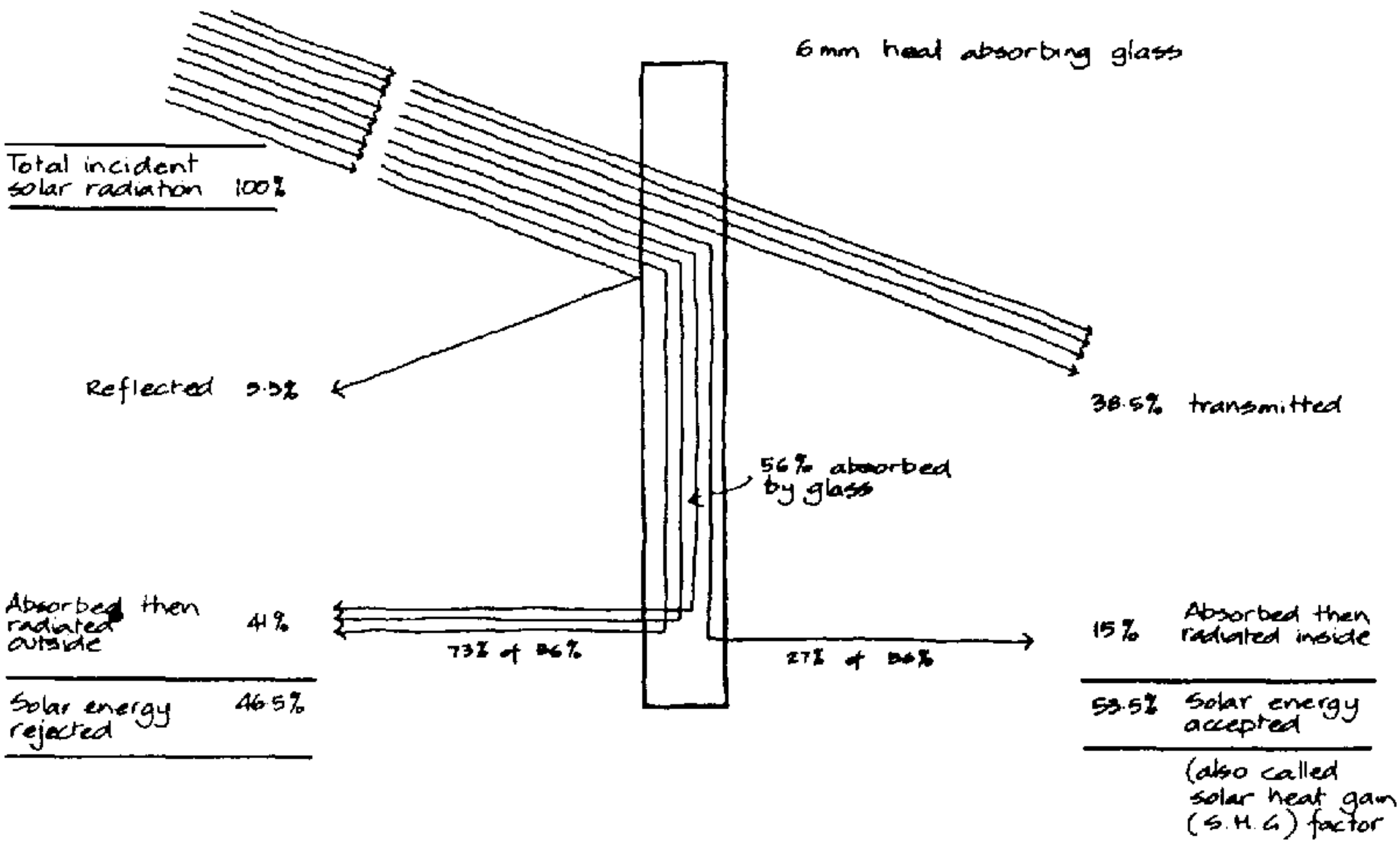


Figure 89. A breakdown of how solar energy passes through 6−mm heat−absorbing glass.

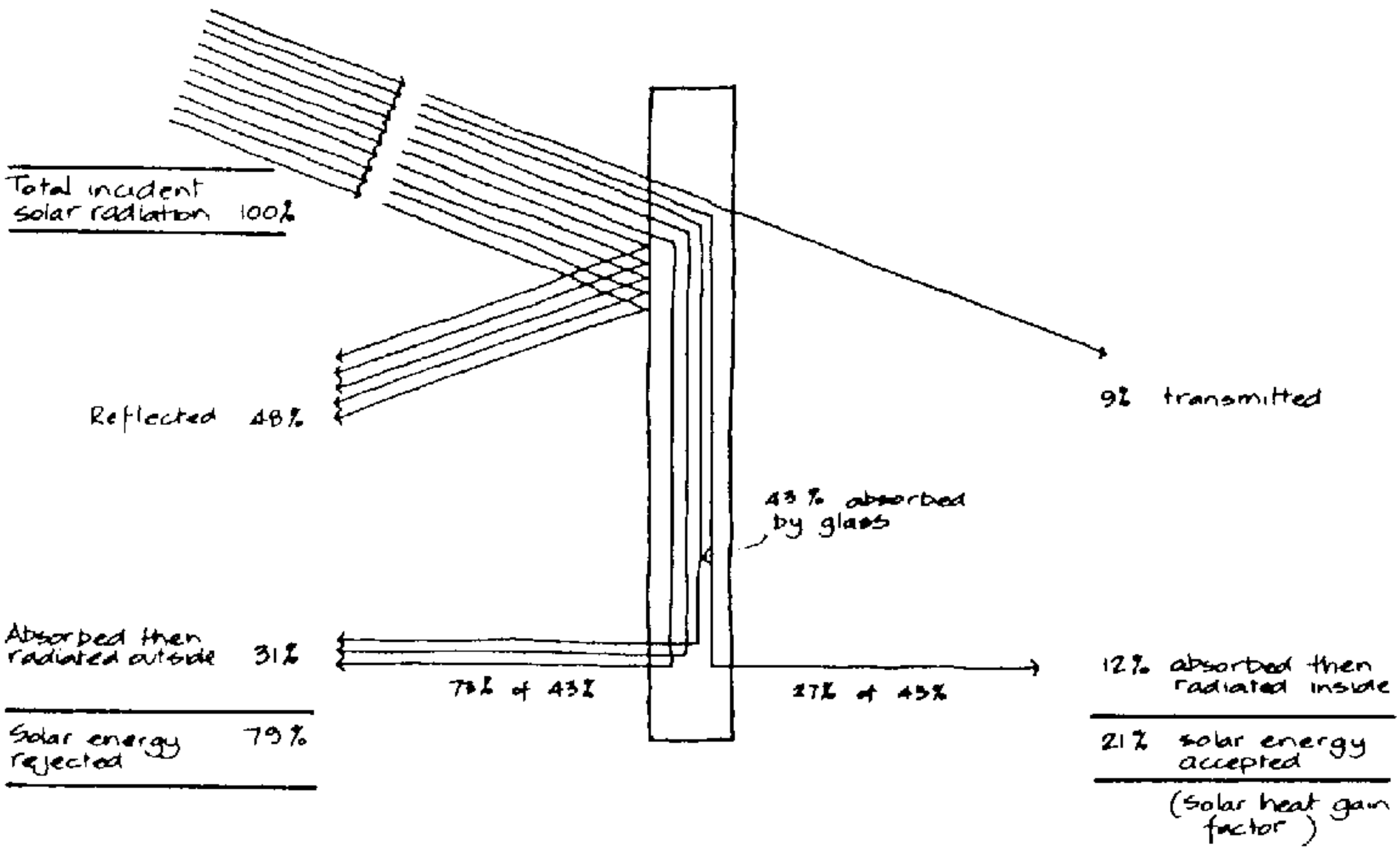


Figure 90. A breakdown of how solar energy passes through 6−mm heat− reflecting glass.

(c) Warm−humid

This climate zone is characterized by wet warm periods with extremes of humidity levels and the lack of a cold season. Extensive shading to exclude the sun all year round without impediment to ventilation and air movement is most important. As these areas tend to be in the low latitudes the sun's path is usually high (refer to sun charts for latitudes below 20) and so the shading of the east and west façades requires the most attention. Extensively shaded areas can also be beneficial as outdoor living space in these zones.

9. Design of glass and window systems (a) Treated glass

An alternative to external shading is the use of tinted or reflective glass that reduces the amount of solar energy transmitted. The use of such an approach to window design is that the available daylight is also reduced. In cases where winter sun penetration is desirable, such glass is not appropriate. However on east− and west−facing facades, treated glass may be the best solution. Table 11 shows the transmission characteristics of a selected range of glass available in Australia.

The technical aspects of the transmission of solar energy through glazing has been described earlier in this book. Each glass type can therefore be described by its shading coefficient, but the difference between the transmitted solar heat and the transmitted visible energy (daylight) should be noted: both must be considered.

If the use of tinted or reflective glass is planned then the day−to−day use of the enclosed spaces must be considered. The quality of light is altered by such glass to the extent that interiors tend to be dull and lacking in daylight at all times. In winter and on dull days this may be considered undesirable in terms of user expectations. Whilst such glazing may reduce glare on bright days, it takes away much of the wonderful dynamic quality of daylight that is available to the designer for modelling interiors. The designer must use such glazing materials with great care. It should be noted that building codes in most parts of Australia limit the visible reflectance of such glass to approximately 20 per cent.

The treated glasses available can be grouped as follows:

(a) Heat−absorbing glass (usually appears tinted with colour throughout) comprising interference particles within the glass. Solar energy is intercepted and absorbed by the glass causing the temperature of the glass to rise. This effect can also be achieved with a range of tinted films or coatings applied to the glass surface (often used to reduce radiant energy transmission in motor car windows). The heat absorbed by the glass is reradiated to both the interior and exterior. This often causes discomfort to nearby occupants in hot climates as they sense a hot surface radiating heat toward them. The relative effectiveness can be seen in a comparison of the absorbed component compared with the reflected component. Figure 89 illustrates the distribution of energy as defined by ASHRAE for a typical sample of heat−absorbing glass.

Table 12. Thermal of various glazing types

Glazing		Heat transmittance U−value(W/m² .degC)	Solar heat gain coefficient (SHG)	Solar shading coefficient (SC)
Single 3−mm glass	e = 0.87.	5.9	0.88	1
Double−glazing 12's−mm air space	e = 0.84	3.2	0.79	0.90
Double−glazing 12.5−mm air space	e = 0.2	2.2	0.76	0.86
Low emittance	e = 0.4	2.6	0.76	0.86
Single−glazing(t = 0.77)	e = 0.6	2.8	0.77	0.87
Low emittance	e = 0.1	3.1	0.79	0.90
Single tinted glass	e = 0.2	3.5	0 79	0 90
Visible transmission 0.2	5.9	0.39	0.45	
Single reflective glass	e = 0.6	4.8	0.33	0.37
Visible transmission 0.2	e = 0.2	3.5	0.24	0.27

(b) Heat−reflecting glass has a mirror like appearance due to an interference coating of finely divided metal particles deposited on one surface (usually the surface to the inside to reduce abrasion of the coating). Solar energy−striking this glass is mainly reflected rather than absorbed. It is widely used in air− conditioned commercial buildings to reduce solar gain. Unfortunately as with heat−absorbing glass it reduces transmitted daylight also. It is not appropriate in certain applications where the building occupants expect to see out at night (i.e., hotels and executive rental space in the top floors of high−rise commercial buildings). Whilst it appears reflective from the outside in the daytime, it reverses at night giving the outside observer an excellent view of the interior and the occupant a mirror−like window.

(c) Low−emissivity glass (low−E glass) has been developed in recent years to reduce the transmittance of heat energy (infra− red) whilst maintaining the radiant transmission of solar energy. Such glass is normally used in a double− or triple−glazed situation where a low emissivity coating is located on one surface inside the unit to reduce the radiant transmission across the air space from the warmer glass layer to the colder layer. This glass can be used to reduce either heat loss from inside a building or heat gain from outside (in hot climates).

(d) Electrochromic glass. New coatings are being developed that allow the building user to vary the transmission characteristics in much the same way as some people have spectacles/hat darken in direct sunlight (they are known as photochromic). The electrochromic glasses are controlled by the application of an electrical charge across the coating thus making them opaque to selected energy wavelengths. Such products are already at the laboratory stage and should be available for use in buildings in the next few years.

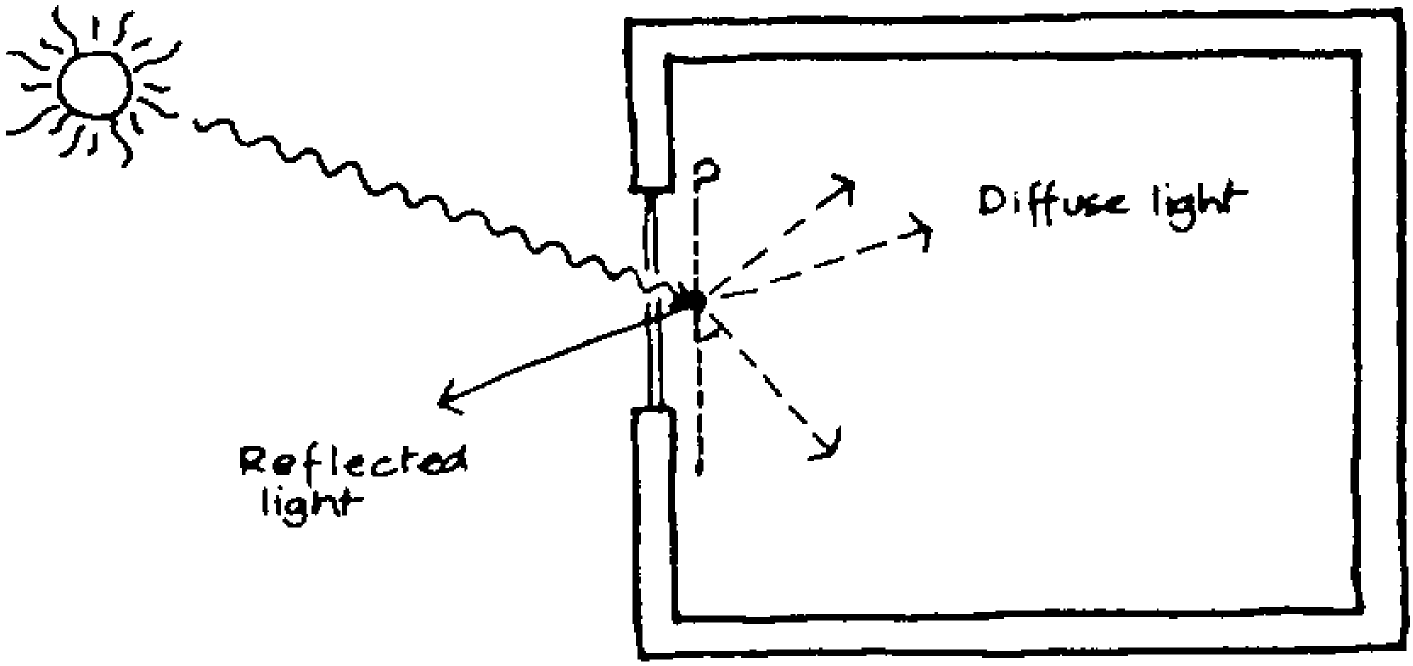
(b) Combination window systems

Multi−layered glazing systems with adjustable shading between the glass layers have been in use for many years. They have been widely used in east− and west−facing glazing of airconditioned commercial buildings. Whilst such systems work, they are dependent on the occupant or the floor maintenance staff for the day−to−day adjustment. If the occupants on the east side of a building forget to close their shading system before they go home in the evening, the air−conditioning system has to cope with the additional load of the early morning sun. This is a serious problem in many commercial buildings where the airconditioning system has been designed on the assumption that the shades will be in place. It is also generally found that maintenance is high on such shading systems with moving parts.

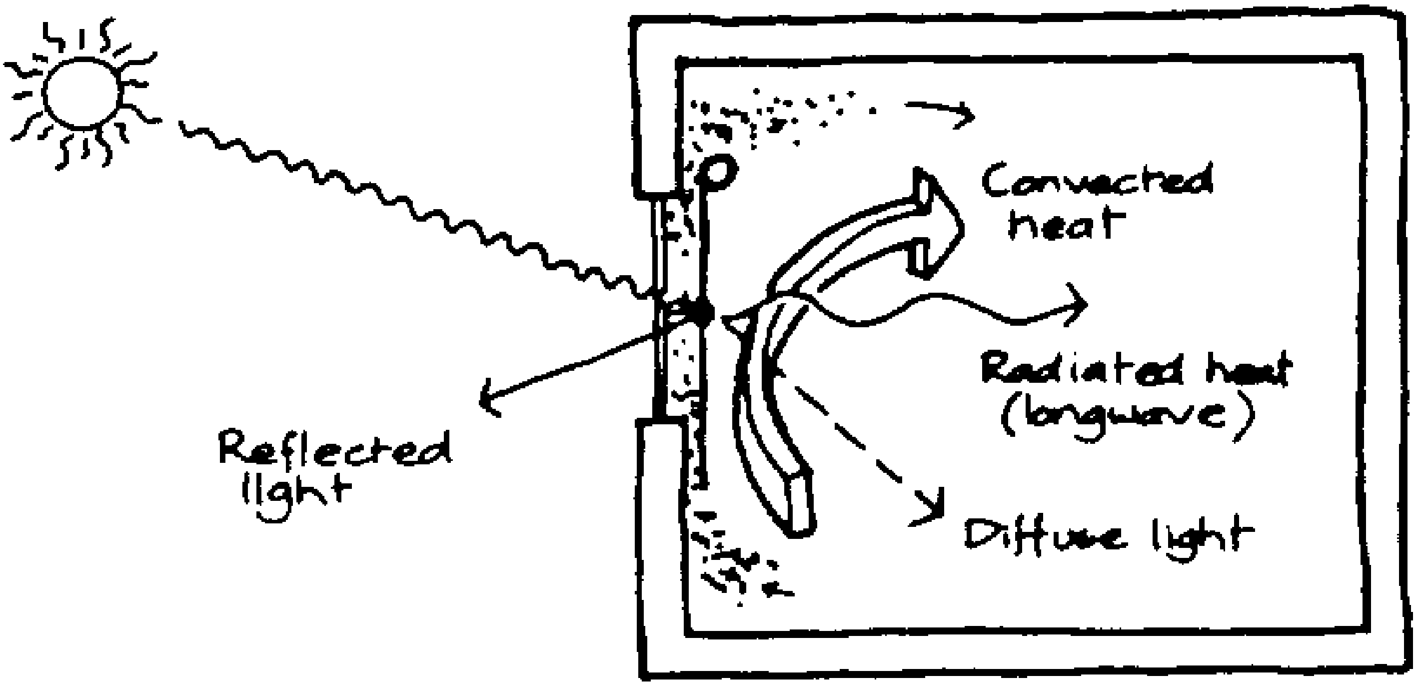
A wide range of shading devices have been tried inside window units from conventional venetian blinds to roll−down reflective films etc., either manually controlled by the occupant or automatically controlled by a computer system. In a study of the latter case in a city building it was found that there would have to be 80 electric motors per floor to drive the shading system, requiring a full−time maintenance person just to keep the motors running.

10. Interior window treatments

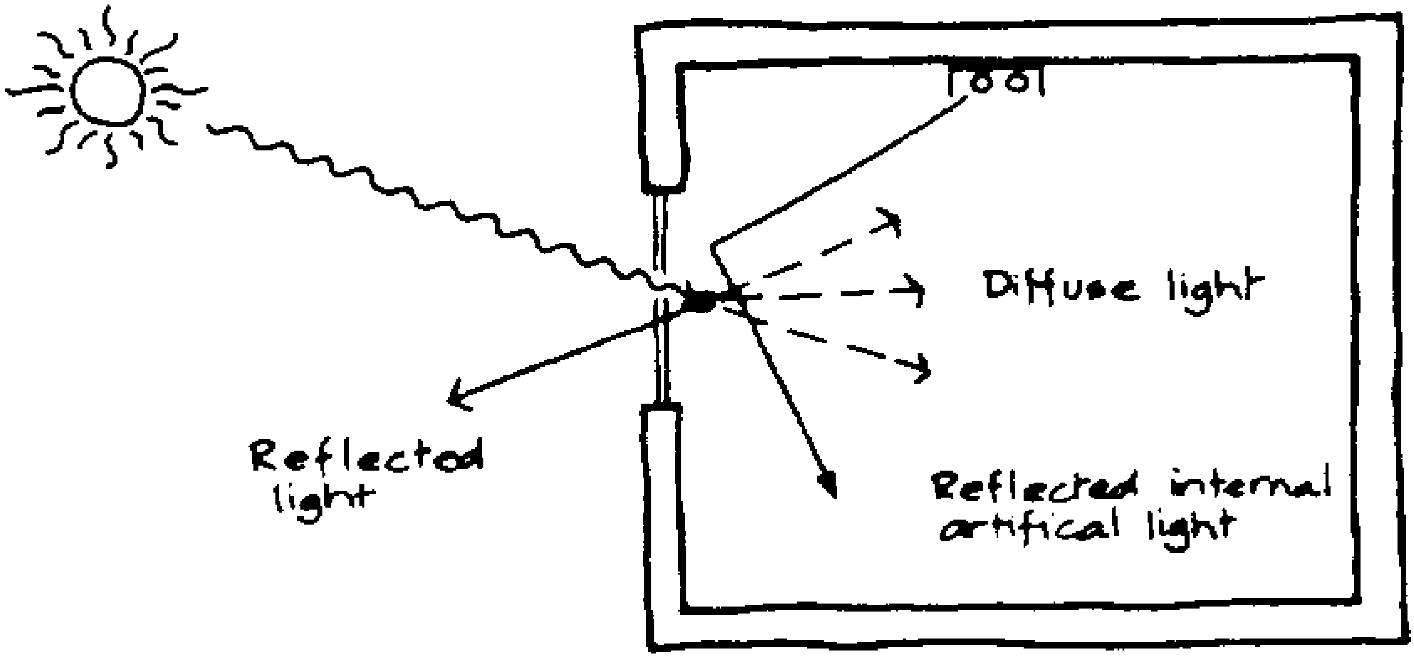
Interior window treatments are generally the least effective in terms of rejecting solar energy. Once the sun's heat has penetrated the glass, it is difficult to ensure that enough is reflected back out as approximately 13 per cent of the energy transmitted through conventional window glass is absorbed by the glass. Even if 100 per cent is reflected off the interior blind or curtain then a further 11 per cent is absorbed into the glass on the return journey out. Usually the best an interior linings can achieve in terms of reflectance is less than 90 per cent. i.e., more than 32 per cent is then trapped. A good exterior shade can stop 80−90 per cent and still provide a view out.



Interior light−coloured blind. More diffuse light enters the room and more heat Is reflected outside (say 70 per cent compared with 5 per cent for the dark blind). It is only half as good at stopping heat getting into the room compared with the dark blind. with a shading coefficient of 0.4



Interior dark blind. This stops the sun directly striking the Interior of the space. Being dark it absorbs heat and only reflects 5 per cent of the incoming heat to the outside. The absorbed heat still gets into the room via convection and radiation. The room will be dark and there is very little diffuse light. The shading coefficient is about 0.8



Aluminized light coloured blind. The surface looks dark (90 per cent of external light is reflected outside) but it is reflective to Internal artificial light.

Figure 91. Thermal transmittance for some commonly−used interior window treatment.

Where such treatments are required to exclude solar radiation they will also restrict ventilation. This may be undesirable. Any energy not reflected off the fabric will be absorbed, causing the surface temperature to rise and radiate energy into the room.

Interior window treatments can vary from the simple holland roller blind to a most sophisticated semi−transparent material with metallized reflective backings or curtains with padded linings to reduce conductive heat flow. The range of fabrics available with alumined coatings are often highly reflective on the window side. The fabric is perforated or loose woven to provide a fine mesh of holes for vision out. The total area of holes can be as little as 10 per cent if they are very small and sufficiently close together to give excellent vision. The costs are as varied as the types and styles. Table 13 illustrates the shading coefficients and figure 91 gives the thermal transmittances for a range of commonlyused interior window treatments.

The hot air trapped between the glass and the fabric will be transported to the room behind by convection unless adequate provisions are made to restrict such flow, as discussed later.

11. Shading coefficients

To evaluate the effectiveness of a particular approach to shading or to compare a range of solutions, it is necessary to have a common standard. One such measure is the property known as the shading coefficient.

Where the reduction of solar gain is desirable in summer but not in winter, some type of adjustable or removable shading should be chosen for north glazing. Where east or west windows are unavoidable then reflective glass may be the most suitable choice to reduce summer solar heat gain. The shading coefficient concept can be used to rate various types of window−shading techniques, the values being used in various thermal evaluation methods or simply to compare the worth of different window treatments in regard to reduction of solar gain.

Table 13. Typical values for coefficients of some window systems

Window system	Shading coefficient (SC)
3−mm clear sheet glass unshaded	1.00
3−mm clear sheet glass with the following:	

Inside dark roller shade completely drawn	0.80
Inside dark venentian blind fully drawn	0.75
Inside medium venentian blind fully drawn	0.65
Inside medium roller shade full drawn	0.62
Dark−coloured drapes fully drawn	0.58
Averooe tree casting shade	0.60−0.50
Inside white Venetian blind fully drawn	0.56
Inside white roller shade fully drawn	0.41
Light−coloured drapes fully drawn	0.40
Outside vertical fixed fins on east/west	0.31
Outside canvas awning	0.25
Overhang. continuous on north side	0.25
Dense tree casting shade	0.25−0.20
Outside venetian blind	0.15
Outside movable horizontal or vertical louvres	0.15−0.10
Heavy drapes with white linings and folds	0.35

Note: For reflective film on glass chechk the relevant data available from the manufacturer and calculate SC for particular reflective film selected.

Values of unfed and reflective glasses available are given in table 11.

C. Control of conductive heat flow

The rate at which heat will flow into or out of a structure is dependent on the temperature difference between inside and outside and the resistance of the various heat paths (as stated before). The designer really only has design control over the latter. The basic units and equations were introduced in chapter III including an explanation of transmittance (U−value) through homogeneous materials and groupings with air cavities such as a brick veneer wall.

In this section the concept of steady−state heat flow and quantity will be discussed.

1. Steady−state heat exchange

The flow of heat through an element (wall, roof, floor etc.) between two different temperature conditions that remain steady can be described as follows:

$$Q = U \times A \times \left(\overline{T}_i - \overline{T}_a\right)$$

where

Q = Heat flow rate (W)
A = Area of element (m²)
(T_i − T_a) = Temperature difference (degC)
U = Transmittance (W/m² .degC)

The steady−state equation is true for conditions that do not vary, but in reality the temperature is continuously varying. The mean temperatures of each side of the element over a number of cycles can be used as an approximation of a steady−state for most purposes. This approach is widely used for simple estimations of heat flow.

Worked example No. 3

Assume the mean monthly ambient temperature. in June Is 12.7C and the inside mean temperature is 21 C. Then the temperature difference (21C − 12.7C) = 8.3 degC. The average heat loss rate through a 5−mof brick wall with render and plaster (U−value 2.3 W/m.degC) through June will be.

2 Total heat losses over time

So far attention has been paid to instantaneous values of energy flow and from this can be calculated the rate of energy flow into or out of a building. Assume a set of conditions as follows: the June mean daily temperature in Sydney is 12.7C: the building to be constantly heated to 21C with a thermostatically controlled heating system. This will create a steady state inside and so make calculations a little simpler.

The temperature difference At = 8.3C (21 12.7) and the average rate of heat flow (Q) = the U−value (U) × the area (A) × the temperature difference (At)

The steady−state heat−flow formula is Q = U × A × at, which, being a rate and not a quantity allowance needs to be made for time to make the formula represent the quantity of energy over a specific time. So if Q = U × A × Dt then:

G (Wh/m²)	= U (W/m²) × T (hours) × Dt (temperature difference)
	= 2.54 × 24 × 8.3 Wh/m²
	= 0.5 kWh/day.m²

This is a little simplistic because it does not consider time lag in the materials, which is discussed later in this guide.

Worked example No. 4

What is the average energy saved per day in August if it is decided to insulate 25m² of brick−veneer wall? (Assume the mean indoor temperature to be 20°C.) Choose double−sided reflective foil as the insulation material, fixed to the outside of the timber frame (providing two reflective air−spaces.)

Uninsulated brick−veneer wall

U−value = 1.98 W/m² .degK

Double−sided foil insulated brick−veneer wall

U−value = 0.66 W/m² .degK

Calculate the heat loss per day;

$$H_{24} = U \times A \times (\overline{T}_i + \overline{T}_a) \times 24 \times 3.6 \times 10^{-3}$$

Therefore the heat saved per day is:

$$H_{sav} = (U_1 - U_2) \times A \times (\overline{T}_i - \overline{T}_a) \times 24 \times 3.6 \times 10^{-3}$$

= (1.98 – 0.66) × 25 × (20 – 12.9) × 24 × 3.6 × 10^{-3}
= 20.24 (rounded off)
= 10Mj/day.

Where T_o is the mean indoor temperature and T_a is a mean daily temperature.

3. Degree−day concept

The term "heating degree days. refers to a measure of the severity of a particular climate in terms of heating to maintain thermal comfort. It has traditionally been based on a comfort level of 21 °C inside a building. In very simple terms, the amount of heat required to keep a building at that temperature will be a function of the external temperature, the amount of solar radiation entering the building and any internal gains from appliances etc., and the resistance of the external shell of the building. It has been found that the average effect of solar radiation on the temperature of a typical house is to elevate the mean internal temperature by about 3°C. On that basis it is assumed that heating would only be required if the external temperature fell below 18°C. This is a very simplistic view but it does provide a useful technique to approximate the heating load of a building. Heating degree days also permit a comparison of the severity of the winter of one place with that of another. A method of calculating the number of heating degree days for a location is described below.

The so called steady−state heat loss calculation as discussed above is only valid when a number of temperature cycles are considered, i.e., a number of days, a week, a month or a full heating season. To consider a period of a month or the full heating cycle it is convenient to use heating degree day values instead of the difference in the mean daily temperatures in the above calculation.

In Australia heating degree days are taken to a base of 18.3°C, although there are some that use a base of 15°C. This handbook presents two methods to evaluate the heating loads of a simple building; the solarch energy performance evaluation and the solarch thermal evaluation method "C". These were prepared to assist designers who did not have access to computers and sophisticated programs. The first is based on the use of heating degree day values and method "C. on a more complete knowledge of the weather data for a particular location, especially the daily amounts of solar radiation received. Heating degree day methods do not give as accurate an answer as those using sol−air temperatures (solarch method "C"), however they are quicker and can be used for simple comparisons of one construction with another. The degree−day values can be determined from basic weather data usually available from the Bureau of Meteorology.

If only the mean daily temperatures for each month are available for a specific location, then the heating degree days for each particular month can be calculated by:

DD = N (18.3− mean daily temperature for month) (where N = number of days in that month)

Example:

July, Sydney: T_a = 11.7°C
that is: 31 × (18.3 − 11.7) = 205 degree days.

The sum of all values for the heating months in Sydney is approximately 732 degree days (some references give 720 as it depends on which station values are given). if the daily mean ambient temperature is not available then it can be estimated by taking half the sum of the daily mean maximum and the daily mean minimum.

Table 14. Heating degree days (Re: 18.3C) for various cities in Australia

Adelaide	1280	Kalgoorlie	1010
Alice Springs	660	Melbourne	1500
Brisbane	310	Tullarmarine	1800
Canberra	2270	Newcastle	770
Darwin	0	Sydney	732
Hobart	2300	Perth	775

D. Evaluation of internal heat loads

The total energy used in dwellings throughout Australia varies largely because of climatic differences. The use pattern for a typical four−person household in Sydney is illustrated In figure 92 while data for other localities can be found in the annexes.

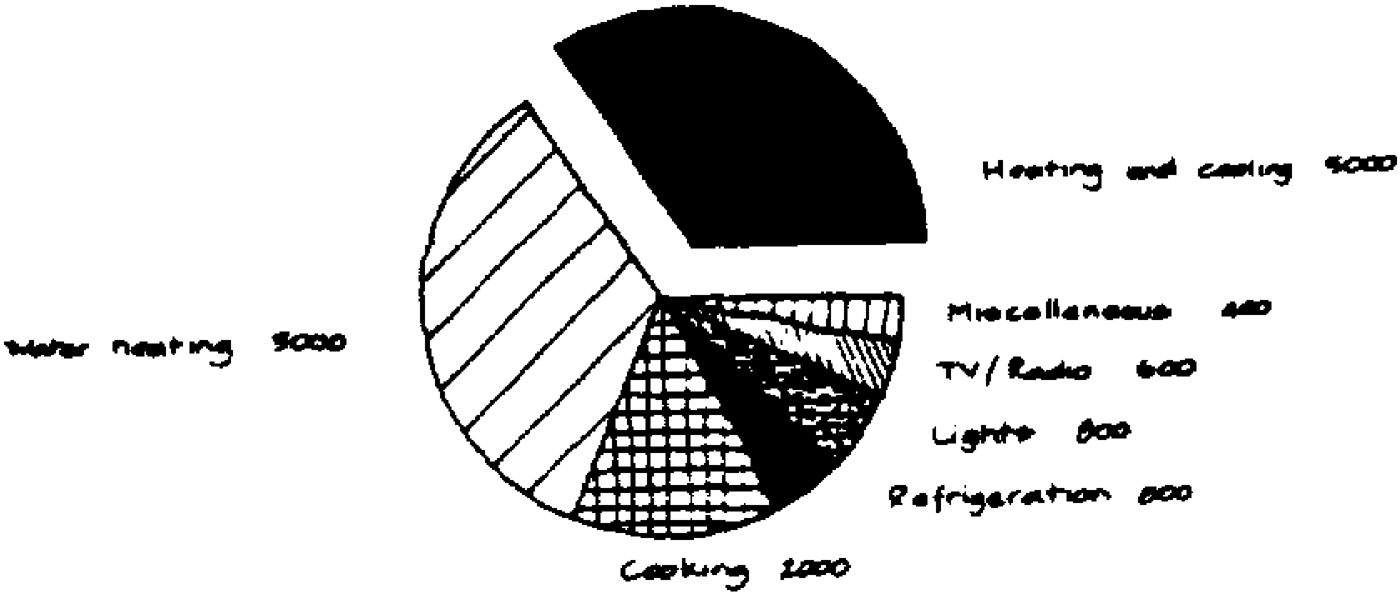


Figure 92. Energy used within the home − Sydney (kWh per annum)

In an energy−efficient building the heat generated inside by the occupants and appliances or equipment in use will compensate for some of the heat lost through the outer fabric. In some of the "super−insulated" houses built in northern Europe and North America, the casual internal heat gain is sufficient to counter the structural heat losses. Very little auxiliary heat is Fresh air is passed through an air−to−air heat exchanger to retain even the heat in the exhaust air.

Table 15. Daily profile of internal heat input from the activities of a tour− person household d. ("Time' is the starting time for the Indicated load, which applies for one hour.)

Time	Living zone (Wh)	Bed zone (Wh)	Service zone (Wh)	Total	Comment
0000	75	225		300	
0100	75	225		300	
0200	75	225		300	
0300	75	225		300	
0400	75	225		300	
0500	75	225		300	
0000	75	225		300	
0700	400	450	800	1650	Breakfast,showers etc.
0800	325		325	650	
0900	100		200	300	Early morning cleaning
1000	150			150	
1100	150			150	
1200	225			225	
1300	150			150	
1400	150			150	
1500	150			1500	
1600	800	200		1000	Children home: cooking
1700	1200	200		1400	
1800	800	100		900	
1900	800	100		900	
2000	800	100		900	
2100	800	100	100	1000	
2200	500	150	650		Bed time

2300	75	225		300	
Total (Wh)	8100	3400	1225	12725	

The magnitude and source of casual internal heat gains will vary from one situation to another. Cultural differences in lifestyle will also impact on energy use. In a typical Australian household the casual internal heat gains can be assumed to be in the order of 8kWh/day in the living zone of a three bedroom−dwelling, with a peak around the time of the evening meal. In mild climates this reduces auxiliary heating for energy−efficient houses. As the stove is the largest single heat source (other than auxiliary space heaters) in the living area, its pattern of use is a key factor in this picture.

The knowledge of internal heat gains is important when determining the thermal behaviour and auxiliary heating and cooling loads of a specific design. Most computer programs require an hour by hour estimate of internal heat gains. Table 15 illustrates the internal heat gains assumed for a typical family home being assessed in the 5−star design rating system, during colder months. Where the maximum outdoor temperature exceeds 27°C the profile should be reduced progressively from 81 00Wh/day to 6670Wh/day when the outdoor maximum is 33°C and above. The reduction should be made to the evening end of the day to reflect the reduced cooking load in warmer weather. The occupancy pattern of the two zones of the building is reflected clearly in the times of significant heat gain.

A table of energy use for a wide range of equipment and domestic appliances is included in annex IV. It must be noted that the main difficulty is to estimate realistic use patterns for these appliances. In many simple evaluations the inclusion of minor appliances is an unnecessary complication.

E. Cross−ventilation and air flow

1. Cross−ventilation and air flow

The ventilation of buildings is mainly influenced by the wind− generated pressure difference across the outside of the building. In the case of openings being at different relative heights it is also influenced by the temperature difference between inside and outside. This latter effect is usually minimal when there is adequate wind pressure for significant cross−ventilation. Design for good cross−ventilation is most important in the design of buildings in any of Australia's climates. It is especially important in the warm−humid climates as it is one of the key strategies for promoting comfort. Unfortunately, it tends to reduce privacy within a building and so a balance must be struck where this is important.

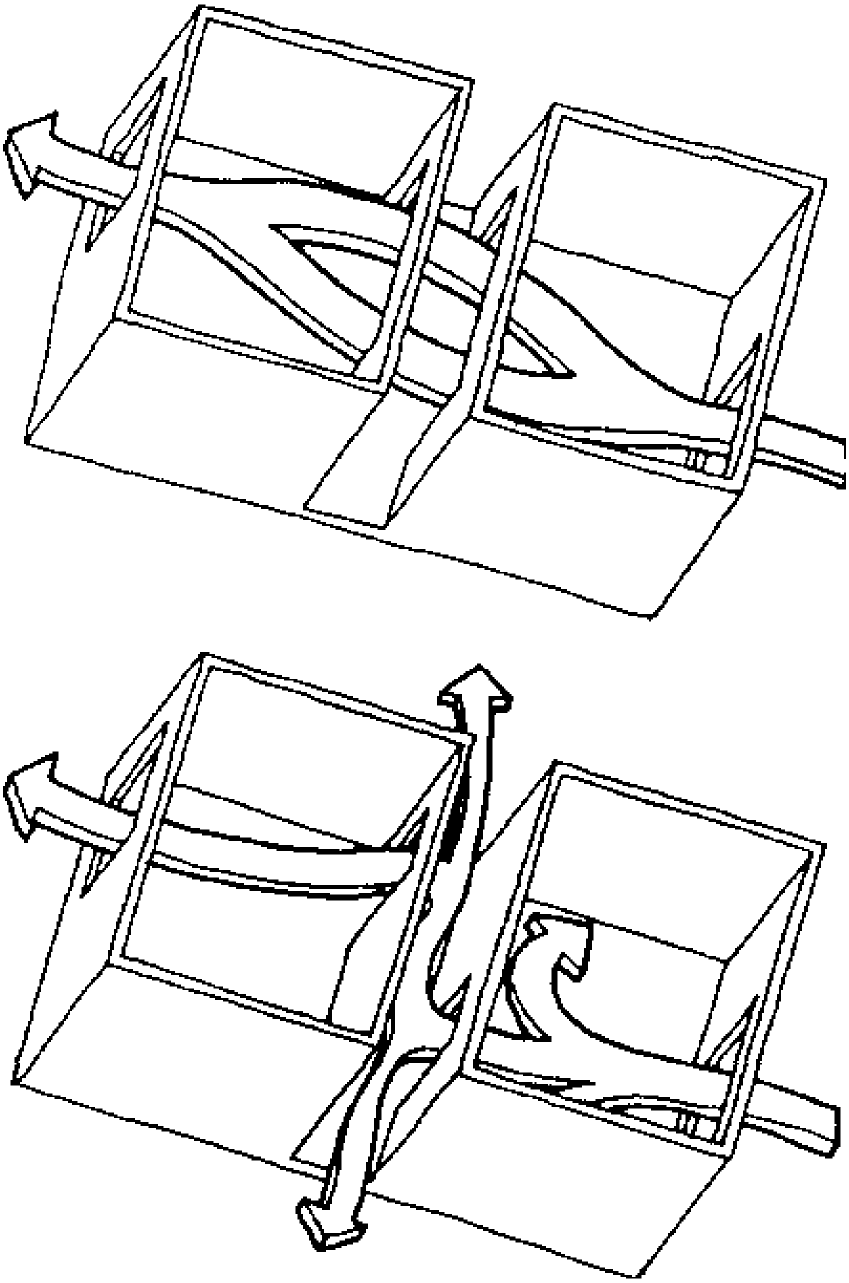
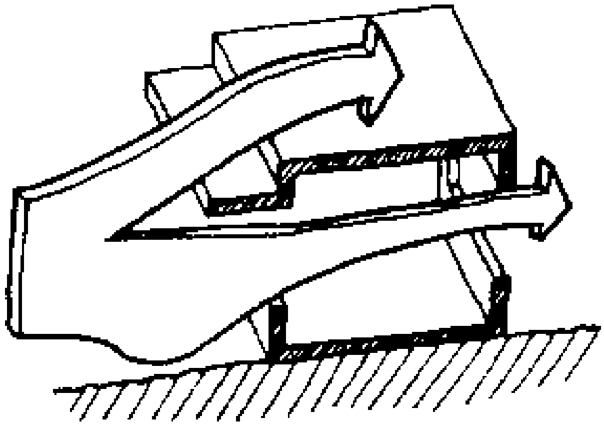
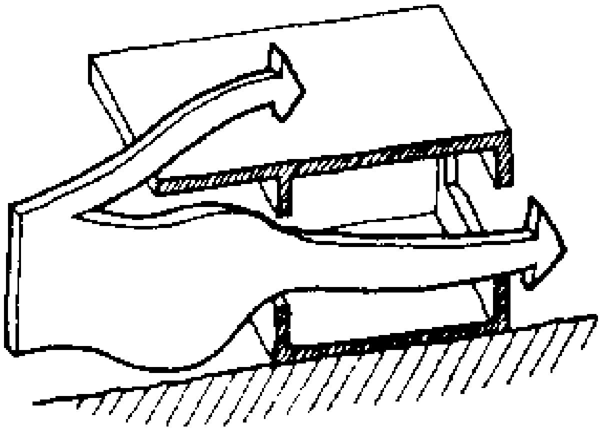


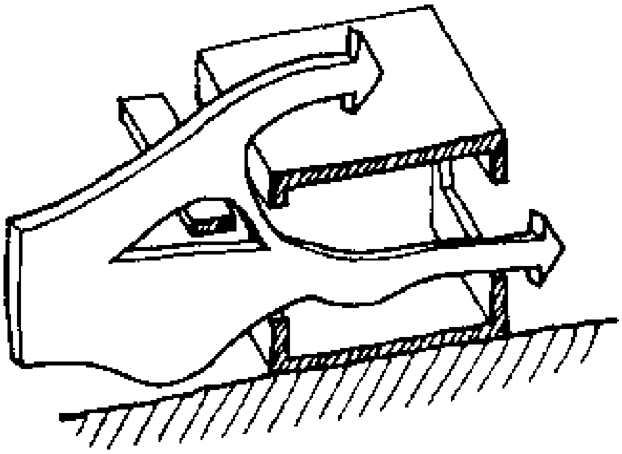
Figure 93. Cross−ventilation − importance of room configuration and position of openings for good air flow

In light winds when air movement is so needed, cross−ventilation will only occur if not hampered by tortuous paths for air flow. Single−sided rooms, which result from restricted paths through a building, are difficult to ventilate unless wind speeds outside are high. Diagrams in figure 93 indicate the possible air flow paths for various enclosures.

External projections made from a variety of materials can be used to direct breezes into rooms as shown in figure 94. Such techniques may well be achieved in the design of appropriate shading devices for such openings.







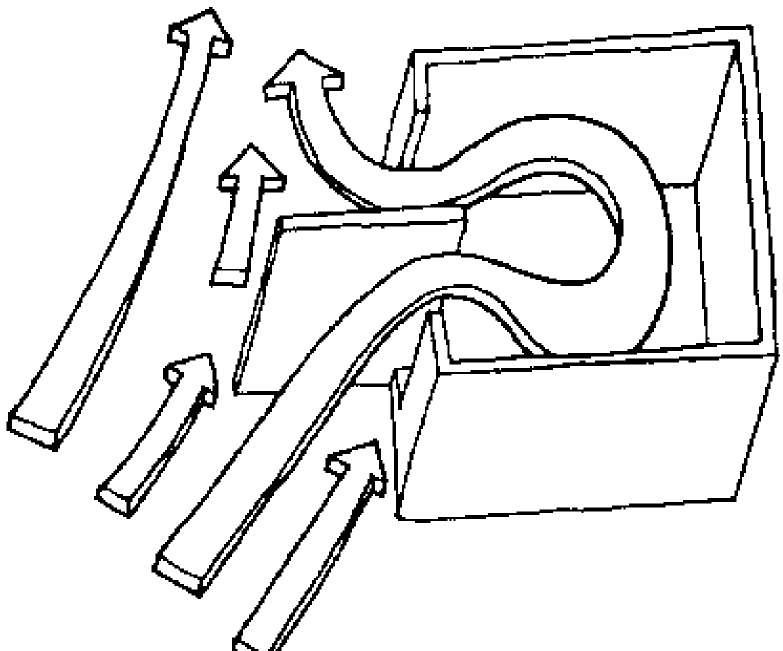


Figure 94. Effects of external projections on the air flow patterns within a building.

It is important from the point of view of ventilation to consider the size of window openings on both the windward and the lee. ward sides. Figure 95 illustrates how the ratio of inlet to outlet will substantially Influence the wind velocity across such a room. It has been found, however, that the wind speed does not increase significantly as the area of the window exceeds 40 per cent of its associated wall area. The larger opening on the windward side causes relatively lower air velocities across the room when compared with a room with the smaller opening facing towards the wind. The volume of air moved in this case will be greater and so rooms with small openings on the windward side and larger openings on the leeward tend to have high velocity air patterns with a poor distribution throughout the room. Such conditions can be annoying as an air movement of 1.5 m/s or greater will cause papers to be blown about.

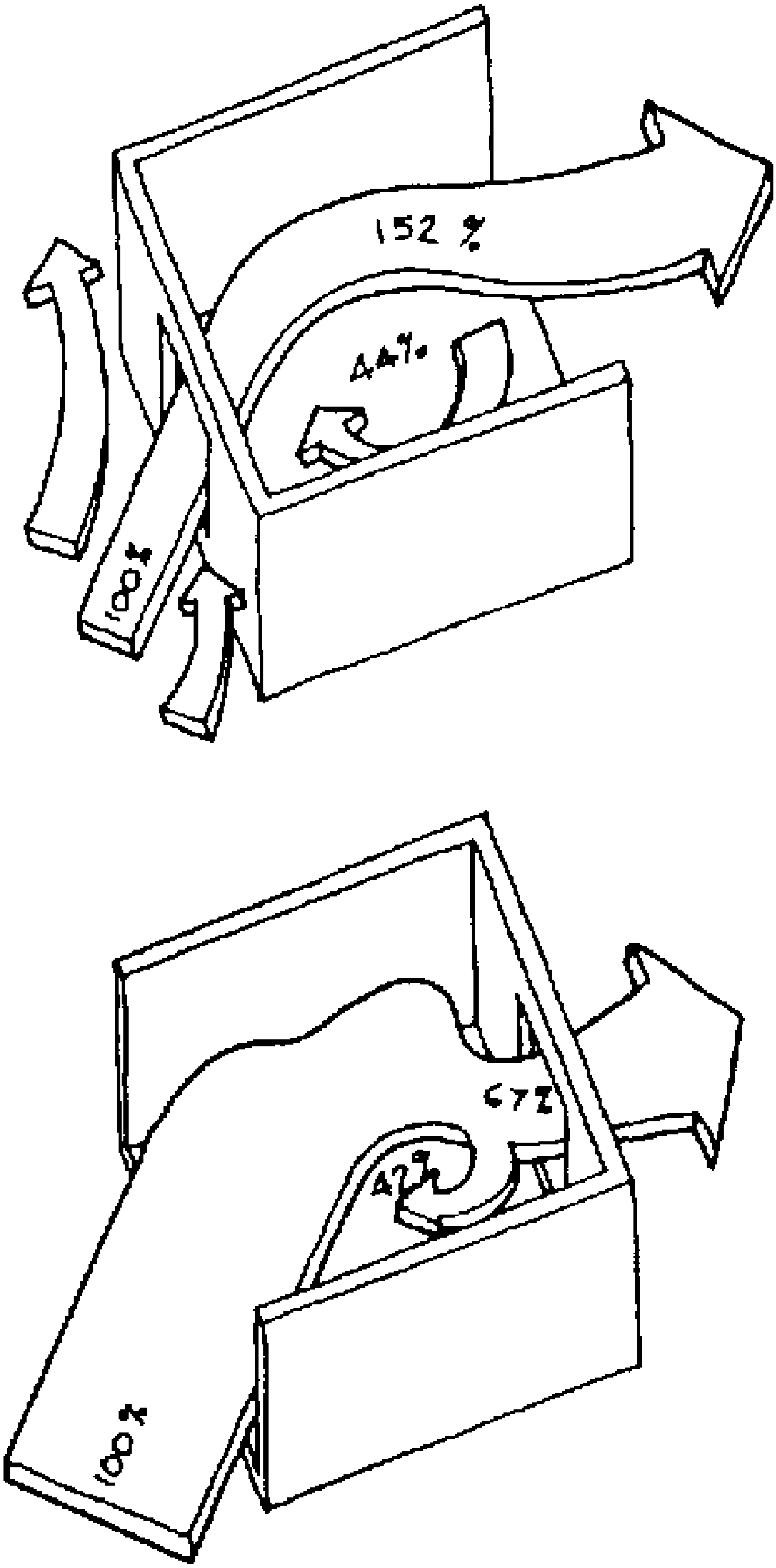


Figure 95. Influence of inlet and outlet ratios on internal air now velocities.

The air flow across a space with openings of equal area on two opposite sides is given as:

V = E.A.v

where

V = air flow in m³/sec
A = area of inlet in m
v = wind velocity in m/s
E = between 0.5 and 0.6 for wind striking the surface normal to the building face

Where the areas of the inlet and outlet differ, the graph in figure 96 can be used to adjust the velocity. It can be seen that the volume of air flow diminishes rapidly as the inlet is made smaller in relation to the outlet. If the inlet is made larger compared with the

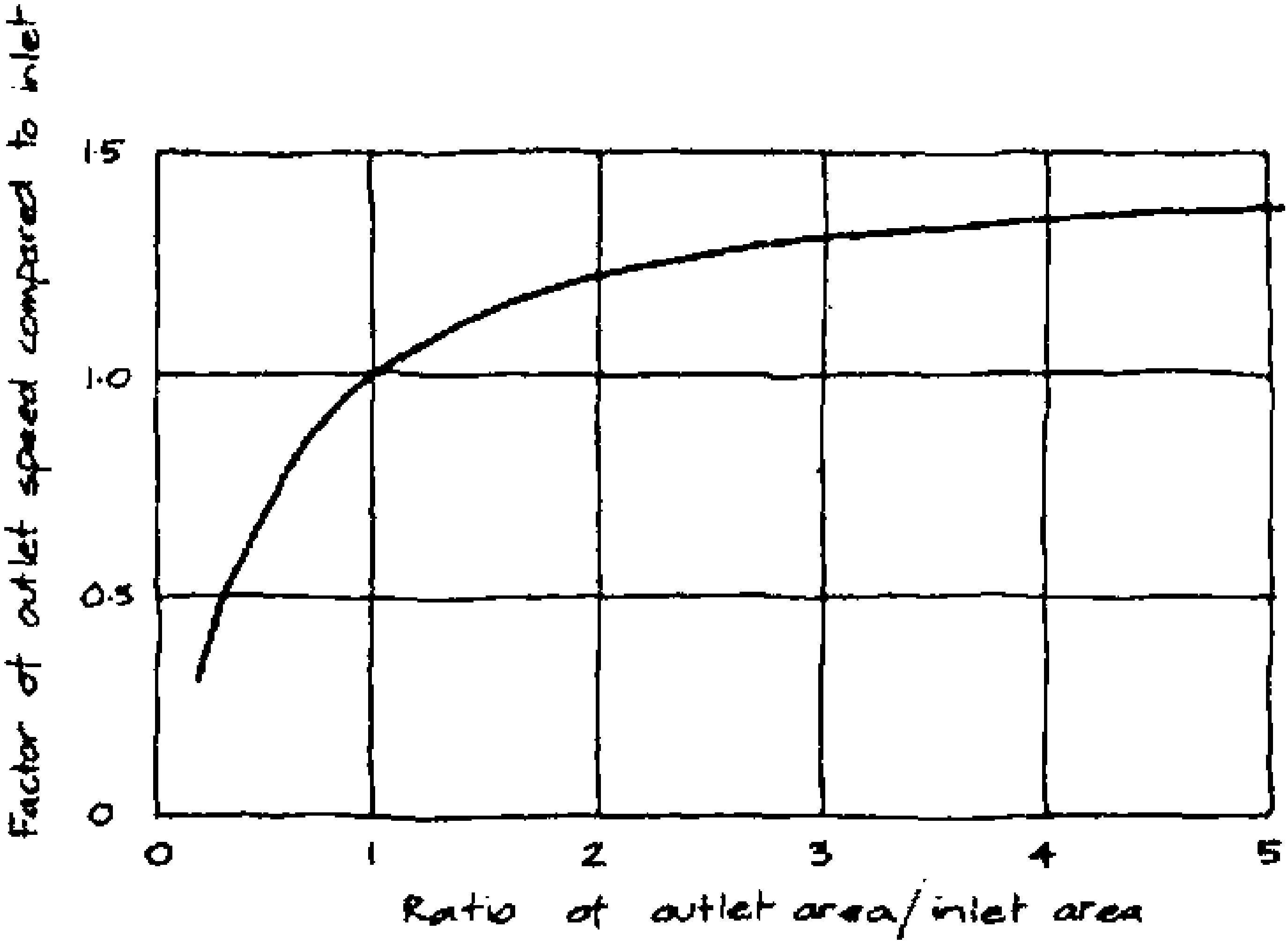


Figure 96. Graph of inlet/outlet areas versus factor of outlet speed compared to inlet speed.

Outlet, there is not the same proportional increase after an initial doubling of the relative area. The combined effect is increased velocity and reduced volume. For body cooling, the increased velocity may be desirable but in most other aspects of comfort it would not be desirable.

2. Air flow around buildings

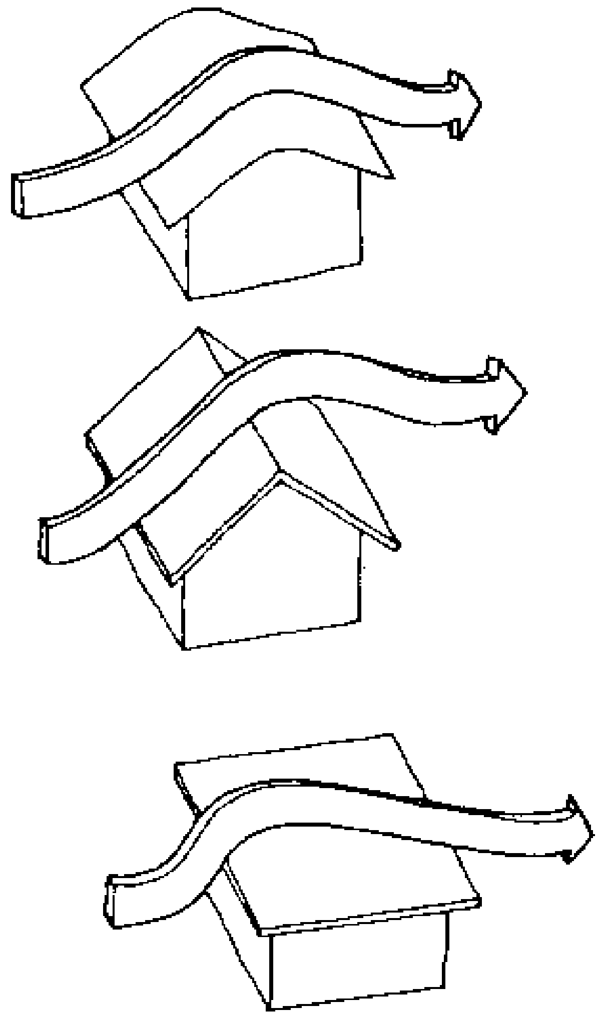


Figure 97. Examples of air flow around buildings showing how sharp edges cause severe eddies and Increase suction effects

The wind pressure distribution pattern around a building will be influenced by both wind direction and building form. The diagrams in figure 97 indicate the general pattern for some simple forms; notice how extremes of pressure occur usually around square corners. This has implications for the through−ventilation of rooms which have ventilation openings on adjacent sides.

Studies undertaken by the BRE in the United Kingdom have found that roof shape also influences air movement patters. Flat−roofed buildings provide the greatest wind shadow on the leeward side and result in the greatest suction at roof level (this is why it is important to securely tie down flat roofs in high wind areas). An important point to note is that the smooth wind−shaped roof does not have a significant suction zone at or near the ridge and so ridge ventilators in such cases are not so effective. despite claims made by some designers.

3. Thermal stack effects

In all buildings or enclosed spaces there is a tendency for warmer air to rise to the upper part of the space and the cooler, less dense air to settle to the bottom. This buoyancy effect will cause a flow of air proportional to the effective height of the stack. In the case of chimneys to unused fireplaces the warm air is lost to the outside to be replaced by cold air. which in winter is undesirable. In the case of buildings of more than one storey. the stairwell and other vertical spaces such as glazed sunspaces provide an opportunity for such air movement.

For a space with two openings separated vertically by a known height, the ventilation rate is given by the following formula:

$V = 0.121 \times A \times H \times (T_i - T_o)$

where

V = ventilation rate m³/sec
A = area of each opening m²
H = vertical distance between opening
T_i and T_o = inside and outside temperatures

A typical two−storey house has a high−level window in the stairwell at a height of 5 m above the ground−floor windows. On a still evening, after a hot day, the windows are fully open. The area of each is 1.2m and the temperature difference is say, 5°C. The air flow through that space will be approximately 3.6m³/see (a velocity of 3m/sec at the window). The structural cooling effect of this is discussed in the section on night ventilation and the cooling of heat sinks.

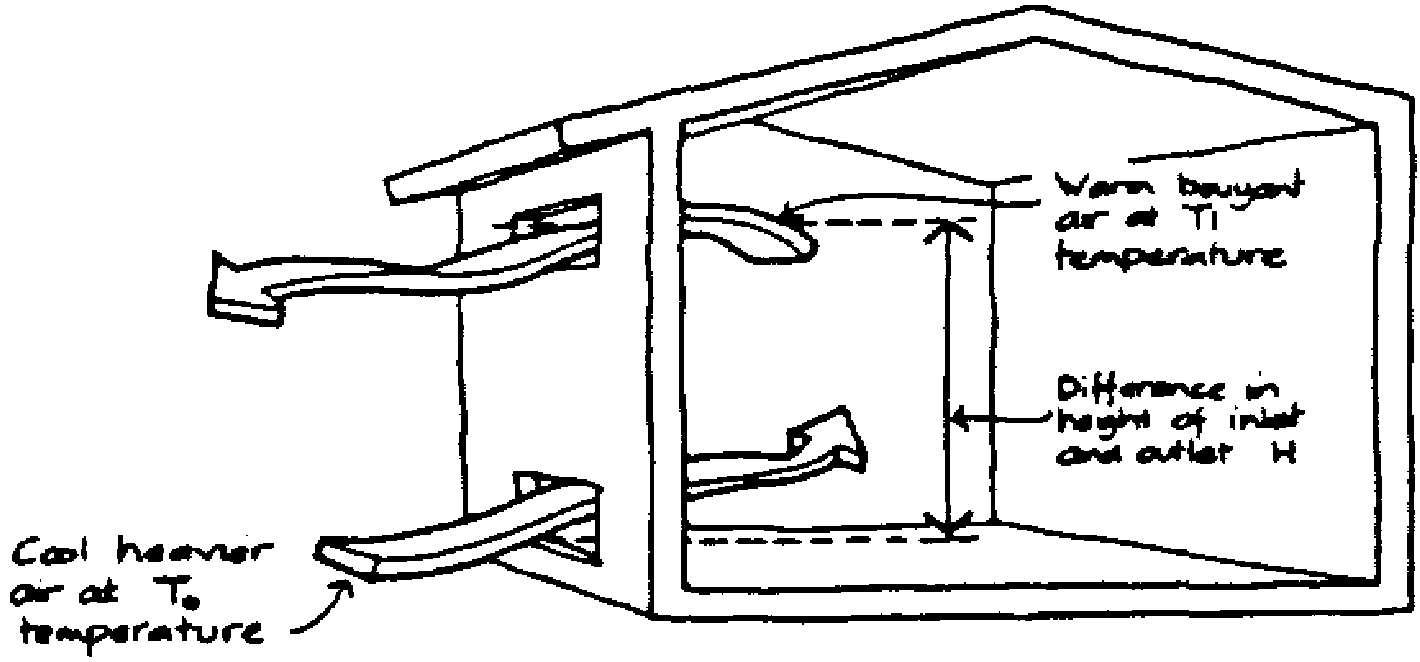


Figure 98. Factors affecting thermal stack ventilation rates

F. Glass−mass relationship

The need for thermal mass (heat−storage materials) inside a building is very climate−dependent. Heavy buildings of high thermal mass are consistently more comfortable during hot weather in hot−arid and cool−temperate climates, while in hot−humid climates there is little benefit. In cool−temperate climates the thermal mass acts as a cold−weather heat store for free−running buildings thus improving overall comfort and reducing the need for auxiliary heating, except on overcast or very cold days. In intermittently heated buildings, however, it tends to increase the heat needed to maintain the chosen conditions.

It has been found from research that there is a direct relationship between the area of north−facing glass and the area of thermal mass. Thermal mass is usually introduced into a design as a concrete slab floor on the ground or as internal masonry walls. A suspended concrete floor tends to act in much the same way as internal walls because it is not attached to the ground. Research has also shown that the behaviour of concrete slab floors is not affected by hard finishes such as ceramic tile, vinyl tile or slate. Carpet and cork tiles tend to insulate the slab from the interior space and so reduce its effectiveness. The particular benefit of a concrete slab on the ground is that the slab and ground work together thermally to provide a much larger "cool. store for summer. In winter, however, there is a continuous flow of heat into the ground. This is far less than the loss of heat from a light−weight timber floor because the ground under a core−slab is not as cold as the ambient winter conditions. Carpet on a concrete floor tends to make the associated room warmer in both winter and summer. The designer must assess the climate and the occupants, needs to determine whether one season is more important than the other.

Figures 99 and 100 illustrate the relative behaviour of a simple house plan located in Sydney. The graphs assume either a concrete slab floor with tile finish (figure 99) or concrete slab floor with wall−to−wall carpet finish. Three construction forms are shown for each: brick veneer, masonry core (internal dividing walls only, in masonry) or full masonry. Each is correctly oriented with major glass areas in a northerly direction. The graphas how the three house constructions with three different north–facing glass areas plotted against winter heating load in Gj and summer discomfort. Research undertaken by the GMI Council and by CSIRO for the 5–star design rating system has shown that the acceptable limit to summer discomfort is 180. Graphs for hot–humid climates such as those in Queensland and the Northern Territory are not available at this time. Graphs for other centres and capital cities in Australia are given in the annexes.

Hard–tiled concrete–slab floors and carpet on concrete–slab floors are shown separately to simplify the picture. An insulated–timber–floor option has been added to the graph for Hobart in the annexes to illustrate minimum thermal mass. This was not included in the other locations because it fell a long way outside the acceptable summer discomfort range.

In the "masonry core" design, the area of internal masonry walls is equal to the floor area. The mass surface area to north–facing glass area ratio for the three steps, always from left to right, on the graph, are 10:1 for minimum windows; 3:1 common design midrange (typical of many of today's project homes), and 2:1 for large glass areas (all of the northern façade in glass).

G. Air infiltration

Air infiltration accounts for a very large proportion of the heat losses in most buildings that are not pressurized by air– conditioning. Infiltration Is generally more significant in winter than summer due to the large difference between inside and outside temperatures. If the building has tight construction at windows and doors then infiltration rates would be expected to be around 0.5 air changes per hour. This may be further reduced by carefully sealing openings in walls and around doors.

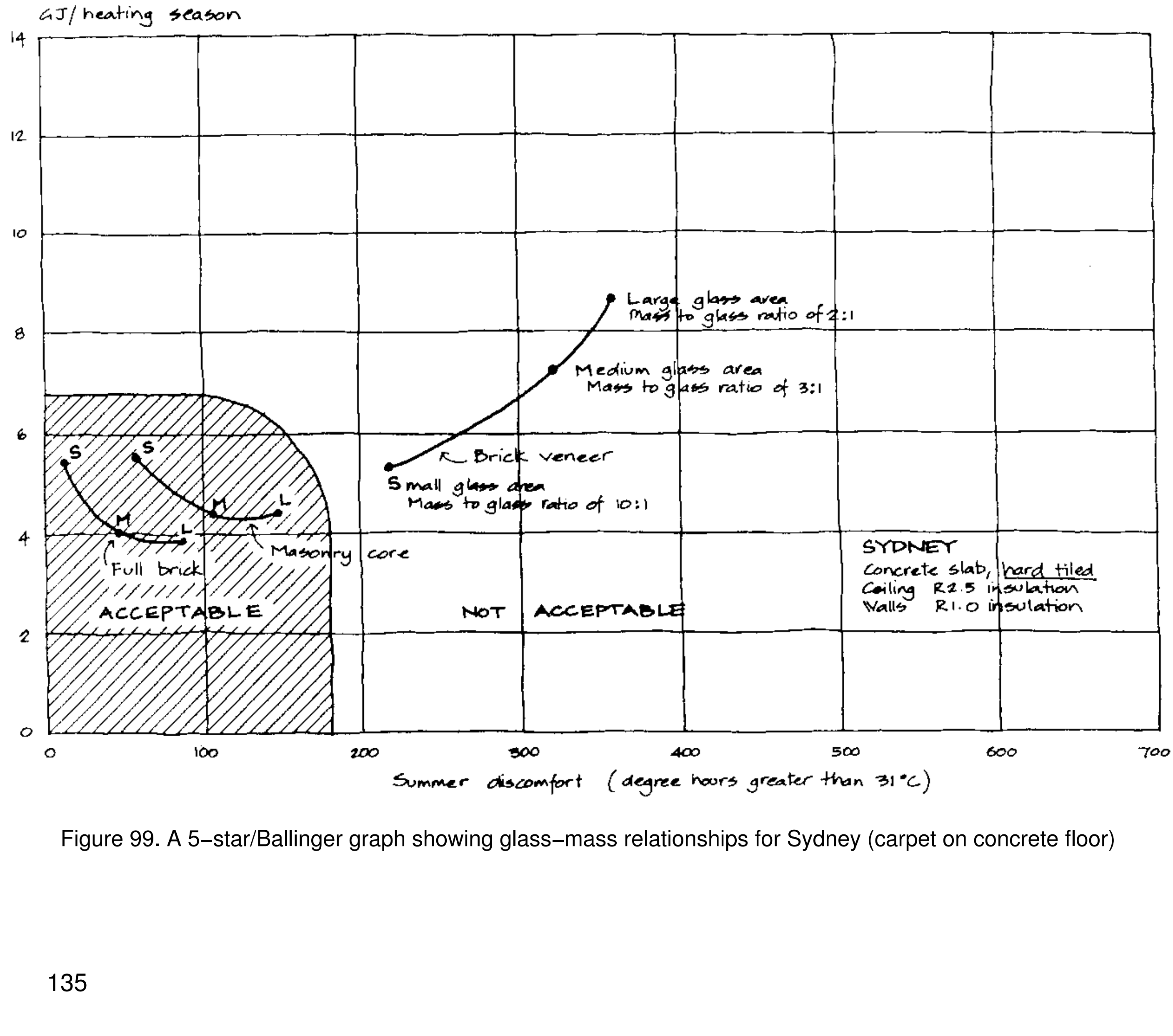


Figure 99. A 5–star/Ballinger graph showing glass–mass relationships for Sydney (carpet on concrete floor)

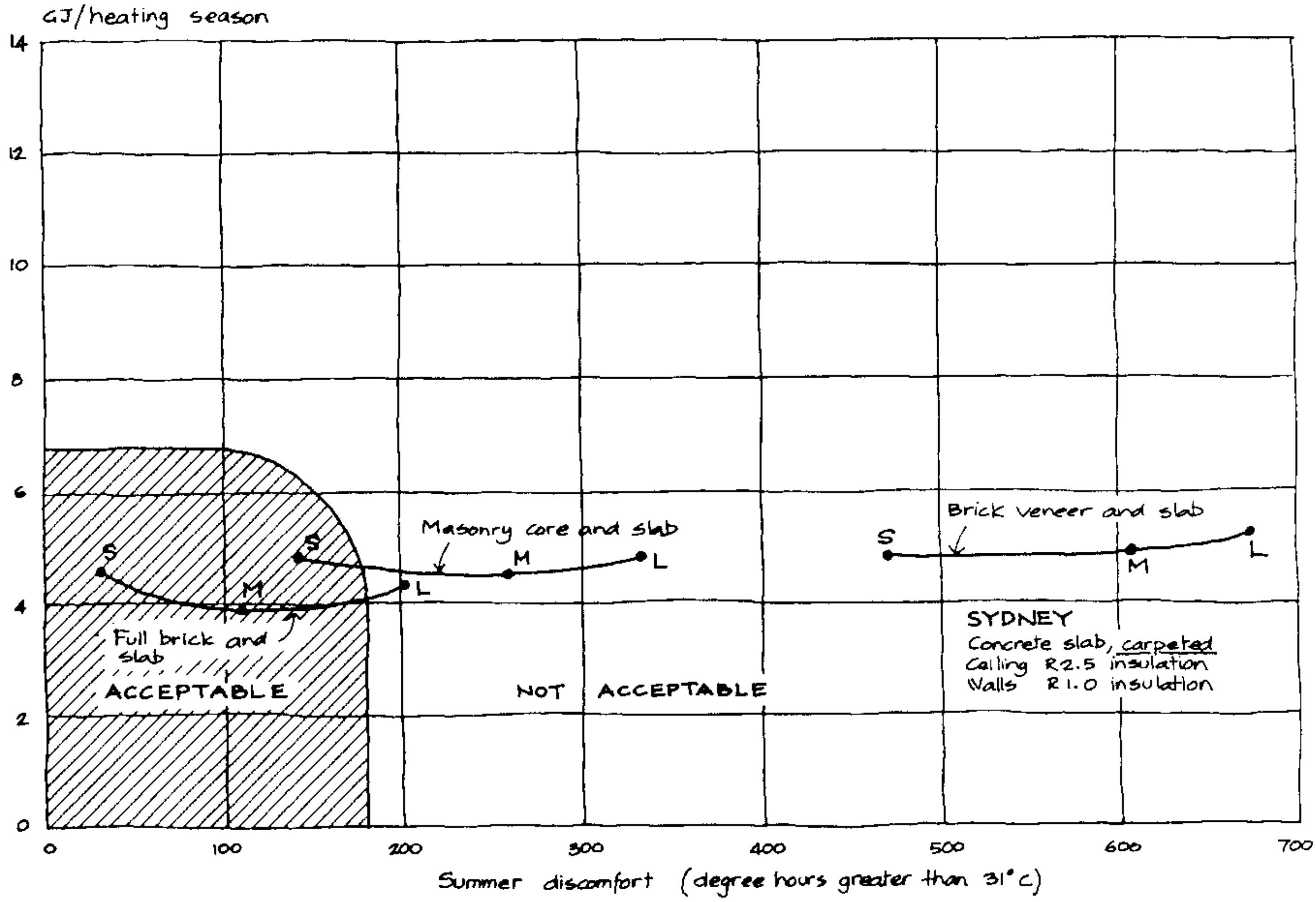


Figure 100. A 5–star/Ballinger graph showing glass–mass relationships for Sydney (tile on concrete door)

Chimneys can provide a very large infiltration loss as illustrated earlier. The top of a chimney is designed to be in an area of low pressure to assist its designed task of removing smoke and hazardous gases from the fireplace. Consequently it provides a continual exhaust and source of winter heat loss when not in use. Chimneys tend to be a greater source of heat loss than do cracks around windows and doors and so a damper should be provided to close off a chimney that is not in use. For a known set of temperature conditions it is possible to calculate the effect of a chimney on the infiltration of a building. This was discussed earlier in the section on cross–ventilation and air flow.

Permanent ventilation should not be used in houses, except where required by regulations. Instead it is better to use exhaust fans with automatic shutters. Kitchens and bathrooms are best ventilated by opening doors or windows, when required. In winter, ventilation should occur during the warm part of the day so that during the cold nights the house can be closed up. Summer ventilation is a different problem. If it is very hot outside it may be desirable to close up a house during the day and open it up at night. If it is not too hot, such as is the case on most summer days in Sydney, then windows are left open at all times. Fixed vents are not then required. A large, slow–turning exhaust fan in the centre of the house, may be the best solution for summer cooling. During still nights it would draw cool air through the house and thus cool down the structure ready for the next hot day.

The heat storage capacity of the air (volumetric specific heat) varies according to the humidity but is generally taken to be 1200 Jm^3.degC and so if the air in a space of say $86m^3$ is changed four times an hour due to infiltration then the energy required to compensate for this over an evening of say six hours can be calculated as shown below. At 1989 electricity costs in Sydney, this amounts to 89C/evening just to compensate for cold draughts. This is just the ventilation losses and does not include the cost of energy lost through the building fabric. The cost in colder places such as the Southern Tablelands of New South Wales and Tasmania would be even greater.

H_v	= 1200 × DT × (N × V) × t /3600
	= .33 × 15 × 4 × 86 × 6

Where

Dt	= temperature difference between inside and outside
N	= number of air changes per hour
t	= hours of heating per evening to compensate for draughts
V	= volume of space m³

A number of locally made seals and gaskets suitable for use on doors and windows are illustrated in figure 101.

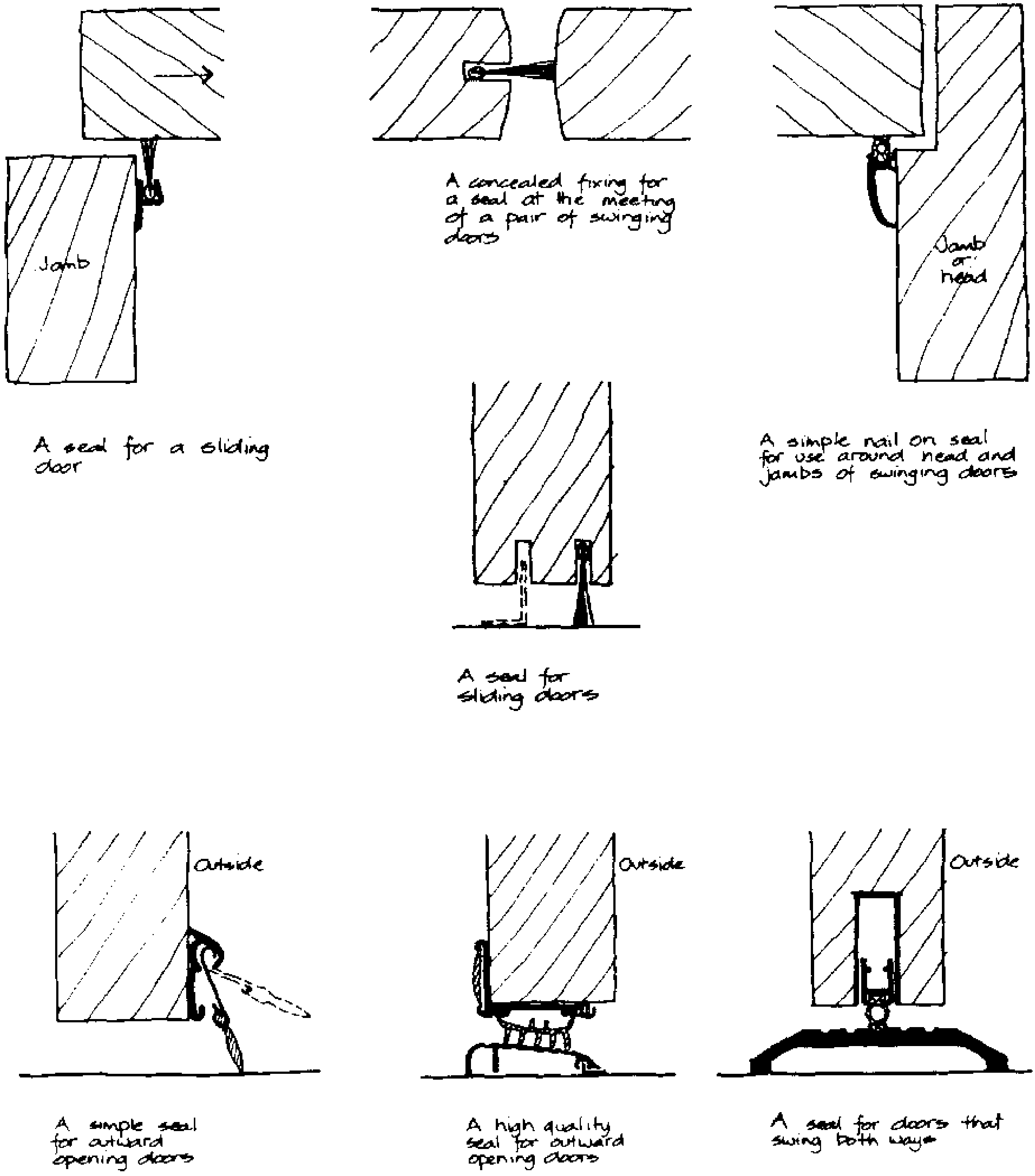


Figure 101. Examples of locally−made seals and gaskets to reduce air infiltration around doors

VIII. Final design evaluation

During the initial design process the designer has available a wide range of design tools and guidelines that begin with climatic analysis of the specific site using bioclimatic analysis and comparative data on glass/mass relationships. The orientation and shading of window areas can be assessed by inspection to determine the design forms and visual implications. Later precise shading dimensions can be determined with sun position charts and other commonly available tools.

On completion of the initial design a variety of methods can be used to test the design detail. This chapter describes four approaches from the very basic steady−state analysis through the 5−star design rating assessment procedure to the use of computer models. The model described in this document is the CSIRO program CHEETAH, an easy−to−use simulation program that uses recorded hourly weather data. When operated on currently available IBM/AT machines the calculations are made very quickly. Modern personal computers have become so powerful that such programs can be used for quick analysis as well as detailed analysis. Results from CHEETAH are discussed later in this chapter. Other methods are described for use where such computers are not readily available.

A. Steady−state evaluation

1. Solarch energy performance evaluation

The solarch energy performance evaluation form illustrated below is a simple method to determine building heat load coefficients (BHLC) and approximations for annual auxiliary energy consumption. The method uses values for site−specific degree−days of heating and so is limited by the accuracy of such data. It is not able to account fully for solar gains nor does it take into account any storage effect that may be afforded by any thermal mass.

The major value of this tool is to identify the significant heat paths for the selection and ranking of insulation, to help identify the need for window insulation or double glazing and the relevance of air infiltration as a heat loss path. The designer experienced in a specific building type (I.e., project−builder houses) may soon find that this technique does not provide any new information. Such techniques are by their nature simplistic and more useful for general education in thermal design of buildings.

2. Solarch thermal evaluation method "C"

The solarch thermal evaluation method "C" is an advanced form of the above method. This method has been developed to take into account specific site data including solar radiation data instead of the generalized degree−day data. As a result there are 10 steps or charts to be completed to analyse a building. Where a designer is designing a number of projects in the same district, much of the early chart entries can be reused.

Designers skilled in the use of computer spreadsheets will find this method is much simpler and less tedious If operated on such a spreadsheet. A worked example for a simple dwelling built in a hot−arid zone is shown in the following sheets.

The results of this analysis indicate a month−by−month picture of the heat balance of the building, providing both heat losses and heat gains as separate values. It is possible for the designer to see where the critical heat paths are and identify more precisely the impact of any design changes.

The example given is for a house built in the mid− 1970s. It is located in western New South Wales near the border of South Australia. The heat gains to the building are greater than the losses thus providing a margin for additional ventilation. The house has been occupied since 1977 and in that time has not required any auxiliary heating other than during extended cloudy periods. The conventional houses on nearby sites require considerable heating for most of the winter months.

SOLARCH ENERGY PERFORMANCE EVALUATION

BASIC CLIMATIC DATA

LOCATION: ________

LATITUDE: ________ LONGITUDE: ________ ALTITUDE: ________

PROJECT: ________ Degree Days (Base 18 °C): ________

STEP No. 1 — BUILDING HEAT LOSS COEFFICIENT (BHLC)

SURFACE	AREA (m^2)	U-value ($W/m^2 K$)	U.A (W/deg C)

BHLC (W/deg C) ________ A

STEP No. 2 — INFILTRATION (INF.)

INF = [Air Changes/Hr.] X [Volume] X [0.361] = ________ B

NOTE: 2 air changes/hour for common construction and 0.5 air changes /hour for tight construction

STEP No. 3 — TOTAL BUILDING HEAT LOSS COEFF. (TBHLC)

TBHLC = [________ A + ________ B] X [24] = ________ C

STEP No. 4 — ENERGY CONSUMPTION OF BUILDING (ECB)

ECB = [TBHLC ________ C] X [Degree Days ________ dd] X 3.6 X 10^{-6}

ECB = ________ GIGA JOULES / YEAR

Pages marked

SOLARCH THERMAL EVALUATION | **METHOD C** | ISSUE: NOV. 1979.

JAN 1981

Project: SOLARCH ARID ZONE HOUSE STAGE 1 Latitude: 31.0 S

Location: FOWLERS GAP NSW Alt: Longitude: 141.5 E

REFER TO PROCEDURES ON PAGE 3 / ...

ARID ZONE CLIMATE
120 km NORTH OF
BROKEN HILL

STEP NO. 1. CLIMATIC DATA

A) MEAN DAILY TEMPERATURES (T_a). FOR EACH MONTH REQUIRING HEATING INCLUDE VALUE FOR MONTH PRECEDING FIRST HEATING MONTH. THIS IS USED TO CALCULATE HEAT LOSS THROUGH FLOORS (STEP 3)

B) CALCULATE MEAN DAILY TEMPERATURE DIFFERENCE FOR EACH OF THE HEATING MONTHS. ($\Delta T_a = (\bar{T}_i - \bar{T}_a)$) SUGGESTED VALUE, $T_i = 21°C$

C) ENTER VALUES OF TOTAL DAILY INSOLATION (I) ON VARIOUS SURFACES OF THE BUILDING (MJ/m²)

D) ENTER VALUES OF SOLAR HEAT GAIN (SHGF) THROUGH NORTH GLAZING (MJ/m²)

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A) MEAN DAILY TEMPERATURE °C ($\bar{T}_a$)		27.7	27.2	22.8	18.4	14.2	10.7	9.9	12.4	15.9	20.0	23.8	26.3
B) MEAN DAILY TEMP. DIFFERENCE °C($\Delta \bar{T}_a$)						6.8	10.3	11.1	8.6	5.1			
C) TOTAL DAILY INSOLATION (I) (MJ/m²) 'CLEAR SKY' VALUES FROM CSIRO. DATA	ORIENTATION: NORTH WALL					21.6	21.5	22.0	21.7	18.2			
	EAST "					7.8	6.8	7.7	10.5	13.5			
	SOUTH "					2.8	2.5	2.8	3.4	4.4			
	WEST "					11.1	10.2	11.4	13.7	15.9			
	ROOF					14.6	13.1	14.8	19.2	25.1			
D) SOLAR HEAT GAIN (SHGF) (MJ/m².day)						18.3	18.3	18.6	17.8	14.1			

Pages marked: continued

STEP No. 2.

CALCULATE MEAN DAILY SOLAIR TEMPERATURE (T_e)
ON VARIOUS SURFACES OF DIFFERENT ORIENTATIONS
$T_e = T_a + (\alpha \times 1/fo \times I \times 11.574) - T_{sky}$

T_a = MEAN DAILY TEMPERATURE, FROM STEP NO. 1 (A)
I = INSOLATION, FROM STEP NO. 1 (C)
T_{sky} = 0 - VERTICAL; 1 - 60° SLOPE; 2 - 30° SLOPE; 3 - HORIZONTAL

SURFACE	ORIENTATION	α	1/fo	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
WALL	NORTH	·6	·03					18·7	15·2	14·5	16·9	19·7			
"	EAST	·6	·03					15·8	12·1	11·5	14·6	18·7			
"	SOUTH	·6	·03					14·8	11·2	10·5	13·1	16·8			
"	WEST	·6	·03					16·5	12·8	12·3	15·3	19·2			
ROOF	ASSUME FLAT	·2	·02					11·9	8·3	7·6	10·3	14·1			

STEP No. 3.

CALCULATE THE MEAN DRIVING TEMPERATURE DIFFERENCE (Δ Td)
$\Delta T_d = (T_i - T_e)$ SUGGESTED VALUE, T_i = 21°C

NB* → NOTE: Δ Td FOR FLOOR, NO NOT USE SOL-AIR TEMPERATURE USE THE MEAN DAILY TEMPERATURE. (IF FLOOR IS CONCRETE, USE VALUE FOR PREVIOUS MONTH).

SURFACE	ORIENTATION	α	1/fo	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
WALL	N							2·3	5·8	6·5	4·1	1·3			
"	E							5·2	8·9	9·5	6·4	2·3			
"	S							6·2	9·8	10·5	7·9	4·2			
"	W							4·5	8·2	8·7	5·7	1·8			
ROOF								9·1	12·7	13·4	10·7	6·9			
FLOOR	CONC. SLAB.							2·6	6·8	10·3	11·1	8·6			

Pages marked: continued

PROCEDURE

THIS METHOD IS INTENDED TO ENABLE THE DESIGNER TO UNDERTAKE A SIMPLE THERMAL EVALUATION OF HIS PROPOSED BUILDING. THE RESULTS, OF COURSE, ARE ONLY AS ACCURATE AS THE DATA USED, AND MUST BE CONSIDERED AS A COMPARISON WITH RESULTS TO OTHER PROPOSALS.

THIS METHOD USES MEAN DAILY VALUES OF VARIOUS CLIMATIC DATA AND SO THE BASIC STEADY STATE EQUATION (Q = A.U. Δ T) IS VALID.

THE DURATION OF THE 'HEATING SEASON' WILL VARY FROM PLACE TO PLACE. IT IS SUGGESTED THAT THE USER ONLY CONSIDER THOSE MONTHS WHOSE MEAN DAILY TEMPERATURE IS LOWER THAN APPROAXIMATELY 18°C. TO TEST THE BALANCE OF THERMAL GAIN TO LOSS IN A DESIGN IT SHOULD ONLY BE NECESSARY TO CONSIDER THE TWO COLDEST MONTHS. HOWEVER, TO CHECK THAT IN OTHER MONTHS THE BUILDING WILL NOT O VERHEAT TOO MUCH, IT MAY BE DESIRABLE TO CHECK ALL HEATING MONTHS.

STEP No. 4. CALCULATE THE TOTAL HEAT GAIN/LOSS PER MONTH THROUGH ALL OPAQUE ELEMENTS

A) CALCULATE AREAS (m²) OF EXTERNAL WALLS VIEWED FROM INSIDE THE BUILDING, CALCULATE CEILING AND FLOOR AREAS LIKEWISE. CALCULATE AREAS OF GLAZING AND RECORD IN STEP NO. 5.

B) CALCULATE U-VALUES (W/m²°C) FOR WALLS AND ROOF. SELECT U-VALUE FOR FLOOR IN ACCORDANCE WITH AVAILABLE DATA.

NOTE: ΔTd FROM STEP NO. 3.

DIMENSION 7.2m x 21m
FLOOR HAS EDGE INSULATION
REFER TO TABLE OF U-VALUES PAGE 192

BUILDING ELEMENT (OPAQUE)	ORIENTATION	AREA (m²)	U-VALUE (W/m²°C)	TOTAL HEAT GAIN/LOSS PER MONTH = A x U x Δ T_d x 2.6											
				JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
WALLS	N	34.0	0.37					75	190	213	134	43			
"	E	23.7	0.37					119	203	217	146	52			
"	S	41.6	0.37					248	392	420	316	168			
"	W	23.7	0.37					103	187	198	130	41			
ROOF	RAKED AREA →	145	0.26					892	1245	1313	1049	676			
FLOOR	-	143	0.38					367	960	1455	1568	1215			
TRANSFER TOTALS TO STEP 10 (H)			TOTALS					1804	3177	3816	3343	2195			

Pages marked: continued

STEP NO. 5.

CALCULATE MONTHLY HEAT GAIN/LOSS THROUGH ALL GLAZING, FOR EACH MONTH. $H = A \times Um \times \Delta T_a \times 2.6$ **Note: ΔT_a FROM STEP NO. 1. (B)**

A) CALCULATE MODIFIED U-VALUE (Um) ACCORDING TO TYYPE OF CURTAINS OR BLINDS USED AT NIGH. (IF ANY).

M = 0.33 - HEAVY DRAPES WITH RESTRICTED AIR CIRCULATION
0.60 - LIGHT DRAPES WITH RESTRICTED AIR CIRCULATION
0.75 - HEAVY DRAPES WITH FREE AIR FLOW
0.85 - LIGHT DRAPES WITH FREE AIR FLOW

REFER P69 FOR DETAILS

$$Um = \frac{U}{24}((M \times H_D) + 24 - H_D)$$

H_D = HOURS PER DAY THAT CURTAINS ARE DRAWN

ASSUME M = 0.6 FOR 13 HRS/DAY (6pm - 7am)

BUILDING GLAZING	ORIENTATION	AREA (m^2)	Um	MONTHLY HEAT GAIN/LOSS FOR EACH MONTH = $A \times Um \times \Delta T_a \times 2.6$											
				JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
WINDOWS	N	17.8	4.7					1479	2240	2414	1871	1109			
"	S	10.2	4.7					848	1284	1384	1072	636			
"	E	NIL													
"	W	NIL													
TRANSFER TOTALS STEP NO. 10 (H_2)			TOTAL					2327	3524	3798	2943	1745			

STEP NO. 6.

DETERMINE HEAT LOSS/GAIN DUE TO INFILTRATION
$H = V \times N \times \Delta T_a \times 0.86$

V = VOLUME OF SPACE (m^3)
N = NUMBER OF AIR CHANGES PER HOUR
ΔT_a = MEAN DAILY TEMPERATURE DIFFERENCE (REFER STEP NO. 1. (B))

VOL x INF x FROM STEP NO. 1 (B)

V: 432 x N (ASSUME): 0.5 x $\Delta \bar{T}_a$ x 0.86 =

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
				1263	1913	2062	1598	947			

TRANSFER VALUES TO STEP NO. 10 (H3)

Pages marked: continued

STEP NO. 7.

DETERMINE HEAT GAIN DUE TO APPLIANCES
HEAT GAIN = (POWER RAQTE (kW) x HOURS USE/DAY x DAYS/MONTH x 3.6)

HEAT GAIN DUE TO APPLIANCES				MONTHLY HEAT GAIN
APPLIANCE	POWER RATE (kW)	HOUR USE/DAY	DAYS/MONTH	
STOVE				
TV				
LIGHTS				
TRANSFER TOTALS TO STEP NO. 10 (H_4)			TOTAL	

DO NOT ASSUME ANY HEATERS BECAUSE THIS IS WHAT YOU ARE TRYING TO ESTIMATE

ASSUME A VALUE OF SAY 1250 FOR THIS INITIAL STUDY. SEE TABLES IN ANNEX FOR MORE DETAIL

x 3.6 = 1250 MJ per mth

STEP NO. 8.

DETERMINE HEAT GAIN DUE TO OCCUPANCE:
HEAT GAIN = Σ (NO. OCCUPANTS x ACTIVITY RATING (W) x HOURS USE PER DAY x DAYS PER MONTH) x 0036

HEAT GAIN DUE TO OCCUPANCE				MONTHLY HEAT GAIN
NO. OCCUPANTS	ACTIVITY (W)	HOURS USE/DAY	DAYS/MONTH	
TRANSFER VALUES TO STEP NO. 10 (H_5)			TOTAL	

ASSUME 750 MJ FOR THIS.

REFER TO EARLIER DATA FOR BETTER ESTIMATES

x .0036 = 750 MJ per mth

Pages marked: continued

STEP NO. 9.

DETERMINE MONTHLY TOTAL SOLAR HEAT GAIN THROUGH NORTH GLAZING
(SHGF) X (SC) X (SU) X (A) X (NO. DAYS/MONTH) = MJ/MTH

SHGF - FROM STEP NO. 1. (D)
SC - SHADING COEFFICIENT USE 1.0 IN WINTER TO OPTIMISE SOLAR GAIN
SU - SOLAR USED FACTOR USE 0.8 FOR DIRECT GAIN SYSTEMS, UNLESS OTHER DATA AVAILABLE
A - AREA OF NORTH GLAZING

CALCULATE FOR EACH MONTH THAT REQUIRES HEATING

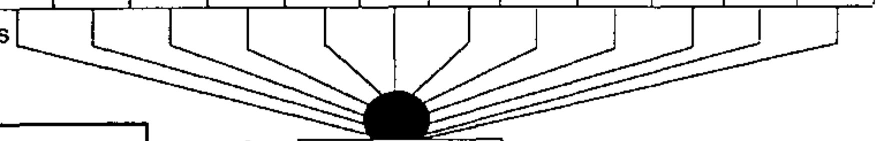
LOCATION	SC	SU	AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
N	1	0.8	17.8					8078	7818	8211	7858	6024			
TRANSFER VALUES TO STEP 10 (H_6)			TOTAL												

Pages marked: continued

STEP NO. 10. DETERMINE THE AUXILIARY HEATING ENERGY REQUIRED:

TRANSFER ALL RELEVANT FIGURES FROM PREVIOUS STEPS

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A TOTAL MONTHLY BUILDING HEAT LOSS OR GAIN	(H_1) OPAQUE					1804	3177	3816	3343	2195			
	(H_2) TRANSPARENT					2327	3524	3798	2943	1745			
	(H_3) INFILTRATION					1263	1913	2062	1598	947			
	TOTAL LOSSES Σ					5394	8614	9676	7884	4887			
B TOTAL MONTHLY BUILDING HEAT GAIN	(H_4) APPLIANCE GAINS					1250	1250	1250	1250	1250			
	(H_5) OCCUPANTS GAINS					750	750	750	750	750			
	(H_6) SOLAR GAINS					8078	7818	8211	7858	6024			
	TOTAL GAINS Σ					10078	9818	10211	9858	8024			
A - B = (IGNORE NEGATIVE VALUES)						—	—	—	—	—			



AUXILIARY HEATING ENERGY REQUIRED → 0 MJ/annum

SUGGESTION: CHECK RESULTS WITH HIGHER INFILTRATION (H3) & LOWER INTERNAL GAINS (H4) & (H5)

NOTE A-B IS ALWAYS NEGATIVE & SO ACTIVE AUX. HEATING IS NOT LIKELY TO BE NEEDED

NOTE: THIS VALUE IS BASED ON VARIOUS ASSUMPTIONS RELATING TO THE USERS BEHAVIOUR AND SHOULD ONLY BE USED FOR COMPARATIVE PURPOSES

Pages marked: continued

B. 5−star design rating system a correlation technique

The "5−star design rating system" (FSDR) is based on guidelines that have been developed from correlation studies of a large number of construction options (approximately 100 computer simulations were undertaken for each location). A house design common to the Australian project home market was chosen for the studies and the results for Sydney are shown in figure 102. In addition to the general graphs a series of assessment graphs have been prepared from the data. These permit the designer to determine more accurately the minimum acceptable mass to glass relationships. They have been used by the 5−star assessment officers in each state for some years and are quite well understood.

The Ballinger graph has been developed to assist designers in the choice of construction materials and design configurations for optimum thermal performance. Full operational guidelines are available in the 5−star design manual available from State Government Energy Information Offices in New South Wales. Victoria and South Australia. This section is written to demonstrate graphic material that will help designers develop an intuitive design sense with regard to energy−efficient solar oriented buildings. Final designs are best evaluated using one of the available computer simulation models. CHEETAH is one such model and is described in section D of this chapter.

As stated earlier, the criteria for the 5−star design rating system graphs were determined with a commonly used project home design and assumes the following general conditions:

(a) Roof insulation levels shall be as specified in Australian Standard AS−2627;

(b) Exterior walls shall be Insulated with not less than R1.0 added resistance;

(c) Total non−north−facing glass shall not exceed 15 per cent of the net floor area of the dwelling; total of east− and west− facing glass shall not exceed 5 per cent of the net floor area; west−facing glass shall not exceed 2 per cent of the net floor area. Trade−offs within these constraints are permitted as are pro−rata increases in area as a result of treatments that reduce the shading coefficient below the assumed design value of 1.0;

(d) Windows shall be well shaded in summer and not exceed the areas specified for the particular location zone;

(e) Orientation of the northerly−facing windows shall not exceed a bearing in the range of 20 West of North to 30 East of North.

The graph illustrated in figure 102 has been developed from a selected range of the data generated during the project's development. The graph has been constructed from the position that the designer may first choose the floor type and construction to sun the site, the clients. needs and the economics of the project. The choices offered here are hard tile on concrete floor (ceramic or hard vinyl but not cork), full carpet on concrete floor, or carpet on a timber floor. More often the floor will be a concrete slab on the ground (currently about 70 per cent of all new houses built in the eastern states have a concrete slab floor). In many of Australia's climate zones the choice of a timber floor will dictate a cavity masonry construction to achieve energy−efficient thermal comfort. The graph illustrated is also based on the current glazing pattern of project homes; approximately 34 per cent north−facing glass to north−facing room−floor area. The data available have been grouped into three floor choices to form three separate shapes or "patches" − hard tile on concrete slab floor (C−T), full carpet on concrete slab floor (C−C) and full carpet on timber floor (T− F). Each "patch" Is based on brick−veneer construction to the right hand side of the patch. full masonry−cavity−brick construction (maximum thermal mass) to the left and masonry−core construction (internal room dividing walls only of masonry of area equal to the room floor area) in the central section, labelled "MC".

The upper horizontal line connecting the three wall construction types represents an uninsulated wall. whilst the lower one represents an insulated wall with R 1.0 added resistance. The designer can see clearly the implications of construction choices in a specific climate type. It is noticeable that in most locations uninsulated brick−veneer walls do not produce either acceptable summer comfort or acceptable reductions in energy consumption for winter auxilary heating.

The effect of variations In the glass area can be seen In a different set of Ballinger graphs described In section F of chapter VII.

C. Monthly mean indoor temperature

A simple technique has been devised by J.D. Balcomb to estimate the monthly average Indoor temperature of a building in the absence of auxiliary heat (known as "freerunning"). A knowledge of the building fabric's thermal properties and the average monthly solar radiation and temperature is needed. This method will provide the mean monthly Indoor temperature but not the daily temperature swing. This can be determined by further calculation or by correlation to other building types with known temperature swings as described later In this section.

The typical response of a passive solar building during a period of clear winter days is illustrated in figure 103. The temperature inside the building is defined by two characteristics, an average value and a diurnal temperature swing.

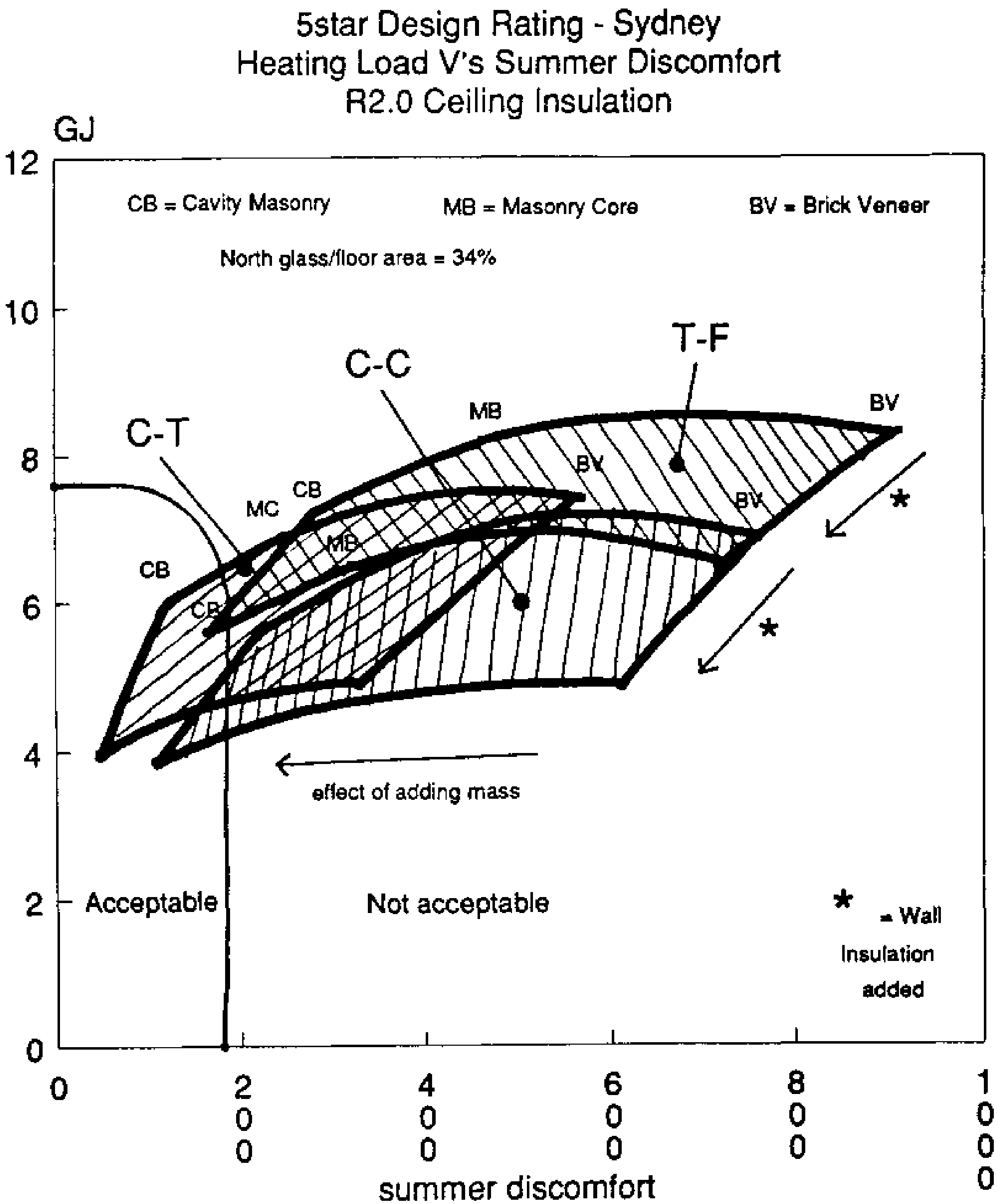


Figure 102. 5–star design rating system–Ballinger heating load– summer discomfort graph for Sydney

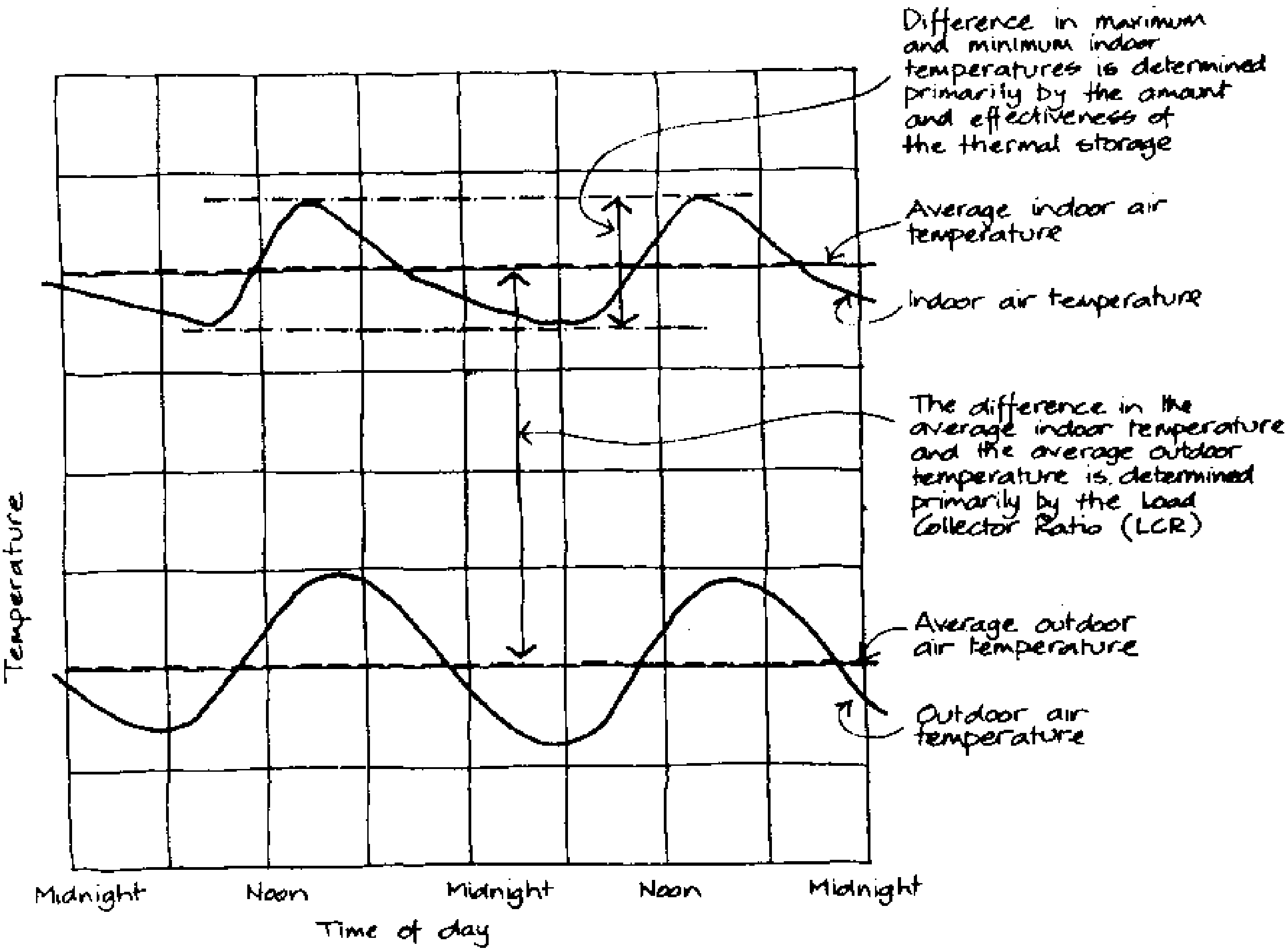


Figure 103. The typical cycles of indoor and outdoor temperature in a solar building in winter under conditions of clear day insolation

The average temperature rise due to solar gains to the building are given by the following:

$$\Delta T(\text{solar}) = \frac{Q_{(s)}}{TLC}$$

Where

$Q_{(s)}$	= average daily solar heat gain (SHGF) during the period Wh/m².day
TLC	= total heat loss coefficient
	= NLC + (24 × Ua.Aa)
NLC	= 24 (SA.U + (N × .33 × V))
LCR	= NLC/Aa

and so

TLC	= LCR + (24 × Ua)degC
Aa	= Solar collection aperture area (direct–gain window area)
Ua	= U–value for the solar collector (window)

This resolves itself into the following:

$$\Delta t_{(\text{solar})} = \frac{Q_{(s)}}{LCR + (24 \times U_a)\text{degC}}$$

The rise in temperature due to internal heat gains is given by the following:

$$\Delta t_{(int.)} = Q_{(i)}/TLC$$

$$= Q_{(i)}/LCR + (24 x U_a)$$

Q(I) = internal heat input, Wh/day

The total average internal temperature will be:

$T_{av} = T_{oa}$ + Dt (solar) + Dt (int)

For example, if a building located in Sydney is to be evaluated for July:

The north SHG $Q^{(s)}$ = 12.2 Wh/m².day
The average outdoor temperature for July is 11.7°C
U−value of the north glass is 6 W/m² .degC
NLC is calculated to be 6348 Wh/degC.day

$$\Delta t_{(solar)} = \frac{Q_{(s)}}{LCR + (24 x U_a) degC} = \frac{12.2}{453.4 + (24 x 6) degC} = 5.7 degC$$

The effect of double glazing the windows is a reduction of the NLC to 5772 and the LCR to 412. The revised mean monthly temperature rise in July due to solar. is 7 degC.

Assume 8100 Wh/day internal energy for people in July

$Dt_{(int)}$	= $Q_{(I)}$/LCR + (24 × U_a)
	= 8100/(453.4 + (24 × 6))
	= 13.6 degC

At the present time the most practical means of determining the average daily swing is to relate the building type to those described below and choose the value of indoor temperature swing matching the typical outdoor temperature swing. The graphs shown in figures 104 and 105 represent data collected from a group of houses built and monitored in Sydney's western suburbs (30km inland from the coast). The daily swings for both indoor and outdoor temperatures were determined from hourly recorded data through a winter cycle. The construction type for each house is noted and the designer can compare the proposed design according to its construction to determine the possible temperature swing due to solar gains. The temperature swing is influenced by both the area of operable thermal storage within the building space being considered and also the ratio of northfacing glass to thermal storage area. These houses were designed with glass areas typical of most project−home constructions in Australia today. The northerly−facing glass/floor ratio is noted below as an indicator. Generally the ratio of indoor to outdoor temperature swing for an insulated building (roof and wall insulation to recommended levels) with at least a hard finished concrete floor slab is approximately 1:4 (houses 340 and 345). For buildings with full masonry wails (344) but with timber floors, the behaviour is similar to house 345 (houses 344 and 345 are identical in design except for the wall and floor construction materials). For buildings with full masonry walls as well there would seem to be little difference to this ratio (house 341). In the case of a standard brick−veneer building with a concrete floor slab on the ground and a sunspace to the north (house 348) the ratio changes to approximately 1:2. House 350 of framed construction with a hard finished concrete floor, has a glass area to the north in between that of the others. The ratio of its indoor to outdoor temperature swing is 1:3. The greater area of glazing is clearly the contributor.

The daily temperature swing in the buildings of framed construction or brick veneer without wall insulation and with timber−framed floors (houses 359 and 357) was found to be approximately 1:1.5. It is also worthy of note that house 357 is also of the same design as houses 344 and 345. These houses were selected this way to investigate the effect of construction changes on the thermal performance).

D. CHEETAH – Thermal behaviour and energy load simulation model

This computer program is available to designers to provide a quick and easy method to evaluate building designs. It will provide either temperature profiles for showing the building conditions under actual weather conditions as shown in figure 106 or heating and cooling loads for specified Indoor temperature conditions as shown in figure 107. CHEETAH uses the response factor method as the basis of the calculations and was developed over many years as a program called ZSTEP by the CAIRO Division of Building Research. It is a little different from the conventional response factor method and has been fully described in the journal, Energy and Buildings. The program can be used on an IBM PC or compatible (either XT, AT or 386 machine: one year of weather data can be processed on a 386 type machine in four minutes) with at least 512K of memory, two floppy disk drives or a hard disk and an appropriate maths co−processor. A colour graphics card and colour monitor are most desirable but not essential.

The program is fully menu driven with a comprehensive easy−to− use help system. Its features are listed in the user manual as follow:

(a) Hourly temperatures and heating and cooling energy requirements are calculated for periods ranging from one day to a full year:

(b) The building may be subdivided into as many as 10 zones. Calculations need only be done for the zones of interest, while still taking into account the interactions of all zones:

(c) Libraries of common building materials and building sections are always available for describing a building:

(d) Occupant behaviour (e.g., the operation of curtains and shading devices) may be taken into account to a limited extent;

(e) Data input is fully interactive. with immediate error checking;

(f) Context−sensitive help, often quite detailed, is available at any stage.

This section illustrates some of the output possible, based on the house plan In figure 105. This house plan was used as the basis of the 5−star design rating system described earlier in this book. The designer enters the physical data about the building and its occupants' lifestyle using the interactive menus that consider the building In detail. At the early design stage, the designer needs only to enter rough approximations of the areas etc. to get a preliminary Indication of the bulidings performance. As the design is refined, so too can the input data file be modified and refined through the menu system. The program allows the designer to investigated the behaviour of the building over a hot or cold period of a day. a week, a month or the whole year. The performance on cloudy or clear days can also be studied. On completion of the calculations the results can be viewed In a graphical form as temperature curves or a bar chart of heating or cooling energy loads, as shown in figures 106 and 107.

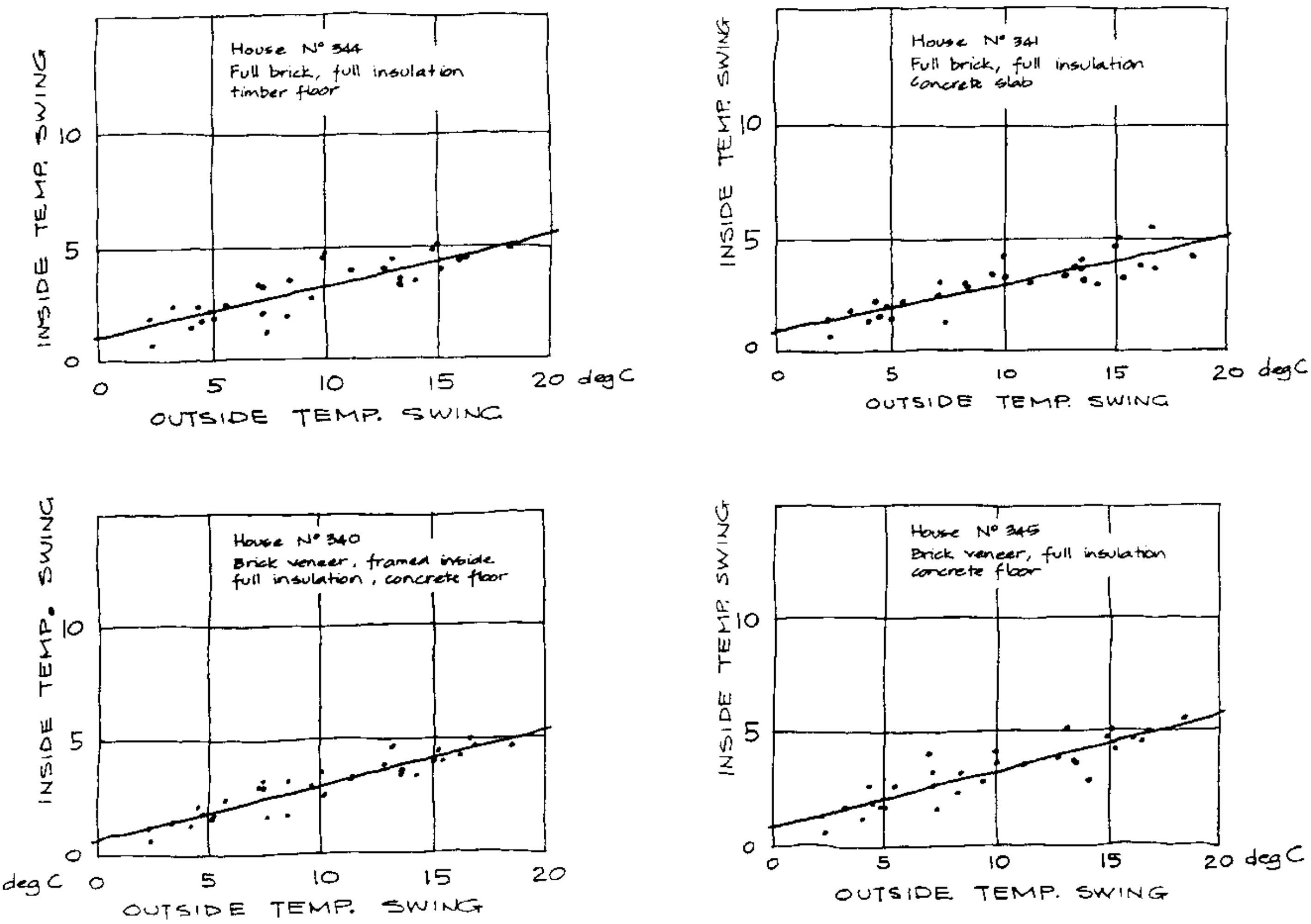


Figure 104. Winter−time dally temperature swings in various constructions

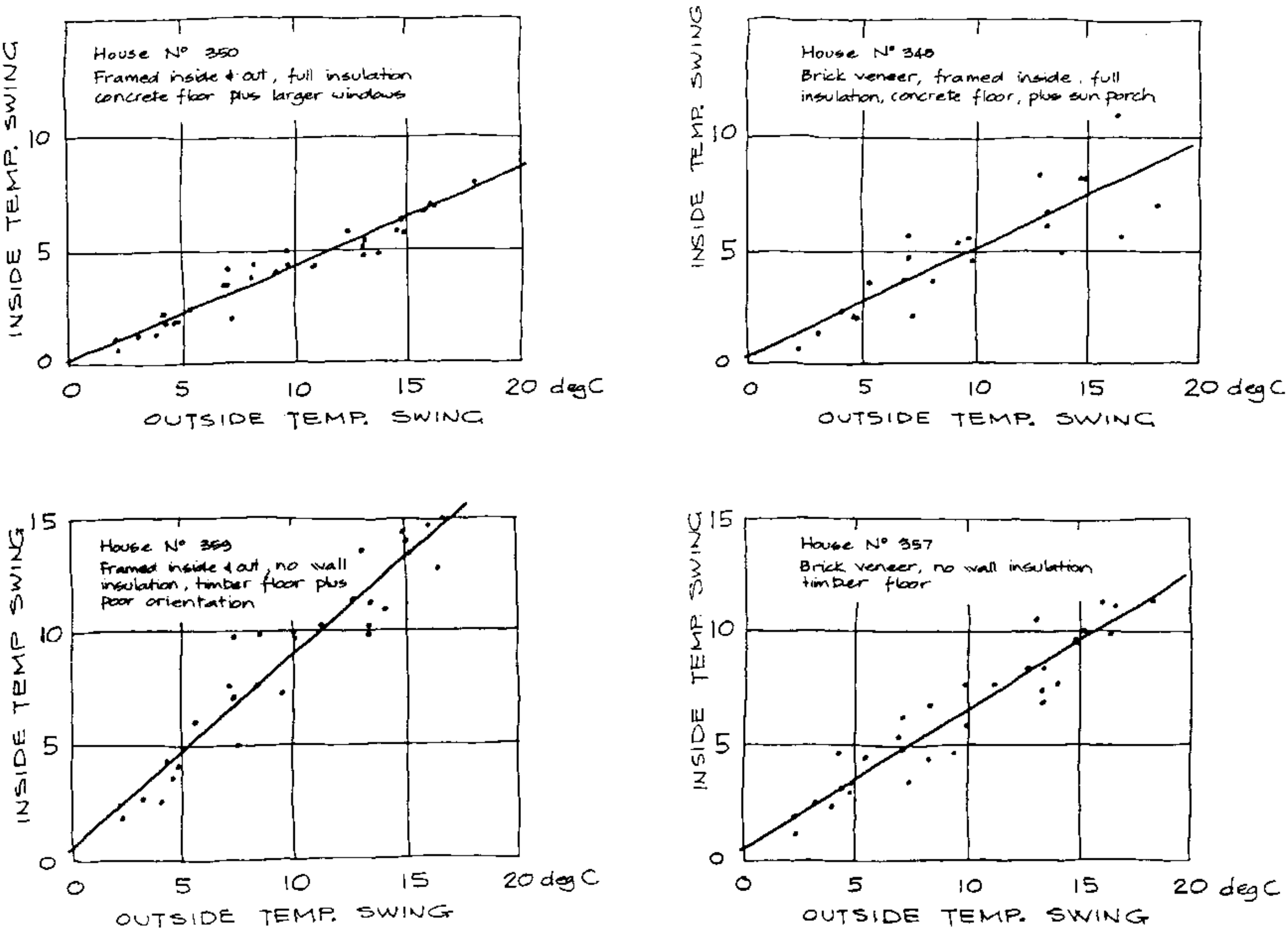


Figure 104 continued

The two design options in figure 106 are described as follows. The plan and building design are the same except that "Lech House 1" is uninsulated and has a carpeted timber floor over a vented air space, whilst "Lech House 34" has a carpeted concretes–lab floor on the ground and an Insulated roof (R2.0) and walls (R1.0). The three days shown are for a cold winter period In the country area of western New South Wales (ambient temperatures of approximately –4C to 15C). The main effect of the change Is warmer conditions at night. The sharp drop during the day Is the result of specifying that the occupants should open the windows when the indoor temperature rose to 25C and should leave them open until it dropped to 20C. The designer has available a number of choices about user–lifestyle patterns. The heating and cooling loads for "Lech House 1" in figure 107 are self explanatory.

As the design develops, it is possible to study various design options to help make better decisions. Figure 108 illustrates a case where external coatings with different surface absorptivities (0.2, 0.6 and 0.9) are compared on a simple test building. From this type of data. one can decide whether a particular surface colour is satisfactory from a thermal design viewpoint.

Many students of architecture in Australia are being taught how to use this package and there are a number of designers who find it helpful in the designing process as they attempt to balance the thermal design requirements with other design factors. Design weather data are available for many locations in Australia and also for London (Kew). Additional locations are being added to the collection as the need arises. Any weather data on floppy disk that have been prepared for SERI–RES can be converted quickly and easily by either the distributor of CHEETAH or a user with computer experience.

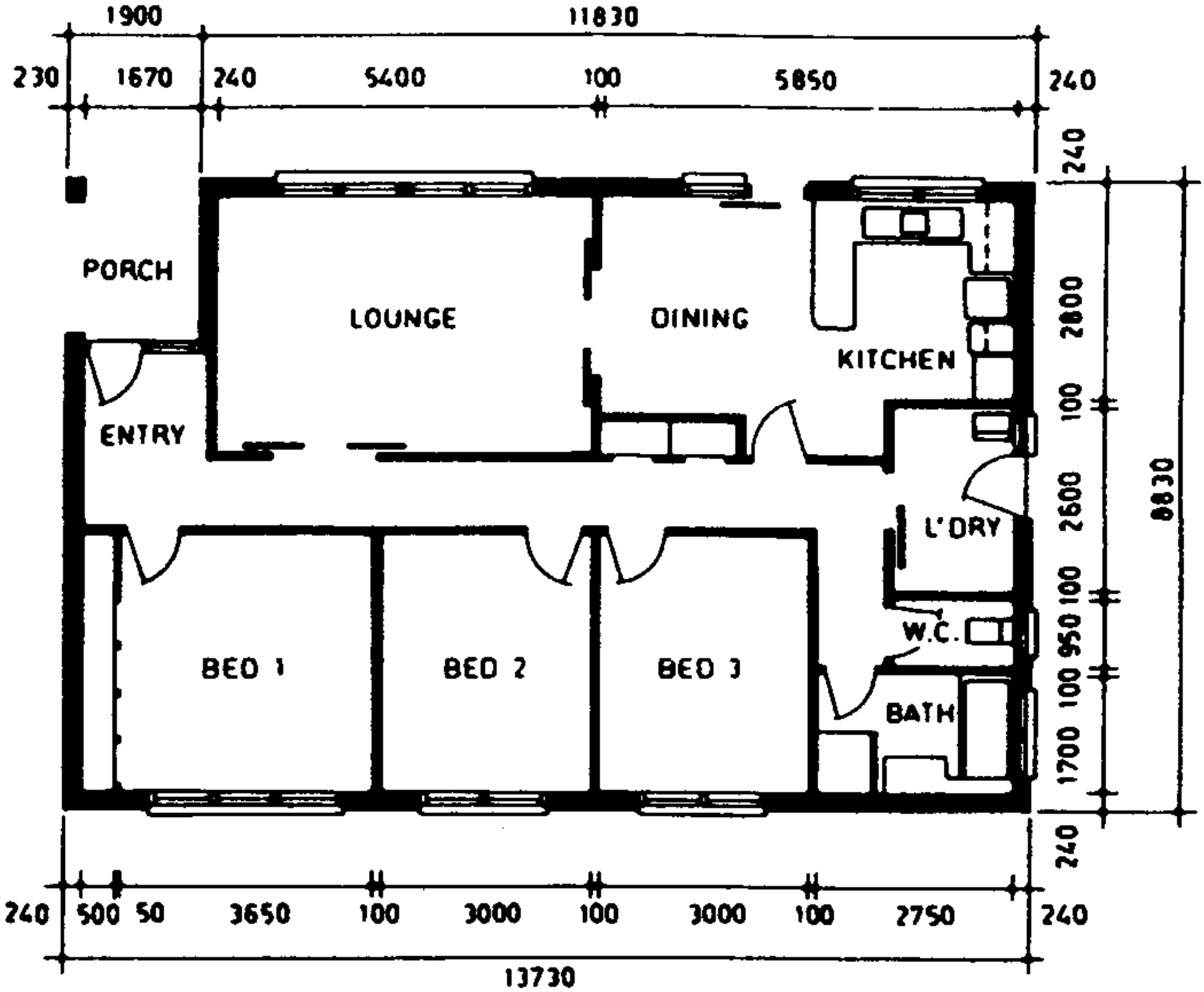


Figure 105. Floor plan of the house used as the example building

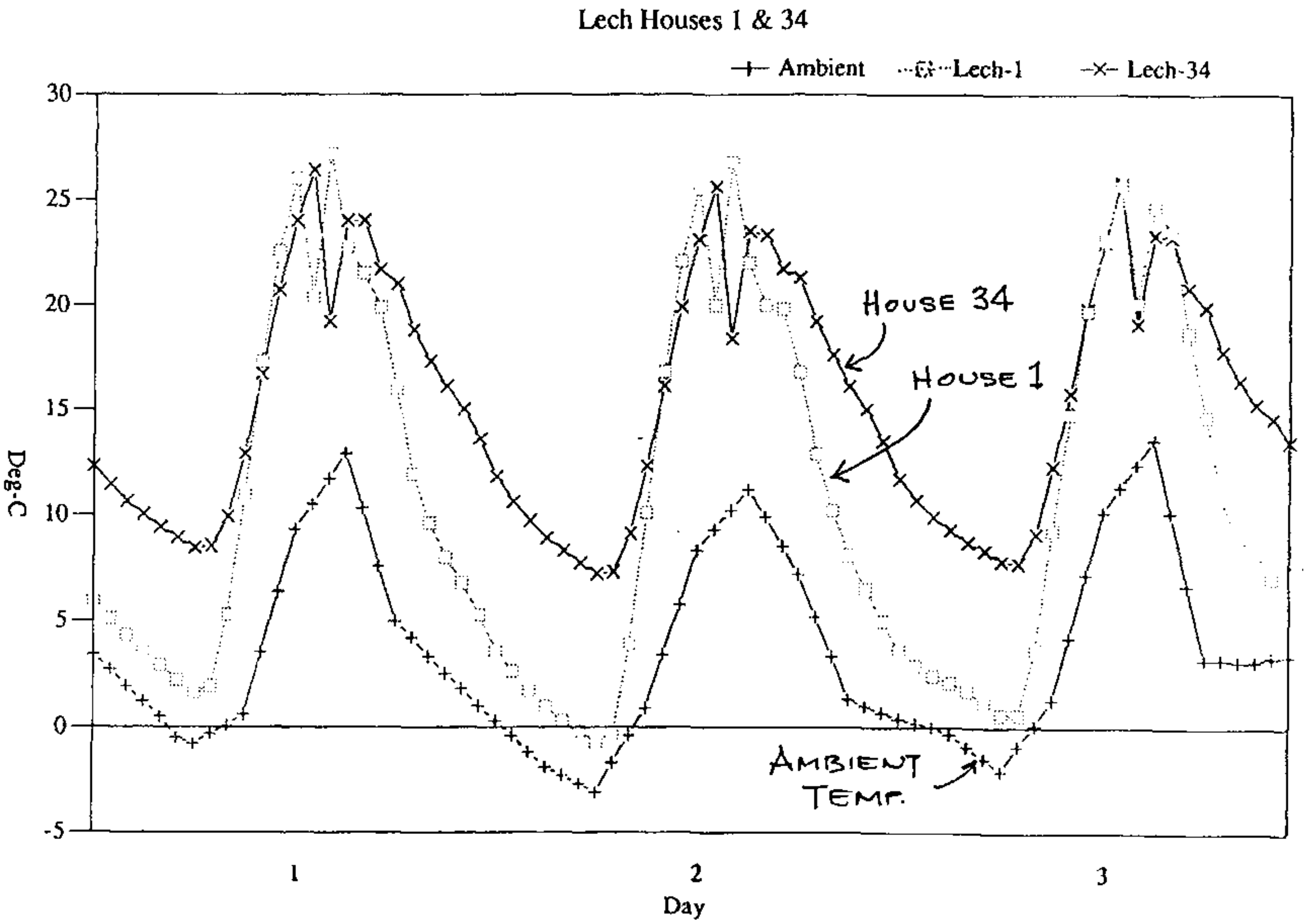


Figure 106. Graphs of temperature comparisons between ambient and the two house configurations based on the plan in figure 105

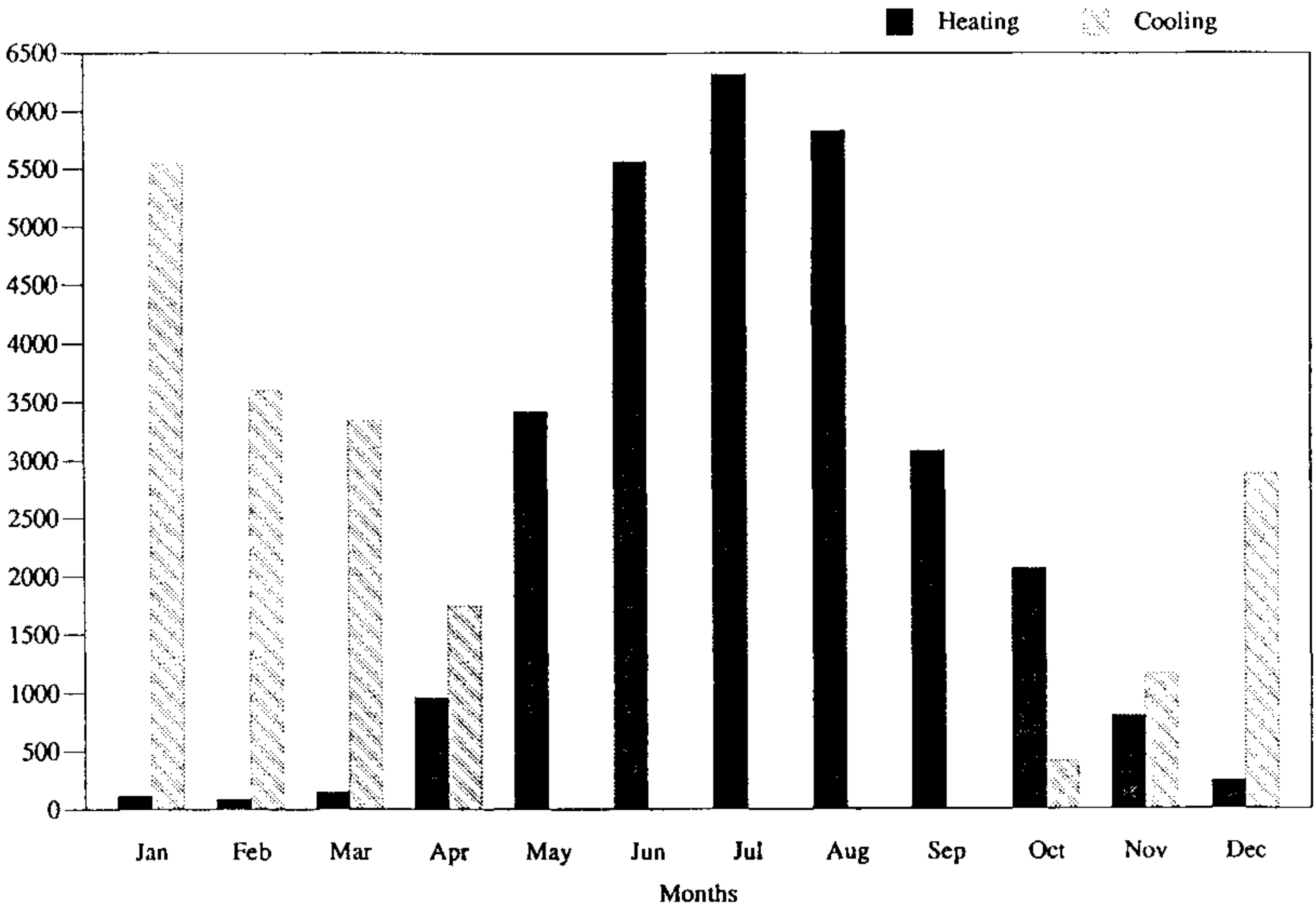


Figure 107. Sensible heating and cooling loads (MJ) for Lech House 1 at Wagga. New South Wales

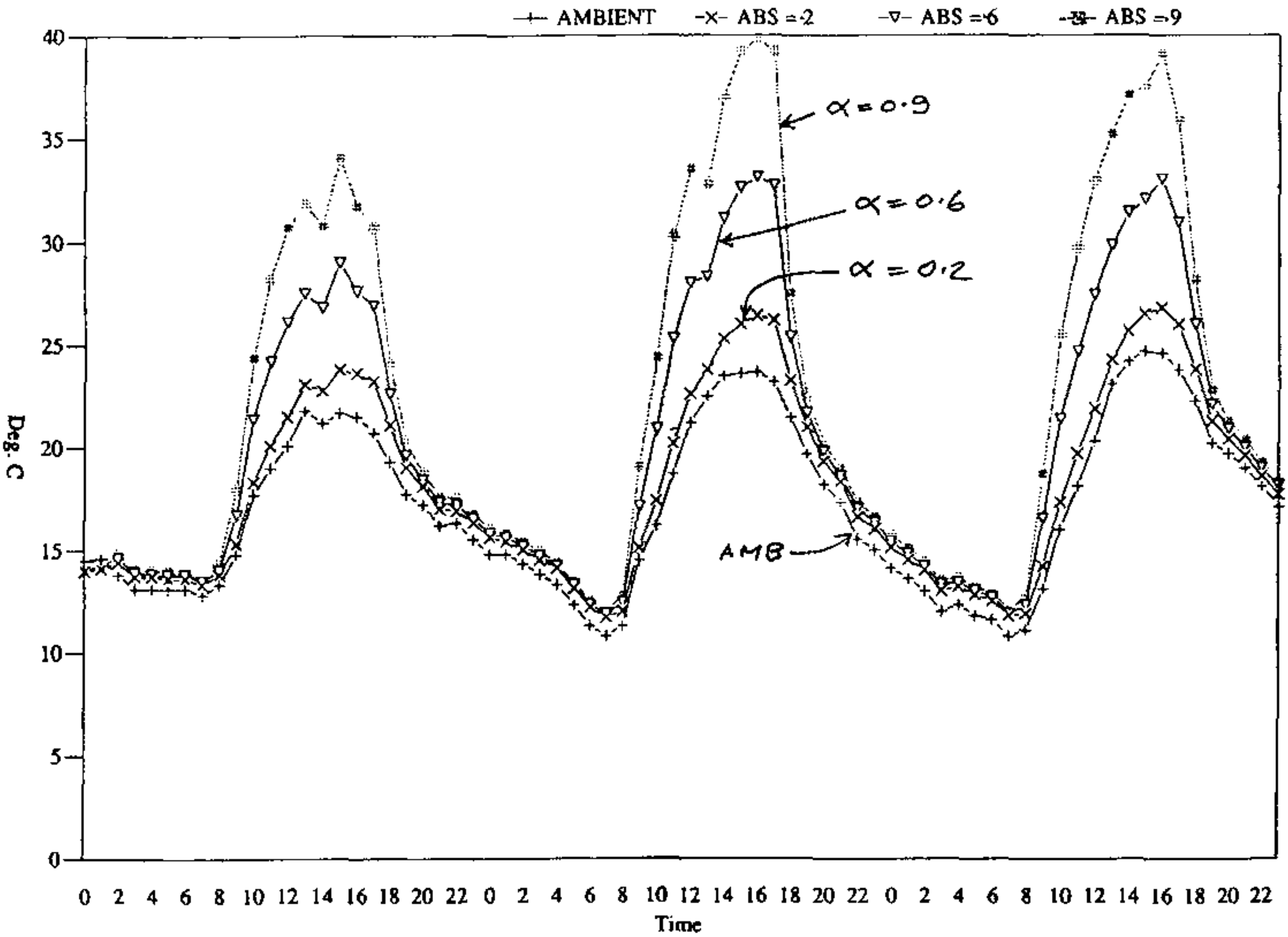


Figure 108. A comparison of the indoor temperature effect of different surface colours on a test room over three warm days
Note: Abs = surface absorptivities

Annex I: Relevant Australian standards

AS 1366.1–1981	Rigid cellular plastics sheets for thermal insulation.
	Part 1. Rigid cellular polyurethane.
	Part 2. Rigid cellular polyisocyanurate.
AS 2461–1981	Mineral wool thermal insulation. Loose fill.
AS 2462–1981	Cellular fibre thermal insulation.
AS 2463– 1981	Sea grass bulk thermal insulation.
AS 2352–1980	Glossary of terms for thermal insulation of buildings.
0.116 1975–1968	Organic fibre insulation board.
K.156– 1965	Expanded polystyrene for thermal insulation.
AS 2002–1979	The installation of household–type solar hot–water supply systems.
AS 1903 and 1904	Reflective foil laminate –1976

Annex II: Glossary of terms

absorbent. A material which, due to an affinity for certain substances. extracts one or more such substances from a liquid or gaseous medium with which it contracts and which changes physically or chemically, or both, during the process.

absorber. A solar absorber Is any dark (black) device used to collect the sun's energy. Usually it refers to the black flat plate absorber used with solar water−heating systems.

absorption ratio. The ratio of the radiation absorbed by a surface to the total energy falling on the surface measured as a percentage.

active solar−energy system. A system which requires the importation of solar energy from outside the Immediate environment; for example, energy to operate fans and pumps.

active systems. Systems which convert energy Into an appropriate form for the benefit of occupants in a house. An oil heater Is making use of an active system.

adsorbent. A material which has the ability to cause molecules of gases, liquids or solids to adhere to its internal surfaces without changing the adsorbent physically or chemically.

air, ambilent. Generally, the air surrounding an object.

air, recirculation. Return air passed through an air−conditioner before being resupplied to the conditioned space.

air, saturated. Moist air in which the partial pressure of wader vapour equals the vapour pressure of wafer at the existing temperature. This occurs when dry air and saturated water vapour coexist at the same dry bulb temperature.

air, standard. Dry air of a pressure of 760m,m (29.92 in) Hg an 21°C(69.8°F) temperature and with a specific volume of 0.833m /kg(13.33ft~/lb.).

air changes. A method of expressing the amount of air leakage into or out of a building or room in terms of the number of building or room volumes exchanged.

air changes per hour. The number of times that the air leakage Into or out of a building or room in terms of the number of building or room volumes exchanged.

air−conditioning, summer. Comfort air−conditioning used primarily when outside temperature and humidity are above those to be maintained in the conditioned space.

dr−conditioning, winter. Heating, humidificadion, air distribution and air cleaning where outside temperature and humidity are lower than those to be maintained in the conditioned space.

air−conditioning unit. An assembly of equipment for the air treatment to control simultaneously its temperature humidity cleanliness and distribution to meet the requirements of a conditioned space.

air cooler, dry. Removes sensible heat from the dehydrated air whenever it leaves the dehydrator at an elevated temperature.

air cooler, dry−type. A forced circulation air cooler where heat transfer is not implemented by a liquid spray while in operation.

air cooler, forced circulation. A cooler including a fan or a blower for positive circulation.

air cooler, free delivery. A cooler taking air from and discharging it directly to the space to be treaded without an element external to the cooler to impose air resistance.

air cooler, natural convection. An air cooler depending on natural convection to aid circulation.

ambient air temperature. Surrounding temperature to the environment; for example, air temperature around a dwelling.

ambient temperature, effective. For elements surrounded by air or other fluid, a suitably weighted mean between the air or fluid temperature and the mean radiant temperature of the surroundings.

auxiliary system. A supplementary heating unit to provide heat to a space when its primary unit cannot do so. This usually occurs during periods of cloudiness or intense cold, when a solar heating system cannot provide enough heat to meet the needs of the space. Also called

"back−up" system. azimuth. The angular distance east or west of the meridian in the horizontal plane.

bats. A non−rigid fibrous mat usually of rectangular cross− section, no greater than 3 m in length.

berm. A man−made mound or small hill of earth.

blanket. A non−rigid fibrous mat usually of rectangular cross section, greater than 3 m in length. bulk thermal insulation. Materials in the form of batts, blankets, slabs or loose fill, or foamed in situ.

cellulose fibre. Material of a fibrous nature made from wood. paper or vegetable fibres.

clerestorey window. A small window or row of windows high in a wall below the ceiling.

Clot. The unit of measurement for the thermal effect of clothing on the human body. One clot is an arbitrary unit of clothing Insulation equivalent to the amount of clothing needed to maintain the comfort of an Inactive person in still air at 20C for relative humidities less than 50 per cent.

collector, flat−plate. An assembly containing a panel of metal or other suitable material, usually of flat black colour, that absorbs sunlight and converts it into heat. This panel is usually In an insulated box, covered with glass or plastic on the sun side to retard heat loss. In the collector, this heat transfers to a circulating liquid (such as water, oil or antifreeze) in which It is transferred to where it is used immediately or stored for later use. collector, solar. Any device for capturing solar energy. comfort zone. The limits to thermal comfort as defined by any combination of humidity and environmental temperature which gives thermal comfort, usually expressed In a graph with boundary (or limit) conditions shown, given certain other factors as constant, such as air movement, level of activity and metabolic condition among others. comfort zone, average. The range of effective temperatures over which the majority (50 per cent or more) of adults feels comfortable. comfort zone, extreme. The range of effective temperatures over which one or more adults feel comfortable. condensation. Process of changing a vapour into liquid by extracting heat; the process occurs when the vapour temperature falls below its dew−point temperature. conductance, thermal. Time rate of heat flow through a body (frequently per unit area) from one of its bounding surfaces to the other for a unit temperature difference between the two surfaces under steady conditions. conduction (thermal). Transfer of heat from one portion of a medium to another without visible motion of the medium. conductivity (K). The quantity of heat that will flow through 1 sq m of material, 1 m thick. in 1 hour, when there is a temperature difference of 1 °C between its surfaces. conductivity, thermal. Time rate of heat flow through unit area and unit thickness of homogeneous material under steady conditions when a unit temperature gradient is maintained in the direction perpendicular to area. conductor, thermal. A material which readily transmits heat by means of conduction. convection. The transfer of heat from one part of a fluid (or gas) to another by flow of the fluid (or gas) from hotter parts to the colder (e.g., rising hot air). convector. An agency of convection. In heat transfer, a surface designed to transfer its heat to a surrounding fluid largely or wholly by convection. The heated fluid may be removed mechanically or by gravity connector). Such a surface may not be enclosed or concealed. cooling (evaporative). Heat exchange between air and water spray or wetted surface. The water assumes the wet−bulb temperature of the air. cooling cdl. An arrangement of pipe of tubing which transfers heat from air to refrigerator or cooling medium within the tube. cooling medium. Any substance the temperature of which Is such that it Is used, with or without change of state. to lower the temperature of other bodies or substances. degree day (dd) heating. An expression of a climatic heating requirement expressed by the difference In degrees C below the average outdoor temperature for each day and an established indoor temperature base of 18.3°C. The total number of degree days over the heating season indicates the relative severity of the winter in that area. dehumiditication. (1) Condensation of water vapour from air by cooling below the dew point. (2) Removal of water vapour from air by chemical or physical methods. dehumidifier. (1) An air cooler or washer used for lowering moisture content of the air passing through H. (2) An absorption or absorption device for removing moisture from air. dehumidifier, surface. An air−conditioning unit, designed primarily for cooling and dehumiditying air through the action of passing the air over wet cooling coils. dew point.

Temperature at which gas containing a condensible vapour (e.g., moist air) becomes saturated and deposits liquid (dew). dew point temperature. The temperature at which condensation of water vapour In a space begins for a given state of humidity and pressure as the vapour temperature is reduced: corresponding to saturation (100 per cent relative humidity) for a given absolute humidity at constant pressure. diffuse radiation. Radiation that has been scattered by particles in the atmosphere, such as air molecules, dust and water vapour. direct radiation. Direct light from the sun, as opposed to diffuse sky radiation. double glaring. A form of glazing which incorporates two panes of glass separated by a vacuum, substantially stationary air or other gas. dry bulb temperature. Temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation. dwelling patterns. The way in which people use a dwelling during their normal daily lives. effective temperature. An American concept which corresponds to the British "equivalent temperature" and was developed by the ASHVE from 1923 onwards. It takes into consideration the temperature. humidity, and speed of movement of the air but does not consider radiation. See comfort zone. efficiency. In solar applications refers to the percentage of the solar energy incident on the face of a solar collector that ends up in use either for water heating or for space heating. emission factor, effective (E). The ratio of the thermal radiation emitted from the same area of a full emitted (black body) at the same temperature. emission factor, spectral (E). The emission factor at a given wave−length interval. emissivity. The capacity of a material to emit radiant energy. Emitance is the ratio of the total radiant flux emitted by a body to that emitted by an ideal black body at the same temperature. energy. Is defined as the capacity to perform work. All work is a consequence of a change of energy from one form to another. environmental temperature. The environmental temperature combines the effects of air temperature and the mean radiant temperature of surrounding surfaces. (This publication uses environmental temperature in preference to "effective temperature"). exfiltration. Air flow outward through a wall, leak membrane etc. frame construction. Any type of construction in which building is supported mainly by a frame, and not mainly by load− bearing walls. Brick−veneer houses, steel−framed buildings, and reinforced−concrete frame buildings all belong to this type. glass fibre (fibreglass, fiberglass). Mineral wool produced from molten glass. glasshouse effect. Refers to the characteristic tendency of some transparent materials such as glass to transmit shortwave radiation and block radiation of longer wavelengths, thus allowing the sun's energy to pass into a space (or glasshouse) but blocking the reradiation energy, causing the space to heat up. heat. Form of energy that Is transferred by virtue of a temperature difference. heat conductor. A material capable of readily conducting heat; opposite of an insulator or insulation. heat exchange. The process of using two streams of fluid for heating or cooling one or the other. heat exchanger. A device specifically designed to transfer heat between physically separated fluids. heat gain. An increase In the amount of heat contained in a space, resulting from direct solar radiation and the heat given off by people, lights, equipment, machinery and other sources. heat loss. A decrease in the amount of heat contained in a space, resulting from heat flow through walls, windows, roof and other building envelope components. heat pump, cooling and heating. A refrigerating system designed to utilize alternately or simultaneously the heat extracted at a low temperature and the heat rejected at a higher temperature for cooling and heating functions respectively. heat sink. A component (surface, volume or mass) that will conduct (and radiate) heat away from where the heat is being used or where it is not required. (Heat sinks into the heat sink.) heat transmission. Any time rate of heat flow; usually refers to conduction, convection, and radiation combined. heat transmission co−efficient. Anyone of a number of coefficients used In calculating heat transmission by conduction, convection. and radiation, through various materials and structures. humidity. Absolute humidity is the weight of moisture present in a unit volume of air. Relative humidity Is the ratio of absolute humidity to the amount of moisture which the same mass and volume of air could hold at a given temperature.

Infiltration. The uncontrolled movement of outdoor air into the interior of a building through cracks around windows and doors or in walls, roofs and floors. inorganic insulation materials. Thermal insulation material made from minerals such as rock, slag, glass and clay, which are processed by exfoliation, aeration or by the formation of fibres from the molten state. insulation, thermal. A material having a relatively high resistance to heat flow and used principally to retard heat flow. isotropic. Said of a medium, the physical properties of which do not vary with direction. joule. Is the international standard (SI) unit for energy and it is denoted by the symbol "J". The joule is a very small unit, 3.6 million of them are equal to 1 kilowatt−hour. kilowalt−hour (kWh). Is the unit that is used for measuring the quantity of energy consumed per hour. For example, If a 1000−watt (single bar) electric radiator is swiched on for one hour it will consume 1 kWh of electrical energy; the same amount of energy would be required to light a

100 watt lamp for 10 hours. The unit of electrical energy that is recorded on domestic electricity meters is in kilowatt−hours. macroclimate. The general climate of a substantial part of the country or a region. mean radiant temperature (MRT). The temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing non−uniform environment. microclimate. The physical state of an atmosphere close to a very small area of a region. mineral wool. Fibres normally made from molten glass, rock or slag, commonly supplied in the form of a bats, blanket a loose fill. See also

rock wool, slag wool. night sky radiation. Under cool clear night sky conditions the earth and structures will radiate stored heat. The clear night sky acts as a heat sink If the air is cooler than the surrounding elements. non−renewable fuels. Fuels derived from fossil remains such as coal, oil, or gas and not capable of being replenished. Although wood is used as a fuel in some cases, and timber can be replaced, the rate of growth of timber is relatively slow compared with the rate at which It is consumed. overall thermal resistance. See R value. (Note. It is calculated as the reciprocal of the overall thermal resistance of an element. The sum of the surface resistance on each side of an element and the thermal resistances of the components including any cavities In the element.) passive system. A system of exploiting natural elements in a building order to modify the indoor climate without using special equipment. For example, the low angle of the winter sun can be allowed to enter through a window to heat up a room while in summer the sun, because it is directly overhead, can be readily excluded. power. The rate at which work is done or the rate at which energy is consumed. primary energy. Is derived from a source that has not undergone any processing that alters its nature before it is converted into useful energy. Oil or coal (although refined or modified) are not changed before they are used as a fuel for combustion. The heat from an oil or natural gas fire is a primary source of energy.

R value. Thermal resistance of the passage of heat provided by an element (roof, floor, wall). It is the reciprocal of the thermal transmittance of U value. radiant flux density. Radiant flux passing through unit area (unit, watt per square metre (W/m^2)). (Note. The unit area usually considered is that normal to the radiant flux.) radiation. The direct transport of energy through space by means of electromagnetic waves. A process by which heat may be transferred from a source to a receiver without heating the intervening medium, or without the existence of a material medium. radiation draught. The draught of cold air that results from air against a window being cooled by radiation, and hence falling to the floor pulling more warm air in at the top to be chilled. reflectance. The ratio or percentage of the amount of light reflected by a surface to the amount incident. The remainder that is not reflected is either absorbed by the material or transmitted through H. reflective foil laminate. A type of reflective insulation defined in AS 1903 as a flexible sheet material, supplied In roll form. (Note. Reflective foil laminate usually comprises two outer layers of aluminium foil, forming an Integral part of the composite sheet material.) reflective Insulation. Thermal insulation having one or more surfaces of high reflection factor and low emission factor for low temperature (longwave) radiation, I.e., thermal radiation encountered within bulidings. (Notes. 1 . Reflective Insulation reduces radiant heat transfer across air spaces In a structure, and should therefore be used in conjunction with airspace. 2. Reflective insulation should not be confused with "solar reflective materials" which are intended to reflect shortwave radiation (solar radiation)). relative humidity. The ratio of the quantity of water vapour actually present in the air to that present at the same temperature in a water−saturated atmosphere. It is commonly expressed as a percentage. renewable fuels. Those fuels that can be used without any loss to the supply. These include solar energy (in all forms including wind and ocean waves which are derived from the effects of heat from the sun). and plants that grow rapidly and in large quantities (still largely in experimental stages). resistance (R). The reciprocal of conductance for a specific thickness of material. resistivity (r). The reciprocal of conductivity. rock wool. Mineral wool produced from molten rock or similar inorganic materials. root space. The space between a ceiling and roof covering. sarking membrane. A pliable membrane designed to collect and discharge any water that may penetrate a roof covering or wall cladding. secondary energy. Energy derived from a primary source. but which arrives at its point of use In a different form. Oil or coal (primary sources) are often used to create heat which is used to create steam to drive turbines that generate electricity. The electricity is wired to houses where it is converted back into heat or used to drive a labour−saving appliance. Electricity is a secondary source of energy. Gas made from coal is a secondary source of energy. skylight. A clear or translucent panel set into a roof to admit daylight into a building. solar heat gain. The amount of the sun's energy that enters a building can be measured in units represented by solar heat gain factor. This Is a measure of the amount of the sun's energy that is transmitted through a sheet of 3 mm thick glass. solar radiation. The electromagnetic radiation that is emitted from the sun. It affects temperatures inside buildings and is a significant influence on the internal climate. specific heat. The amount of heat required to increase the temperature by 1 K (unit. joule per kilogram Kelvin (j/kg.K)) stack effect. The tendency of air or gas in a duct or other vertical passage to rise when heated due to Its lower density in comparison with that of the surrounding air or gas. In buildings. the tendency towards displacement (caused by the difference in temperature) of internal heated air by unheated outside air due to the difference in density of the outside and inside air. sun position.

altitude. The angular distance above the horizon in the vertical plane. − azimuth. The angular distance east or west of the meridian in the horizontal plane. − meridian. The sun reaches its greatest altitude each day at solar noon when it crosses the meridian of the place where the observer is standing. temperature. Defined as the degree or intensity of heat of a body or atmosphere. The basic unit for measuring temperature value is the degree Celsius (°C). Temperature interval is measured in degrees Kelvin denoted by the international standard (SI) symbol K. temperature, absolute. Temperature expressed in degrees Kelvin. temperature, dew point. The temperature at which a given sample of moist air will become saturated. without change in moisture content or atmospheric pressure and below which condensation will occur. temperature, dry bulb. The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation. temperature, effective. The dry−bulb temperature of a black enclosure 50 per cent relative humidity in which a solid body or occupant would exchange the same heat by radiation convection. and evaporation as the existing non−uniform environment. thermal conductance. The quotient of the steady rate of heat flow normal to unit area of a planar element and the difference between the surface temperatures on either side of the element (unit. Watt per square metre Kelvin ($W/m^2.K$)). (Notes. 1. The value of thermal conductance is peculiar to the specific geometric configuration of the particular body or assembly. 2. Conductance differs from overall heat transfer co−efficient in that the temperatures used in the calculation differ. For conductance. the temperature Is the surface temperature of the faces of the element. For overall heat transfer co−efficient. it is the effective ambient temperature on either side of the element. Thus the overall heat transfer co−efficient (U) involves both the thermal conductance and the surface coefficients of the element.) thermal conductivity (k). The quantity of heat under steady−state conditions passing in unit time through unit area of a homogeneous material of infinite extent with flat and parallel faces and unit thickness when unit temperature difference is maintained between these faces (unit.

Watt per metre (W/m.K)). (Notes. 1. Materials may be considered as homogeneous when the value of thermal conductivity is not affected by variations in thickness or in area within the range normally used. 2. A thermal conductivity value should be identified with respect to: (a) mean temperature. since it may vary with temperature; (b) direction of heat flow and orientation of sample. since some materials are not isotropic with respect to heat flow: and (c) factors such as density, porosity. moisture content, fibre diameter and pore size.) thermal diffusivity (D). The quotient of the thermal conductivity and the thermal capacity per unit volume of a material (unit. square metre per second (m^2/s)). thermal insulation. A material or assembly of materials used to provide resistance to heat flow. thermal isolation. The ability to isolate a body from the thermal affects of the climate. thermal mass. The amount of potential heat storage capacity available in a given assembly or system. Drum walls, concrete floors and adobe walls are examples of thermal mass. thermal resistance (R). The reciprocal of "thermal conductance" (unit. square metre Kelvin per watt ($m^2.K/W$)). (Notes. 1. Thermal resistance may be conceptualized as the time for unit energy to pass through unit area of a building component having unit temperature difference between its two surfaces. 2. When heat passes in succession through the components of an element the resistances can be added together and the total thus obtained is the resistance of the element.) thermal resistivity (1/k). The reciprocal of "thermal conductivity" (unit: metre Kelvin per watt (m.K/W)). thermal transmission. The amount of heat flowing per unit time under conditions prevailing at that time (unit. watt (W)). thermosyphon. The method establishing circulation of a liquid by using the slight difference In density of the hot and the cool portions of the liquid. transmission factor (T). The ratio of the radiant flux transmitted by a body to that incident upon the body. (Notes. 1. Transmission factor varies with the wavelength of the incident radiation. 2. In the case of transparent and translucent materials, such as glass, the transmission factor will vary with thickness. 3. In the case of opaque materials, the transmission factor is zero.)

U value (coefficient of heat transfer). A figure determined by experiment for a certain situation which tells how many watts per hour will pass through one square metre of the wall when the temperature difference of the air between both sides is 1 °C. It is the amount of heat transferred due to temperature differences in the air on both sides of the element. vapour. A gas, particularly one near to equilibrium with the liquid phase of the substance and which does not follow the gas laws. vapour barrier. A component used to restrict the transmission of vapour (general water vapour). ventilations. The process of supplying or removing air by natural or mechanical means to or from any space. Such air may or may not have been conditioned. volumetric heat capacity. The amount of energy (in joules) that a volume of material (m^3) can store with a 1°C rise in its temperature. watt. Is the international standard (SI) unit for power and it is denoted by the symbol "W". One watt represents one joule per second.

W/m^2K. Watts per square metre Kelvin is the international standard unit of thermodynamic temperature. The temperature interval of 1 Kelvin (K) equals of 1 °Celsius (C). wind rose. A diagram that Indicates the relative direction, frequency and mean velocity of winds for a given location.

Annex III: Metric units of measurements

When studying thermal design of buildings, thermal comfort, solar energy and other related areas a number of units of measurement will be repeatedly encountered. Some will be familiar whilst others may not. To help clarify these the following information is provided.

Preferred multiples and submultiples

Prefix	Symbol	Factor	Magnitude
tera	T	10^{12}	1000000000000
giga	G	10^{9}	1000 000 000
mega	M	10^{6}	1000 000
kilo	k	10^{3}	1000
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000.001
nano	n	10^{-9}	0.000000001
pico	p	10^{-12}	0.000000001

Reference: Metric Handbook (SAA−MHI)

Temperature is measured in degrees Celsius (°C); this unit replaces degrees Farenheit (°F) the conversion being:

$$(^{\circ}F - 32) x \frac{5}{9} = ^{\circ} C$$

In scientific work one may often encounter the Kelvin scale (°K). This scale has the same interval as °C but the starting point, known as absolute zero is equal to −273.15°C. i.e. 0°C = 273.15°K and a temperature difference of 5 deg C is the same as a temperature difference of 5 deg.K.

Note: The temperature of an object is written "°C" whilst the difference in temperature of two objects is written "deg.C".

The following are commonly used terms:

T = temperature difference (delta T)
Ta= ambient temperature (usually the air temperature surrounding the object concerned).
T = outside air temperature (usually dry−bulb temperature)
Ti = inside air temperature
Tei = environmental temperature

Work, heat and energy are measured in units called Joules (j)

1 joule = 1 watt for 1 second = rate of energy flow × time = a quantity

The unit of heat flow, energy flow or power Is the watt (W) as shown above.

Generally quantities of energy or heat in relation to buildings will be given in Mj, Gj or kWh. Heat or energy flow rates will be W or kW.

1 kWh=3.6MJ

(1000W × 3600 sec = 3 600 000 J = 3.6 MJ)

Many large single bar electric radiators give out heat at a rate of 1000W. Such a radiator would therefore consume 1 kWh of energy in one hour.

It is preferable to refer to quantities of heat or energy in Joules rather than watt−hours to avoid confusion with the watt.

Density of heat flow rate

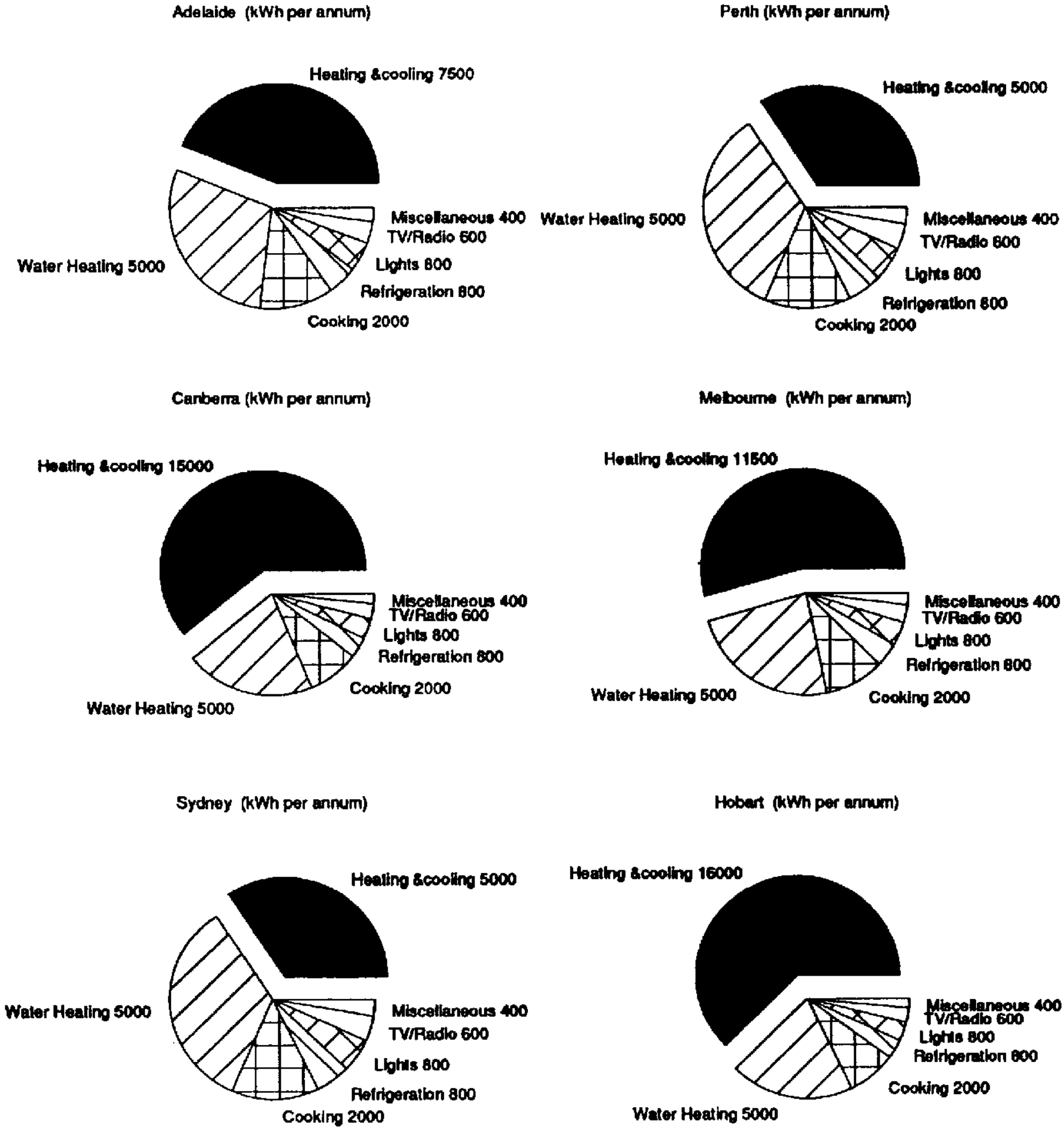
If the total rate of heat flow from an identifiable unit is to be measured (such as heat loss from a given building or the radiation received from the sun) the unit of measurement is the watt (W or kW). The density of that flow rate (or intensity) is measured per unit area. Therefore the density or intensity of heat flow or solar radiation is measured in W/m².

Annex IV: Typical internal heat loads for appliances

Appliance	Average Input (W)	Average weekly hours of use	Estimated quarterly consumption (kWh)	Period of use for 1 kW	
Heating					
Convection heater	1000	112	546	1h	
with thermostat	2000	112	1079		30 min
Fan heater	2400	112	1300		25 min
with thermostat	3500	112	1885		17 min
Infrared heater	550	3.5	26	1h	49 min
	1100	35	507		55 min
Panel radiators	1500	112	806		40 min
oil filled	2000	112	1079		30 min
Radiators, fires	2000	21	546		30 min
	2400	21	650		25 min
Heat storage					
Heat banks	3000	112	247		20 min
	6000	112	494		10 min
Midi bank	2000	168	1040		30 min
	3500	168	1820		17 min
Coolers– air–conditioning					
	2500W	1400	112	559	43 min
	6000W	2900	112	1170	20 min
Water heaters:					
Bath heater	1000	–	299	1h	
Sink heater	750	–	195	1h	35 min
Day rate continuous					
2 people	3600	–	650	1 h	35 min
Storage off–peak					
2 people	2500	–	780		24 min
4 people	3500	–	1170		17 min
Lighting					

100W incandescent	100	30	39	10h	lamps
60W incandescent	60	30	23	16	36 min
40W fluorescent	50	30	20	20h	
Kitchen appliances					
Blender	450	1	6	2h	13 min
Cooking					
Deep fryer	1500	1	13		40 min
Frypan	1350	3	26		45 min
Horizontal grill	1500	1.5	30		40 min
Microwave	1200	3.5	55		50 min
Ranges:					
Light use	7000	–	209		8 min
Heavy use	10,000	–	416		6 min
Dishwasher	2300	7	46		26 min
Electric kettle	1500	4	78		40 min
Freezers:					
Chest type 200L	160	–	269	6h	15 min
Vertical type 310L	200	–	338	5h	
Percolator	650	3.5	30	1 h	32 min
Refrigerators:					
Small 70L/absorption	125	–	140	8h	
1 door manual defrost	170	–	130	5h	33 min
2 door automatic defrost 410L	230	–	247	4h	21 min
2 door frost–free	280	–	468	3h	32 min
General appliances					
Clothes driers:					
Rotary plug–in	2400	5	156		25 min
Cabinet with fan	2400	3	91		25 min
Clothes washer:					
Automatic	900	6	70	1 h	7 min
With heater	2400	14	260		25 min
Electric blanket:					
Double bed	120	35	49	8h	20 min
Fan (over 250 mm)	85	7	8	11	45 min
Iron – steam	1000	3	12	1h	

Radio	60	28	22	16	40 min
Sewing machine	75	2	2	13	10 min
Stereo system	78	21	21.3	12	50 min
Toaster auto	1300	1	17		46 min
TV−colour	200	30	78	5h	
Vacuum cleaner	500	1.5	10	2h	



Energy use within the home (Selected capital cities)

Annex V: Minimum additional thermal resistance requirements

Locality	R1−value	R1−value ext.walls ceilings
Adelong	1.5	3.5
Albury	1.0	3.5
Ardlethan	1.0	3.0
Armidale	1.0	3.5
Badgerys Creek	–	2.0
Balranald	1.0	2.5
Bankstown	–	2.0
Baradine	1.0	2.5
Barraba	1.0	3.0
Bathurst	1.5	3.5
Bega	1.5	3.5
Bellingen	–	1.5
Berrigan	1.0	3.0
Bingara	–	2.0
Black Springs	1.5	3.5
Blayney	1.5	3.5
Bombala	1.5	3.5
Bondi Forest	1.5	3.5
Boorowa	1.5	3.5
Bourke	–	1.5
Bowral	1.5	3.5
Braidwood	1.5	3.5
Brewarrina	–	1.5
Broken Hill	1.0	2.5
Brookfield	1.5	3.5
Bundarra	1.0	3.0
Burrinjuck	1.5	3.5
Cabramurra	1.5	3.5
Camden	–	2.0
Campbelltown	–	2.0
Canberra	1.5	3.5
Canobalas	1.5	3.5
Canowindra	1.0	3.0
Carabost	1.5	3.5
Carcoar	1 5	3.5
Cassilis	1.0	3.0
Centennial Park	–	1.5
Cessnock	–	2.0
Charlott Pas	1.	3.5
Clouds Creek	1.0	3.0
Cobar	–	2.0
Coffs Harbour	–	1.5
Collarenebri	–	1.5
Condobolin	1.0	3.0
Coolah	1.0	3.0

Coolongolook	–	2.0
Coonabarabran	3:o	3 5
Coonamble	–	2.0
Coopernook	–	1.5
Cootamundra	1.5	3.5
Corowa	1.0	3.0
Cowra	1.5	3.5
Crookwell	1.5	3.5
Cumberland	–	2.0
Deepwater	1.5	3.5
Deniliquin	1.0	2.5
Dubbo	1.0	3.0
Dunedoo	1.0	3.0
Dungog	–	2.0
East Maitland	–	2.0
Euston	1.0	3.0
Finley	1.0	3.0
Forbes	1.0	3.0
Frogmore	1.5	3.5
Gilgandra	1.0	2.5
Girard	1.0	3.0
Glen Innes	1.5	3.5
Gienfield	–	2.0
Glenorie	–	2.0
Goodooga	–	1.5
Goulburn	1.5	3.5
Green Cape	1.0	3.0
Grenfell	1.0	3.0
Griffith	1.0	3.0
Gudgenby	1.5	3.5
Gulgong	1.0	3.0
Gundagai	1.0	3.0
Gunneaah	–	2.0
Guyra	1.5	3.5
Harden	1.5	3.5
Harrington	–	1.5
Hay	1.0	2.5
Hillston	1.0	2.5
Hoisworthy	–	2.0
Honeysuckle Crk	.5	3.5
Hume Weir	1.0	2.5
Inverell	1.5	3.0
Ivanhoe	1.0	2.5
Jenolan Caves	1.5	3.5
Jerrys Plains	–	2.0
Jervis Bay	–	2.0
Junee	1.0	3.0
Katoomba	1.5	3.5
Kendall	–	1.5
Khancoban	1.5	3.5

Kiandra	1.5	3.5
Kirkconnell	1.5	3.5
Kulnura	1.0	2.5
Lake Cargelligo	.0	2.5
Lake Victoria	1.0	2.5
Laurel Hill	1.5	3.5
Leeton	1.0	2.5
Lidsdale	1.5	3.5
Lithgow	1.5	3.5
Liverpool	–	2.0
Lostock	–	2.0
Lucas Heights	–	2.0
Maitland	–	2.0
Marsfield	–	2.0
Maryville	–	1.5
Mathoura	–	2.5
Menindee	–	2.0
Merimbul	1.	3.0
Millthorpe	1.5	3.5
Moira	1.0	3.0
Molong	1.5	3.5
Monkstadt	1.0	2.5
Montague Island	–	20
Moree	–	2.0
Moruya Heads	1.0	2.5
Moss Vale	1.5	3.5
Moulamein	1.0	2.5
Mount Hope	1.0	2.5
Mt. Mitchell	1.5	3.5
Mount Topper	1.0	3.0
Mount Victoria	1.5	3.5
Mudgee	1.0	3.0
Mullion Creek	1.5	3.5
Mungindi	–	1.5
Murraguldrie	1.5	3.5
Murrurundi	1.0	3.0
Muswellbrook	1.0	2.5
Nalbaugh	1.5	3.5
Naradhan	1.0	2.5
Narara	1.0	2.5
Narooma	1.0	3.0
Narrabri	–	2.0
Narrandera	1.0	2.5
Nelson Bay	–	1. 5
Nerrilga	1.5	3.5
Newcastle	–	1.5
Newnes	1.5	3.5
Nimmitabel	1.5	3.5
Nowra	1.0	2.5
Nyngan	–	2.0

Oberon	1.5	3.5
Olney	1.0	2.5
Orange	1.5	3.5
Orchard Hills	–	2.0
Orroral Valley	1.5	3.5
Parkes	1.0	3.0
Parramatta	–	1.5
Paterson	–	2.0
Peak Hill	1.0	2.5
Picton	1.0	2.5
Port Macquarie	–	1.5
Prospect	–	2.0
Quambone	–	2.0
Quandialla	1.0	3.0
Quirindi	1.0	2.5
Rathmines	–	1.5
Raymond Terrace	.0	2 5
Red Hill	1.5	3 5
Richmond	–	2.0
Riverview	–	1.5
Sandy Hollow	1.0	2.5
Scone	1.0	2.5
Seven Hills	–	2.0
Singleton	–	2.0

Annex VI: Climate data for Sydney region – mean daily insolation for Sydney

Mean daily solar radiation on surfaces of various orientations

Average for years 1972–1976 computed from measured hourly global insolation on a horizontal surface (University of New South Wales)

(Bugler Solar Energy Journal vol. 19 (1977), p.477) –34 deg. latitude

Vertical surface oriented	Azimuth degrees	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
S	180.0	8.1	6.4	5.2	4.0	3.0	2.5	2.8	3.8	5.2	6.5	8.3	9.2	5.4
SSE	157.5	8.7	7.2	5.5	4.1	3.0	2.5	2.8	3.8	5.4	7.2	9.1	10.0	5.8
SE	135.0	10.2	8.6	6.4	4.8	3.2	2.7	3.1	4.5	6.6	8.7	10.6	11.5	6.7
ESE	112.5	11.3	9.8	7.6	6.1	4.3	3.6	4.5	6.2	8.2	10.1	11.8	12.5	8.0
E	90.0	11.8	10.6	8.8	7.8	6.0	5.3	6.7	8.1	9.8	11.2	12.4	12.9	9.3
ENE	67.5	11.5	10.8	9.6	9.3	8.0	7.1	9.1	9.8	11.1	11.6	12.4	12.5	10.2
NE	45.0	10.7	10.4	10.0	10.6	10.0	9.0	11.4	11.2	11.9	11.4	11.6	11.4	10.8
NNE	22.5	9.3	9.6	10.2	11.7	12.0	10.7	13.5	12.2	12.3	10.8	10.4	9.9	11.1
N	0.0	8.5	9.0	10.5	12.6	13.3	11.4	14.3	12.6	12.6	10.1	9.5	9.2	11.2
NNW	-22.5	9.7	9.9	11.0	12.3	13.1	10.8	13.4	11.7	12.4	10.4	10.5	10.2	11.3
NW	-45.0	11.6	10.9	11.2	11.4	11.5	9.0	11.3	10.3	12.1	11.0	12.0	12.0	11.2
WNW	-67.5	12.8	11.4	10.9	10.2	9.5	7.1	8.9	8.9	11.4	11.1	13.0	13.3	10.7
W	-90.0	13.2	11.3	10.1	8.6	7.3	5.3	6.6	7.4	10.2	10.7	13.1	13.8	9.8
WSW	-112.5	12.7	10.5	8.7	6.8	5.2	3.8	4.6	5.8	8.6	9.7	12.5	13.4	8.5
SW	-135.0	11.4	9.0	7.1	5.1	3.6	2.7	3.2	4.5	6.9	8.5	11.1	12.1	7.1
SSW	-157.5	9.4	7.4	5.7	4.1	3.0	2.5	2.8	3.8	5.6	7.2	9.4	10.3	5.9
S	-180.0	8.1	6.4	5.2	4.0	3.0	2.5	2.8	3.8	5.2	6.5	8.3	9.2	5.4
SHGF	5.7	6.5	8.2	10.5	11.4	9.8	12.2	10.5	9.8	7.2	6.3	6.2		
SHGF/25%	3.5	3.8	5.7	8.5	9.8	8.6	10.5	8.5	6.8	4.2	3.9	4.5		
SHGF/50%	3.3	2.2	3.3	6.4	8.1	7.3	8.8	6.4	3.9	2.4	3.6	4.2		
SHGF/100%	2.9	2.0	1.5	2.4	4.9	4.8	5.3	2.4	1.7	2.2	3.3	3.8		

VERTICAL SURFACES mean insolation Mj/m² day

Annex VII: Selected thermal properties of various building material

Material	Density (kg/m³)	Thermal conductivity k(W/m.k)
Asbestos (Fibre cement)	1490	0.32
Brick common (individual)	1970	1.42
brickwork (including mortar)		1.15
Cement render		0.532
Concrete		
1:2:4	2400	1.44
Fibreboard	215	0.062 at 23°C
	215	0.048 at 21°C
Glass float, window	2510	1.05
Glass fibre insulation batts (generally specified by R value rather than thickness)	12	0.042
Linoleum inlaid	1300	0.22
Particle board		
(wood chips bonded with resin)	480	0.108
Plaster (wall finish)	0.46	

Polystyrene expanded (white board) extruded (blue)	24	0.036
Polyurethane rigid, foamed new	24	0.016
rigid, foamed aged	24	0.025
Rock wool batts	48	0.035
Sandstone	2000	1.30
Slate	2650	1.50
Steel mild	7850	47.5
Straw compressed, faced with paper	320	0.081
slabs of compressed wheat straw, wire	213	0.041
Timber hardwood	660	0.14
pitch pine	660	0.14
plywood	530	0.14
Ureaformaldehyde foam	8	0.038
Vermiculite loose granules	80	0.065
Vinyl (floor tiles)	2050	0.79
Vinyl−asbestos semi−flexible floor covering	1970	0.05
Water	1000	0.60

Thermal resistance of various hallow or irregular materials (substitute resistance (R) for b/k in U−value calculations.)	
Material	**Resistance (R) M².C/W**
100 mm concrete block (hollow)	0.125
200 mm concrete block (hollow)	0.195
300 mm concrete block (hollow)	0.225
cement roofing tiles	0.014

Annex VIII: Selected u−values and r−values

U−values for solid floors in contract with the earth with tour exposed edges

Dimensions of floor	U−value (W/mN.degC)
Very long × 30 m broad	0.16*
Very long × 15 m	0.28*
Very long × 7.5m	0.48*
150 m × 60 m	0.11
150 m × 30 m	0.18
60 m × 60 m	0.15
60 m × 30 m	0.21
60 m × 15 m	0.32
30 m × 30 m	0.26
30 m × 15 m	0.36
30 m × 7.5 m	0.55
15 m × 15 m	0.45
15 m × 7.5 m	0.62
7.5 m × 7.5 m	0.76
3 m × 3 m	1.47

* This value applies also for any floor of this breadth and losing heat from two parallel edges. (Breadth here is the distance between exposed edges.)

Corrections to the above values for edge insulation floors

Dimensions of floor	Percentage reduction in U–value for edge Insulation extending to a depth (m)		
	0.25	**0.5**	**1.0**
Very long × 150m	2	6	10
Very long × 60m	2	6	11
Very long × 30m	3	7	11
Very long × 30m	3	8	13
Very long × 6m	4	9	15
Very long × 2m	6	15	25
150m × 150m	3	10	15
60m × 60m	4	11	17
30m × 30m	4	12	18
15mx 15m	5	12	20
6mx6m	6	15	25
2mx2m	10	10	35

Basic thermal resistance values for suspended floors directly above ground

Actual floor dimension Thermal resistance 1/ft + Rair + Re $(m^2.°C/W)$

Very long × 30m broad	5.3
Very long × 15m	2.8
Very long × 7.5m	1.7
150m × 60m	7.1
150m × 30m	4.6
60m × 60m	5.9
60m × 30m	4.0
60m × 15m	2.5
30m × 30m	3.4
30m × 15m	2.3
30m × 7.5m	1.6
15rn × 15m	2.0
15rn × 7.5m	1.4
7.5m × 7.5m	1.3
3m × 3m	0.8

The U–value of suspended floors can be estimated from this table where height above ground is not greater than approximately 1.5m and ventilation is limited. (The literature gives ventilation as $2000mm^2$ per 1000mm of perimeter.)

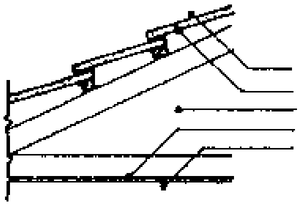
$$U = \frac{1}{R_s + 1/f_i + R_{air} + R_e}$$

1/fi = inside surface resistance
Rair = air space resistance vented as specified above
Re = resistance of the earth

Refer to table above for suspended floors. Source: IHVE Guide 1977–A3

Tiled roof systems **U-value (W/m^2.degC)**

1.

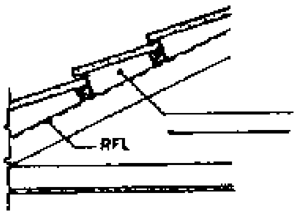


1. Outside air film
2. Tiles
3. Attic space
4. Plasterboard 12mm
5. Inside air fil

Winter 4.18

Summer 1.35

2.

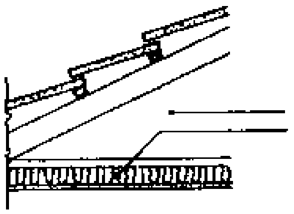


1. Outside air film
2. Tiles
3. Air space 20mm.
4. Attic space (RFL)
5. Plasterboard 12mm.
6. Inside air film

Winter 1.06

Summer 0.64

3.

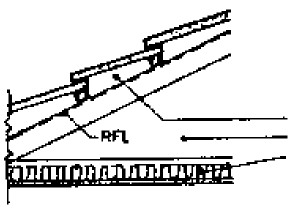


1. Outside air film
2. Tiles
3. Attic space
4. Glass fibre R2.0
5. Plasterboard 12mm.
6. Inside air film

Winter 0.45

Summer 0.36

4.



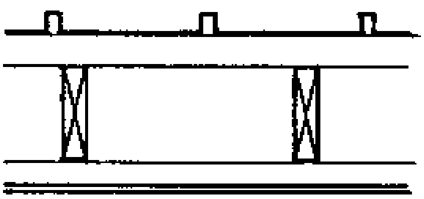
1. Outside air film
2. Tiles
3. Air space 20mm
4. Attic space (RFL)
5. Glass fibre R2.0
6. Plasterboard 12mm.
7. Inside air film

Winter 0.34

Summer 0.28

Metal deck roof systems **U-value (W/m^2.degC)**

1.

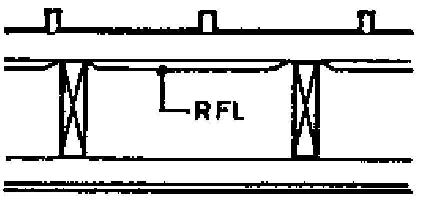


1. Outside air film
2. Metal deck
3. Air space
4. Plasterboard 12mm
5. Inside air film

Winter 2.66

Summer 2.05

2.

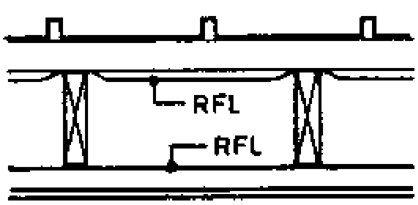


1. Outside air film
2. Metal deck
3. Air space 40mm
4. Air space (RFL)
5. Plasterboard 12mm
6. Inside air film

Winter 1.38

Summer 0.49

3.

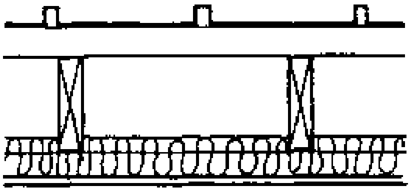


1. Outside air film
2. Metal deck
3. Air space 40mm
4. Air space (RFL)
5. Air space 25mm (RFL
6. Plasterboard 12mm
7. Inside air film

Winter 0.98

Summer 0.38

4.

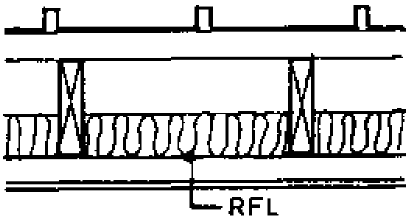


1. Outside air film
2. Metal deck
3. Air space
4. Glass fibre R2.0
5. Plasterboard 12mm
6. Inside air film

Winter 0.42

Summer 0.40

5.

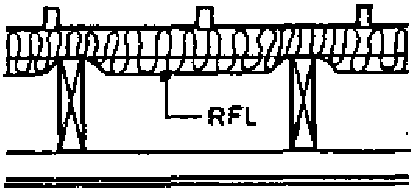


1. Outside air film
2. Metal deck
3. Air space
4. Glass fibre R2.0
5. Air space (RFL)
6. Plasterboard 12mm
7. Inside air film

Winter 0.37

Summer 0.32

6.



1. Outside air film
2. Metal deck
3. Glass fibre R2.0
4. Air space
5. Plasterboard 12mm
6. Inside air film

Winter 0.39

Summer 0.26

Concrete roof systems

U-value ($W/m^2.degC$)

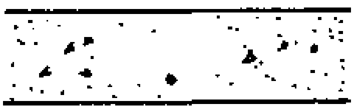
1.

1. Outside air film
2. Concrete slab 100mm
3. Inside air film

Winter 4.55

Summer 3.79

2.



1. Outside air film
2. Concrete slab 150mm
3. Inside air film

Winter 3.94

Summer 3.34

3.

1. Outside air film
2. Concrete slab 100mm
3. Glass fibre R1.5
4. Plasterboard 12mm
5. Inside air film

Winter 0.56

Summer 0.54

4.

1. Outside air film
2. Cocnrete slab 150mm
3. Glass fibre R1.5
4. Plasterboard 12mm
5. Inside air film

Winter 0.55

Summer 0.53

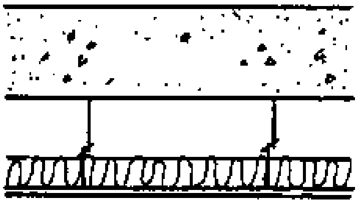
5.

1. Outside air film
2. Concrete slab 100mm
3. Air space 100mm
4. Glass fibre R1.5
5. Plasterboard 12mm
6. Inside air film

Winter 0.51

Summer 0.49

6.



1. Outside air film
2. Concrete slab 150mm
3. Air space 100mm
4. Glass fibre R1.5
5. Plasterboard 12mm
6. Inside air film

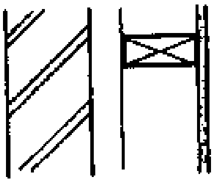
Winter 0.51

Summer 0.48

Brick-veneer and brick wall systems

U-value ($W/m^2.degC$)

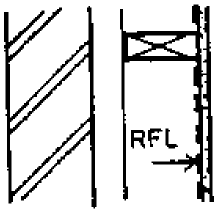
1.



1. Outside air film
2. Brickwork 110mm
3. Air space 140mm
4. Plasterboard 12mm
5. Inside air film

U-value: 1.95

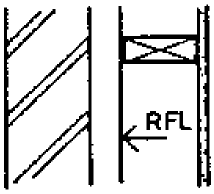
2.



1. Outside air film
2. Brickwork 110mm
3. Air space 140mm (RFL)
4. Plasterboard 12mm
5. Inside air film

U-value: 1.23

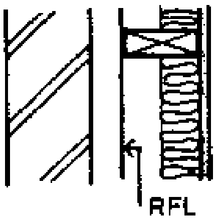
3.



1. Outside air film
2. Brickwork 110mm
3. Air space 50mm (RFL)
4. Air space 90mm (RFL)
5. Plasterboard 12mm
6. Inside air film

U-value: 0.77

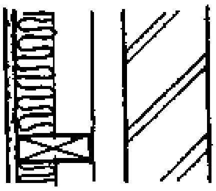
4.



1. Outside air film
2. Brickwork 110mm
3. Air space 90mm
4. Glass fibre R1.5
5. Plasterboard 12mm
6. Inside air film

U-value: 0.50

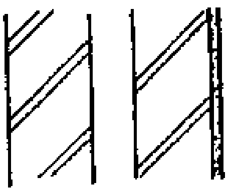
5.



1. Outside air film
2. Brickwork 110mm
3. Air space 45mm (RFL)
4. Air space 90mm (RFL)
5. Glass fibre R1.5
6. Plaster
7. Inside air film

U-value: 0.35

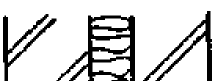
6.



1. Outside air film
2. Brickwork 110mm
3. Air space 55mm
4. Brickwork 110mm
5. Plaster 15mm
6. Inside air film

U-value: 1.75

7.

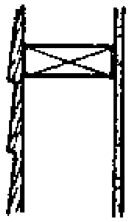


1. Outside air film

Weatherboard wall systems

U-value (W/m^2.degC)

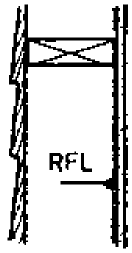
1.



1. Outside air film
2. Weatherboard 12mm
3. Air space 100mm
4. Plasterboard 12mm
5. Inside air film

U-value: 1.98

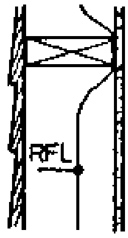
2.



1. Outside air film
2. Weatherboard 12mm
3. Air space 100mm (RFL)
4. Plasterboard 12mm
5. Inside air film

U-value: 1.25

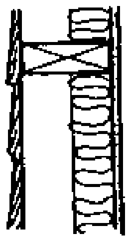
3.



1. Outside air film
2. Weatherboard 12mm
3. Air space 50mm (RFL)
4. Air space 50mm (RFL)
5. Plasterboard 12mm
6. Inside air film

U-value: 3.75

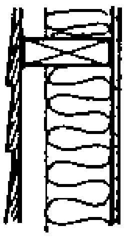
4.



1. Outside air film
2. Weatherboard 12mm
3. Air space 50mm
4. Glass fibre R1.5
5. Plasterboard 12mm
6. Inside air film

U-value: 0.50

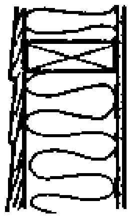
5.



1. Outside air film
2. Weatherboard 12mm
3. Air space 25mm
4. Glass fibre R2.0
5. Plasterboard 12mm
6. Inside air film

U-value: 0.40

6.



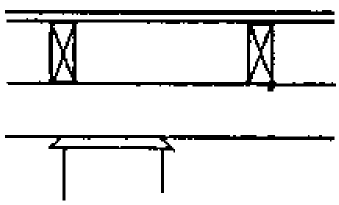
1. Outside air film
2. Weatherboard 12mm
3. Glass fibre R2.5
4. Plasterboard 12mm
5. Inside air film

U-value: 0.35

Timber and concrete floor systems

U-value (W/m^2.degC)

1.

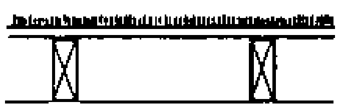


1. Inside air film
2. Floorboards 20mm
3. Outside air film

Winter
2.16

Summer
2.83

2.



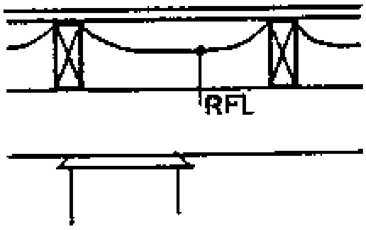
1. Inside air film
2. Carpet with underfelt
3. Floorboards 20mm
4. Outside air film

Winter
1.24

Summer

U–values for various constructions (Continued)

3.

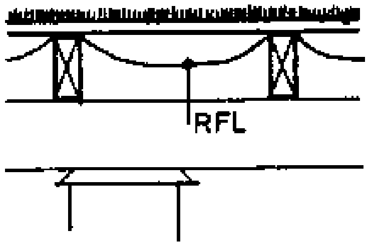


1. Inside air film
2. Floorboards 20mm
3. Air space 20mm
4. Outside air film (RFL)

Winter
0.78

Summer
1.63

4.



1. Inside air film
2. Carpetand underfelt
3. Floorboards 20mm
4. Air space 20mm
5. Outside air film (RFL)

Winter
0.60

Summer
1.04

5.

1. Inside air film
2. 125mm concrete slab 0.68
on ground.

6.

1. Inside air film
2. 125mm concrete slab
3. Outside air film

Winter
2.43

Summer
332

7.

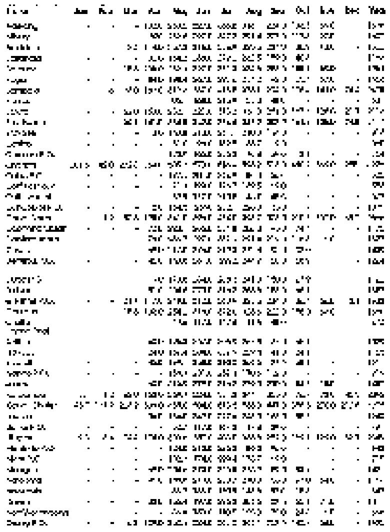
1. Inside air film
2. Carpet and underfelt
3. 125mm Concrete slab
(suspended)
4. Outside air film

Winter
1.32

Summer
1.54

U–values for various constructions (Continued)

Annex IX: Heating degree day data – new south Wales



HEATING DEGREE DAYS (base 18.3°C) – SYDNEY REGION

Parke P.O.	-	-	-	18.0	176.7	237.0	291.4	241.8	159.0	40.3	-	-	1164
Por Macquarie	-	-	-	-	86.8	141.0	179.8	155.0	81.0	31.0	-	-	675
Tamworth	-	-	-	3.0	161.2	228.0	285.2	235.6	144.0	27.9	-	-	1085
Taree	-	-	-	-	102.3	156.0	204.6	170.5	196.0	-	-	-	730
Thredb Village	136.4	137.2	226.3	312.0	440.2	495.0	551.8	508.4	414.0	331.7	282.0	189.1	4024
Tibooburra	-	-	-	-	86.8	168.0	207.7	158.1	36.0	-	-	-	657
Wagga	-	-	-	60.0	207.7	282.0	325.5	272.8	204.0	83.7	9.0	-	1445
Walget P.O.	-	-	-	-	102.3	174.0	223.2	164.3	60.0	-	-	-	724
Wentworth	-	-	-	27.0	148.8	210.0	260.4	207.7	117.0	12.4	-	-	984
Wlicanni P.O.	-	-	-	-	120.9	195.0	232.5	176.7	42.0	-	-	-	767
Yass	-	-	15.5	135.0	285.2	345.0	384.4	334.8	267.0	158.1	84.0	-	2009
Young	-	-	-	96.0	244.9	309.0	356.5	313.1	234.0	117.8	45.0	-	1716

HEATING DEGREE DAYS (base 18.3°C) – SYDNEY REGION

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sydney Office					78	138	174	143	78	10			609
Mascot					109	168	208	174	105	25			788
Lucas Heights				12	121	180	217	186	114	40			870
Campbelltown				24	143	207	251	211	129	47			1011
Liverpool				9	133	195	236	192	117	31			913
Richmond				21	133	198	245	192	108	12			910
Camden Airport				33	143	207	242	198	108	16			946
Parramatta					118	147	211	171	78	9			733
Bankstown				9	127	192	233	189	111	22			882
Marsfield				30	136	198	236	192	99	31	9		931
Glenorie				12	130	195	233	189	111	22			892

For monthly calculations of heat loss assume months with values less than 100 to not require heating.

HEATING DEGREE DAYS (base 18.3°C) – SYDNEY REGION (Continued)

Annex X: Glass–mass performance graphs

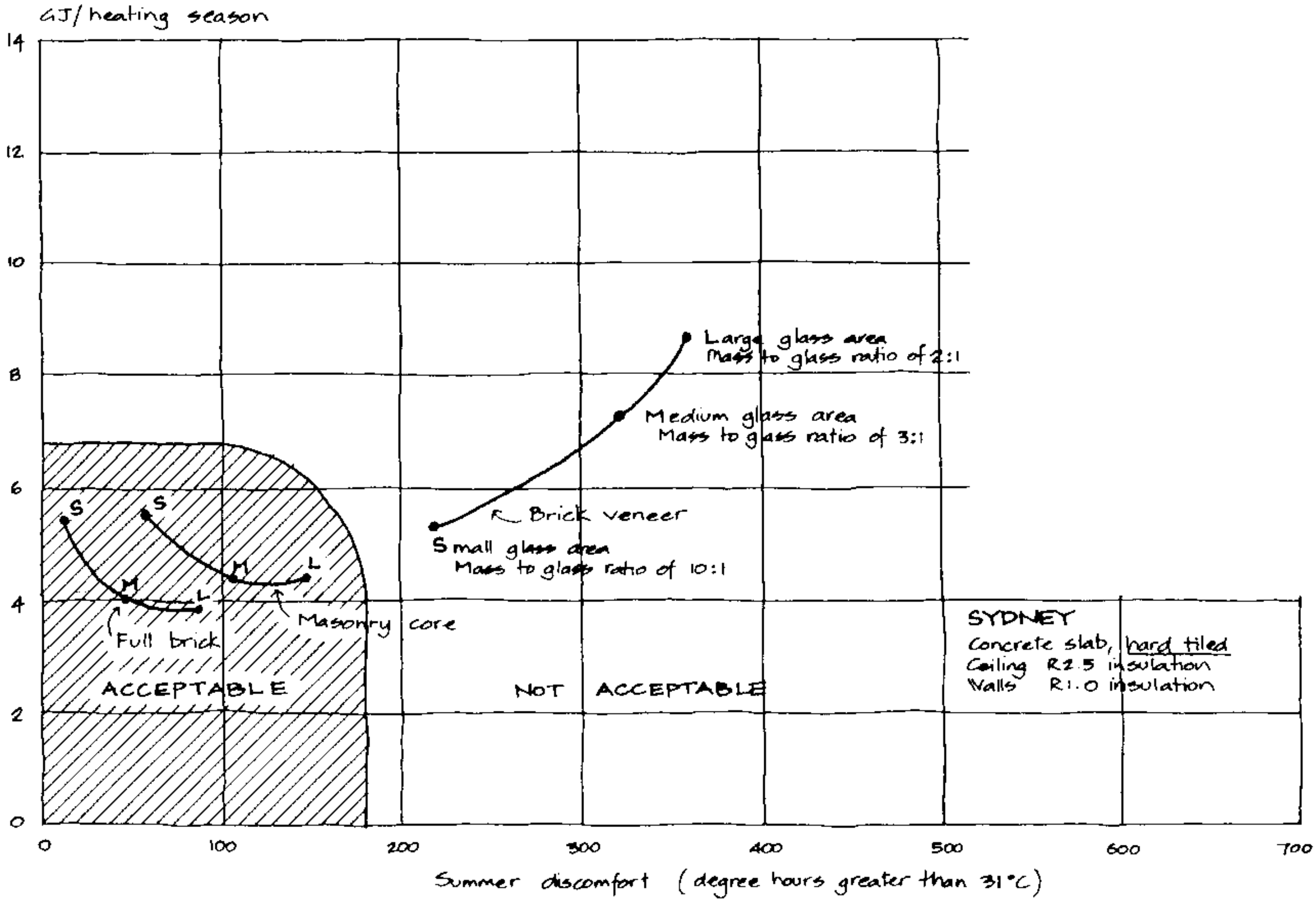


Figure X. 1 Glass–mass performance graph for Sydney – hard tile on concrete dab floor

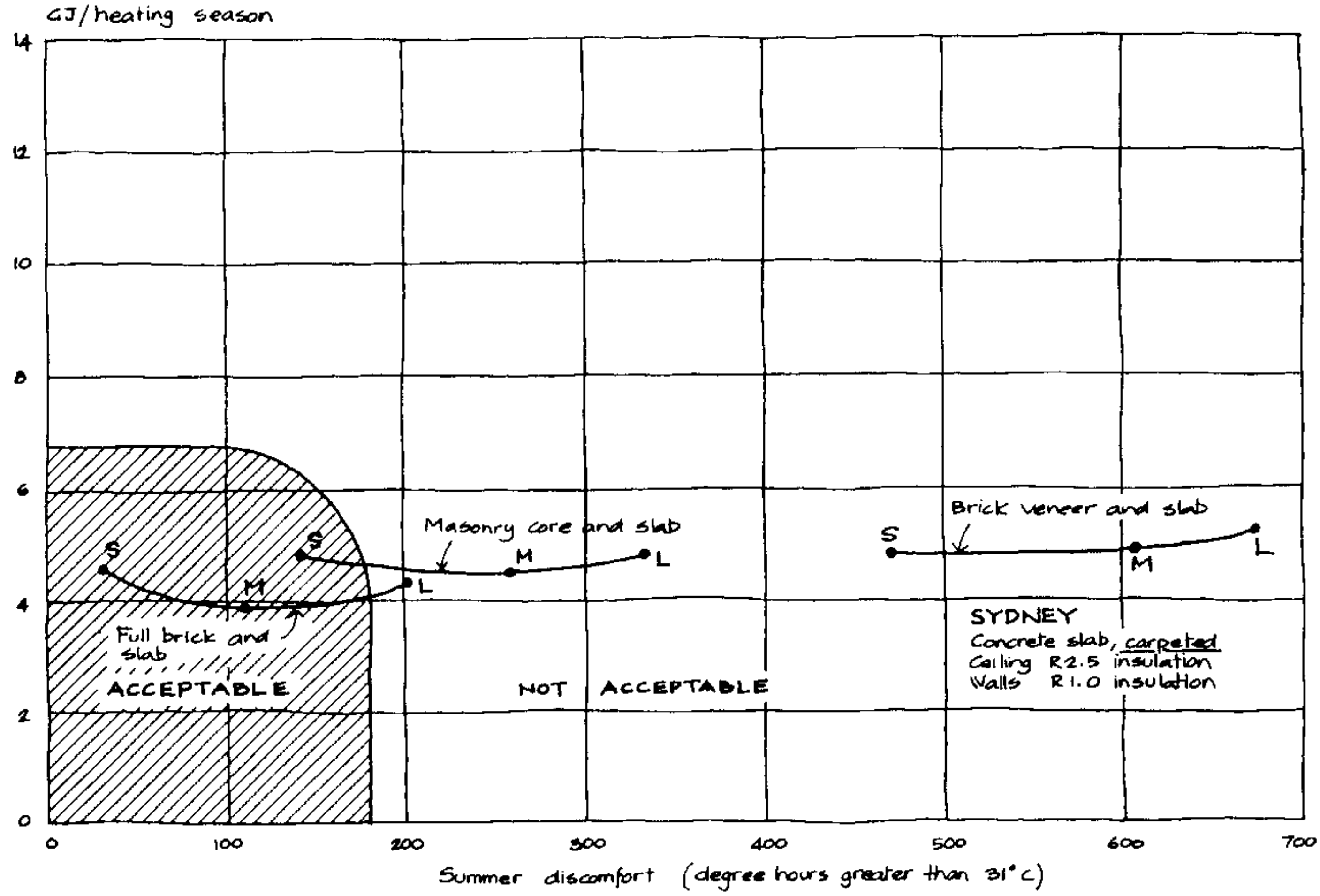


Figure X.2 Glass–mass performance graph for Sydney – carpet on concrete sate floor

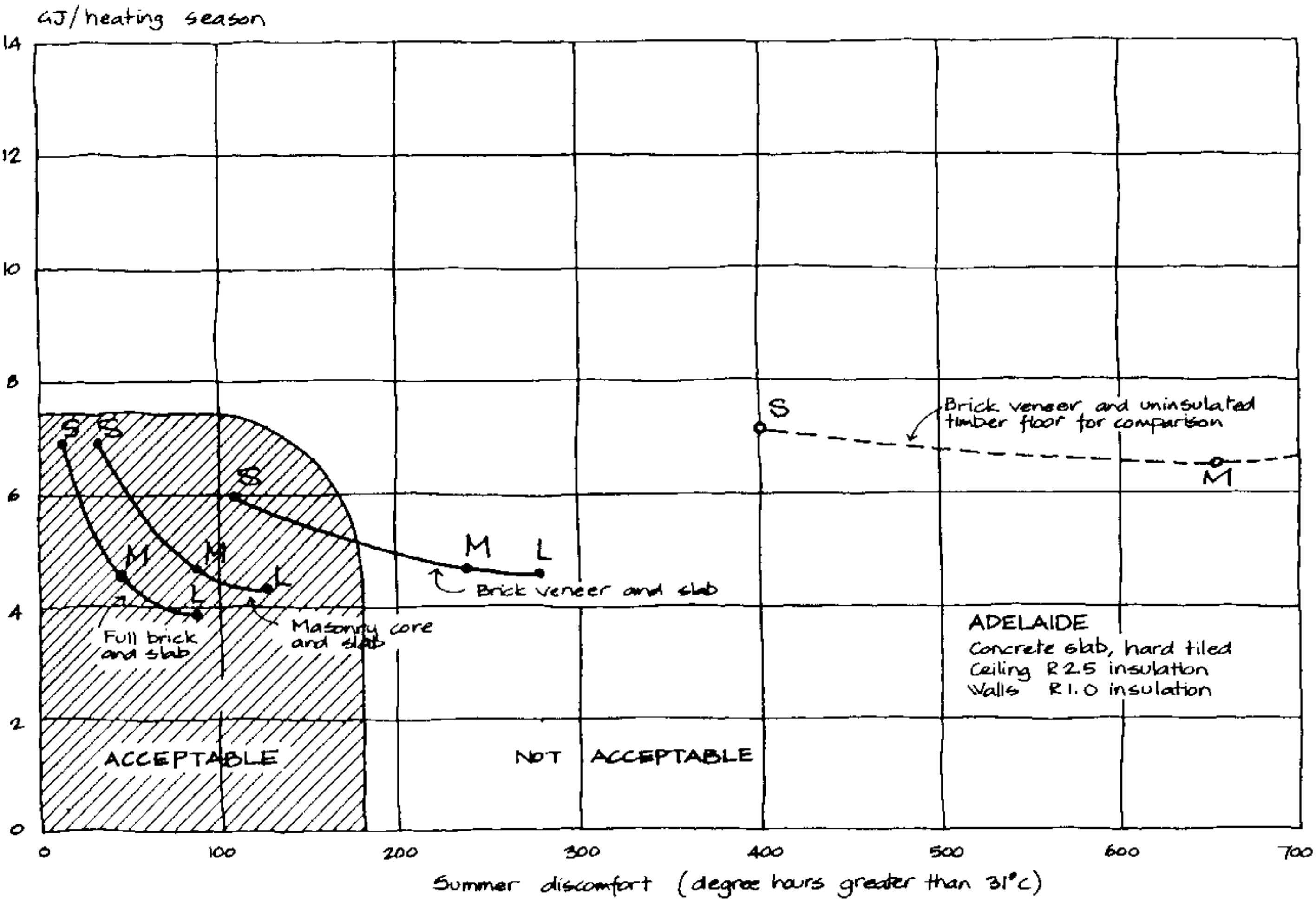


Figure X.3 Glass–mass performance graph for Adelaide – hard tile on concrete slab floor

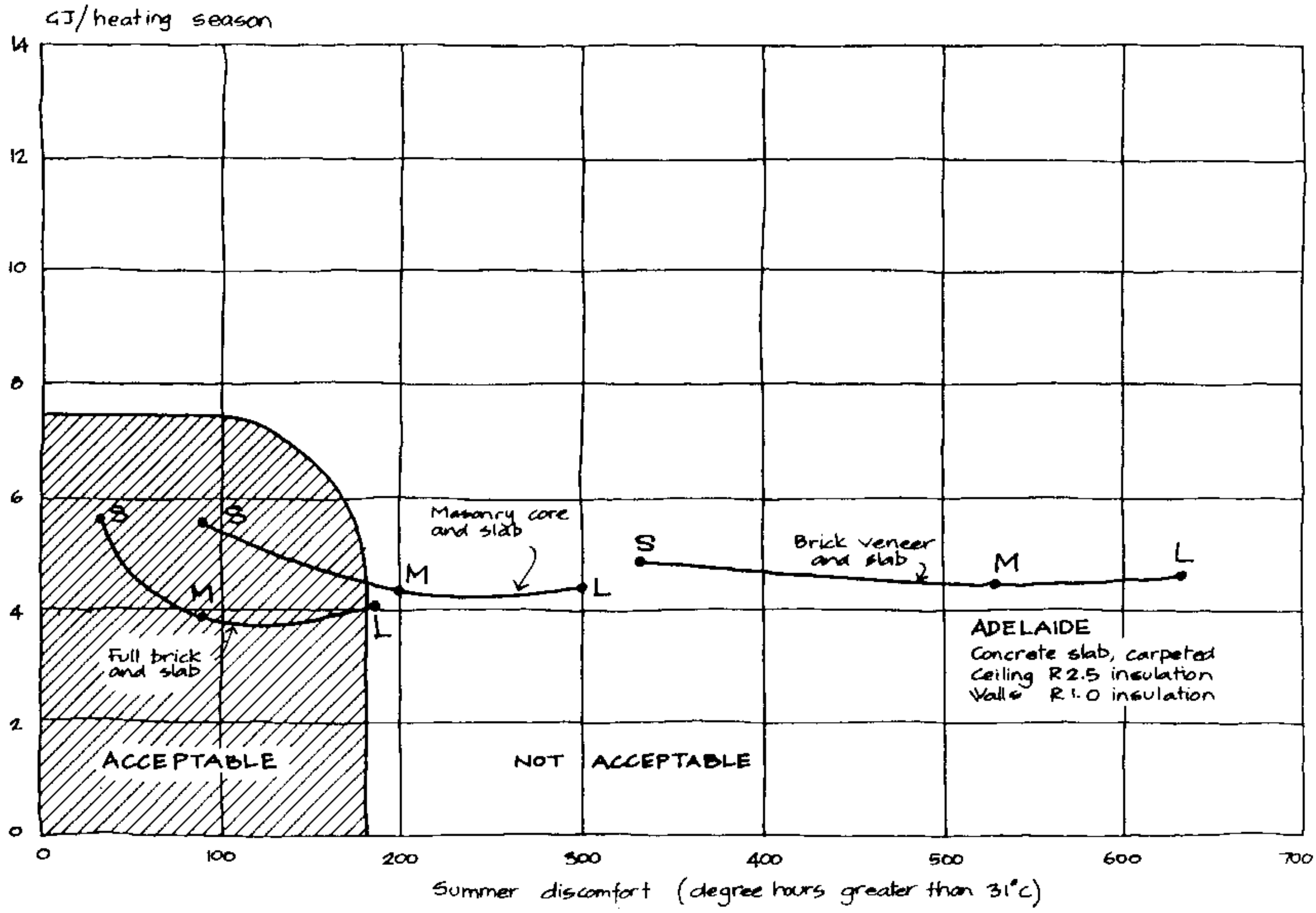


Figure X.4 Glass−mass performance graph for Adelaide − carpet on concrete slab floor

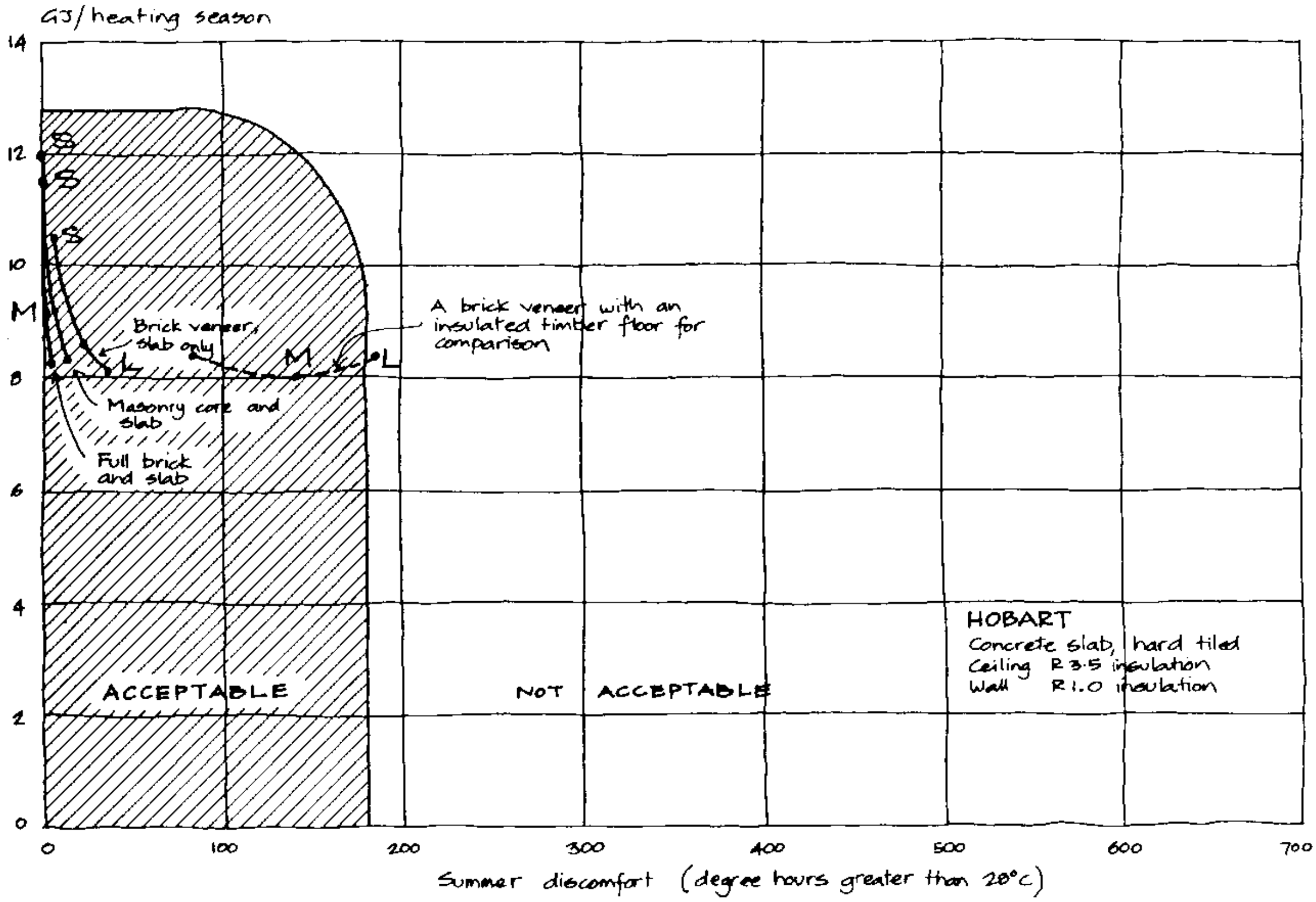


Figure X.5 Glass−mass performance graph for Hobart − hard tile on concrete slab floor

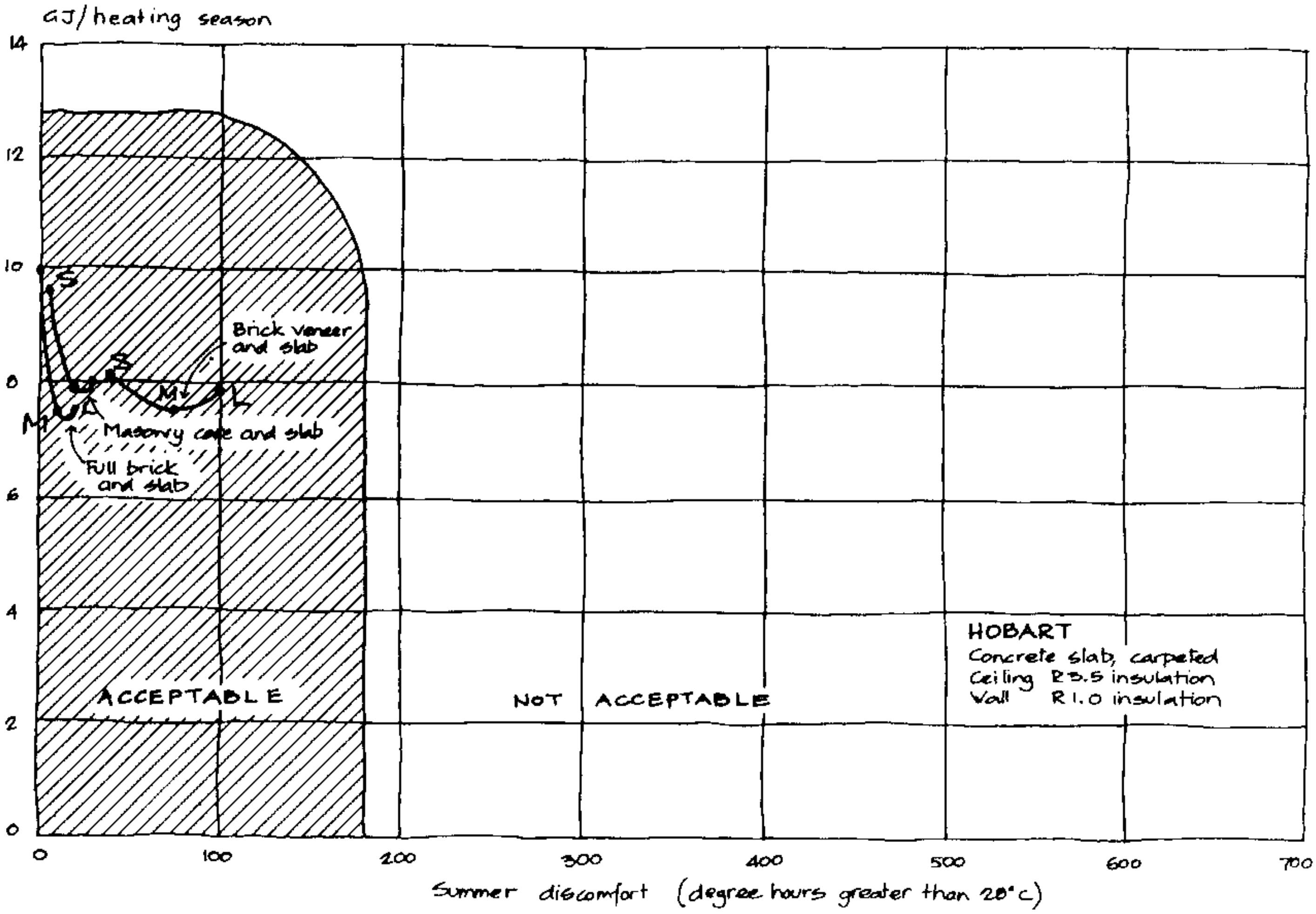


Figure X.6 Glass−mass performance graph for Hobart − carpet on concrete slab floor

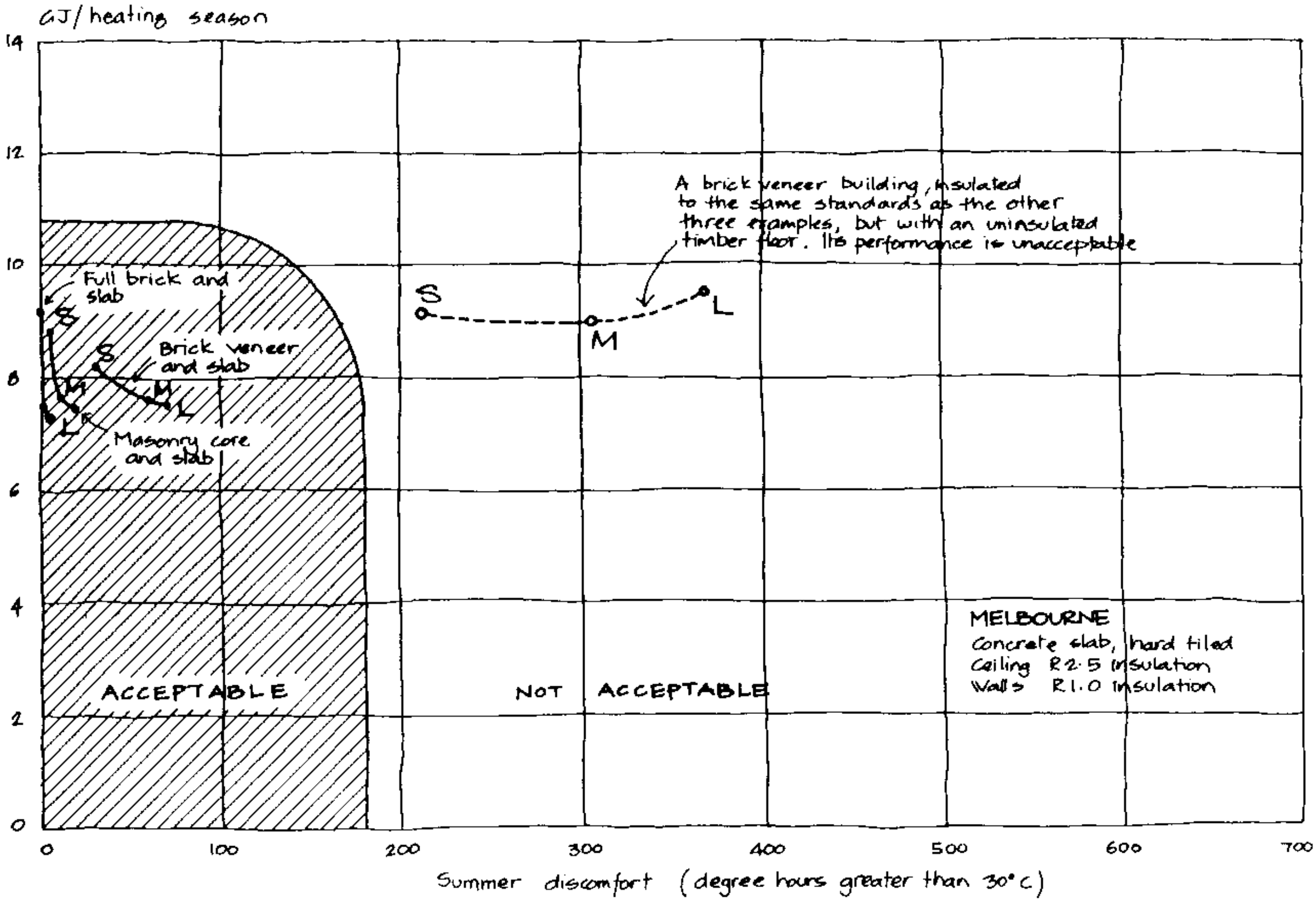


Figure X.7 Glass−mass performance graph for Melbourne − hard tile on concrete slab floor.

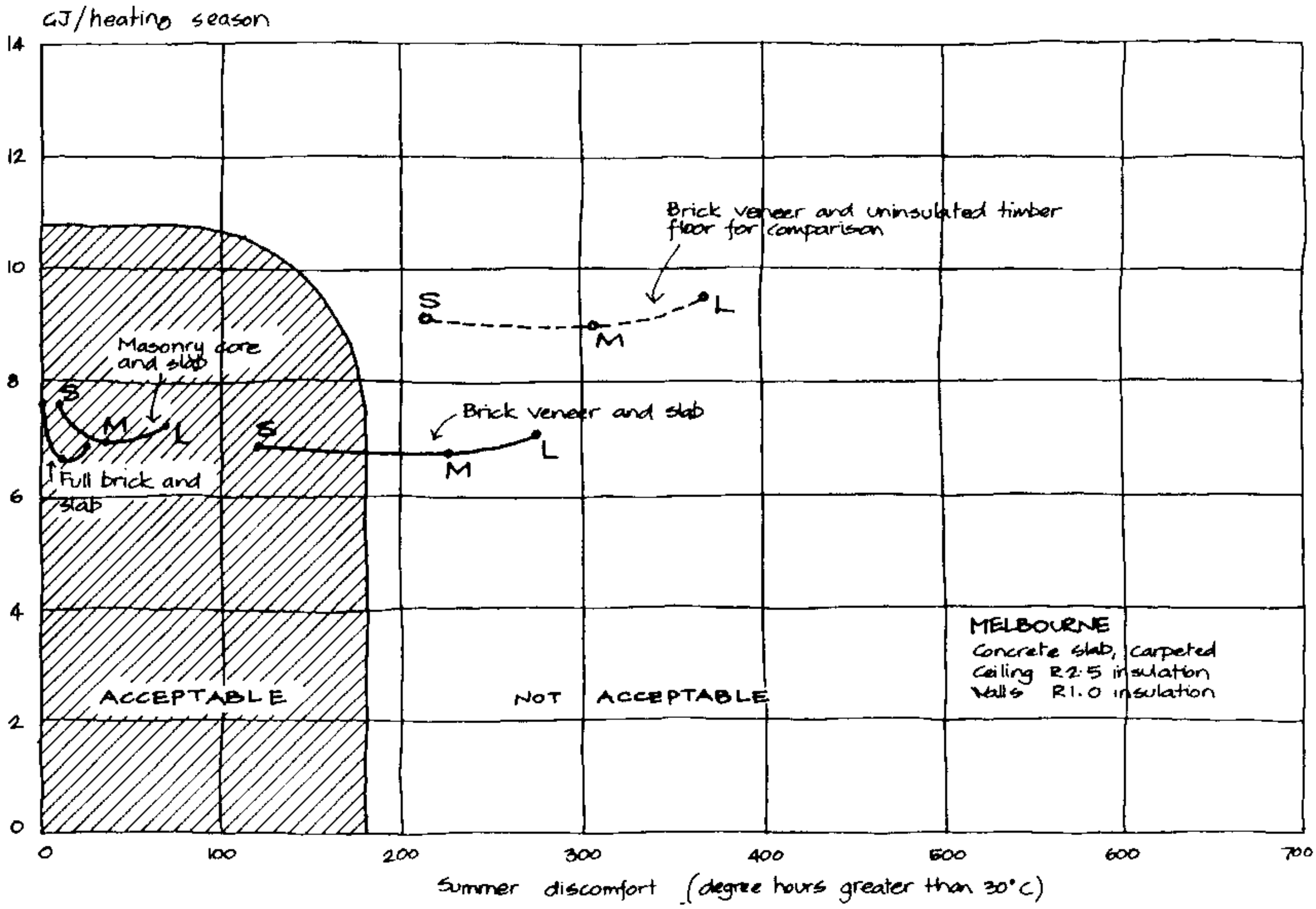


Figure X.8 Glass−mass performance graph for Melbourne − carpet on concrete slab floor

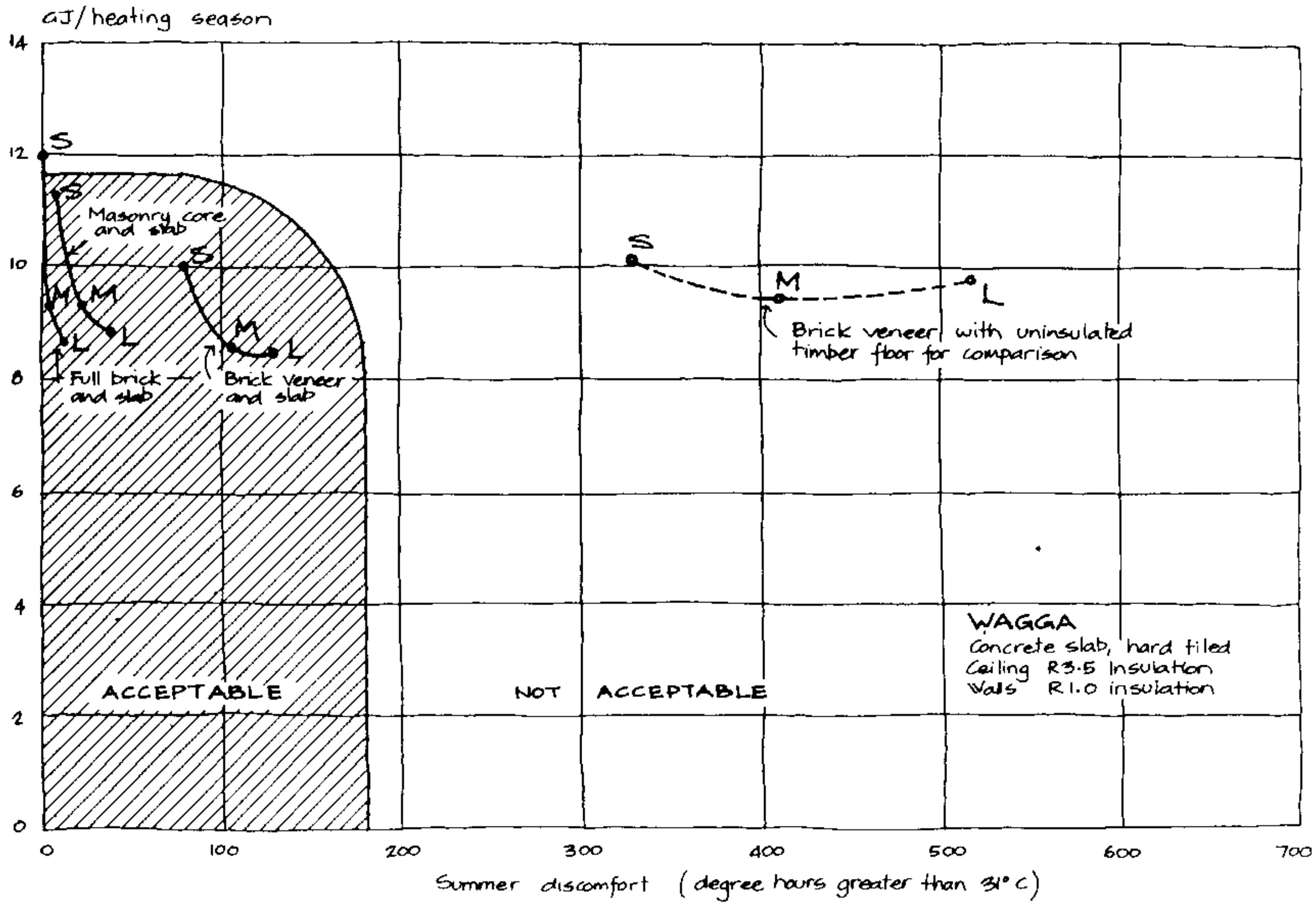


Figure X.9 Glass–mass performance graph for Wagga Wagga – hard tile on concrete slab floor

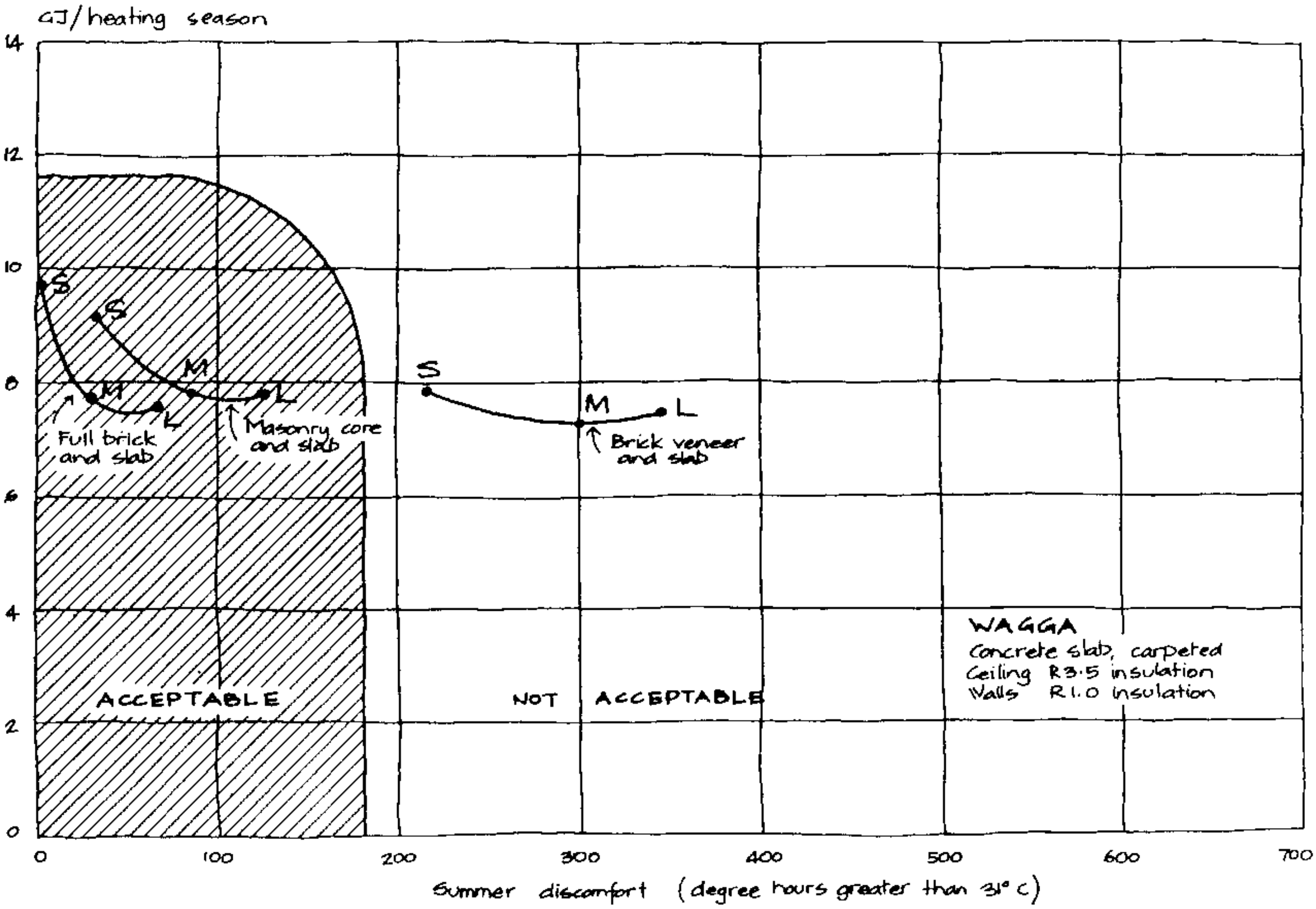


Figure X. 10 Glass−mass performance graph for Wagga Wagga − carpet on concrete slab floor

Annex XI: Appraisal graphs for the 5−star design rating system

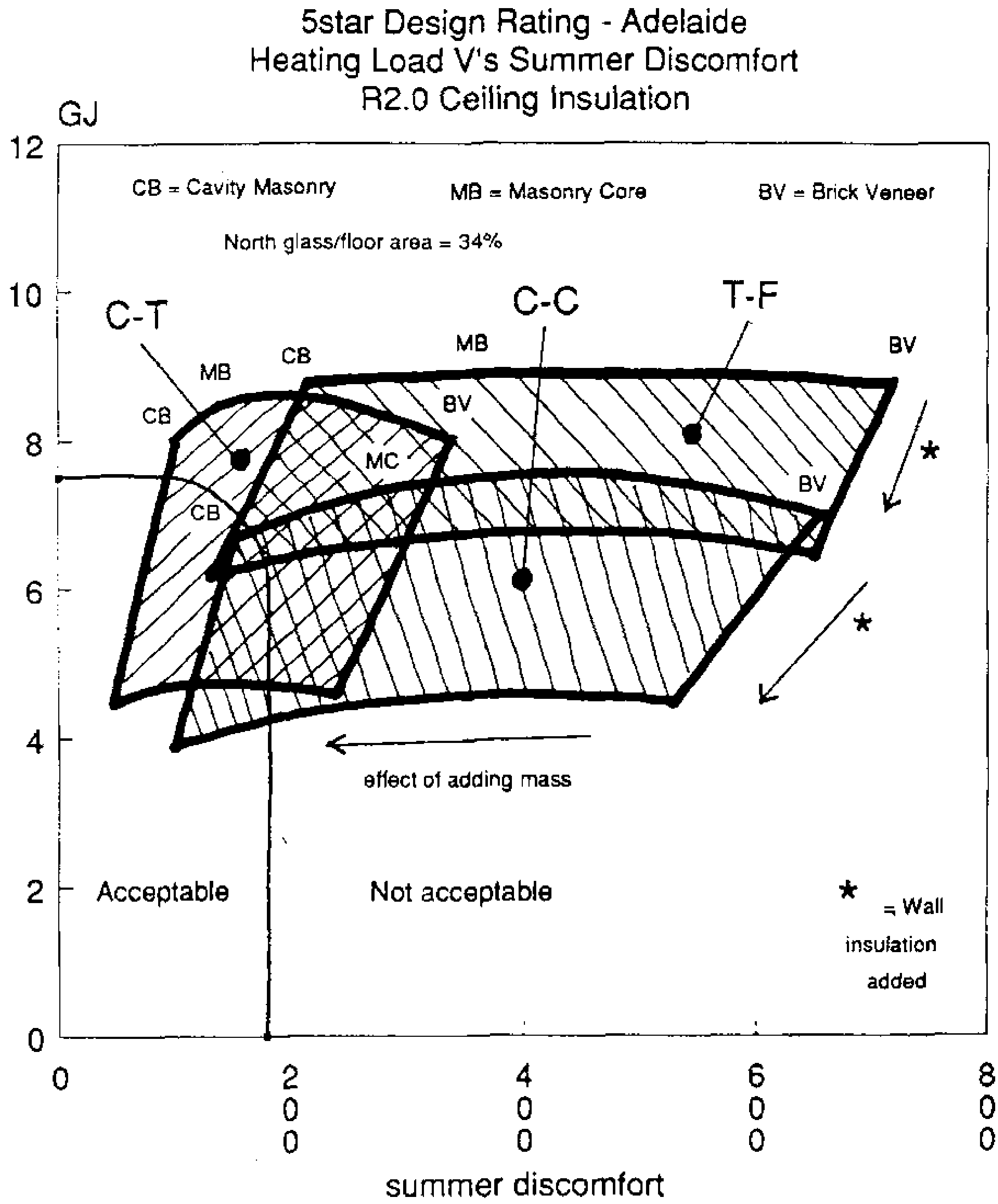


Figure XI. 1 5–star design rating appraisal graph for Adelaide

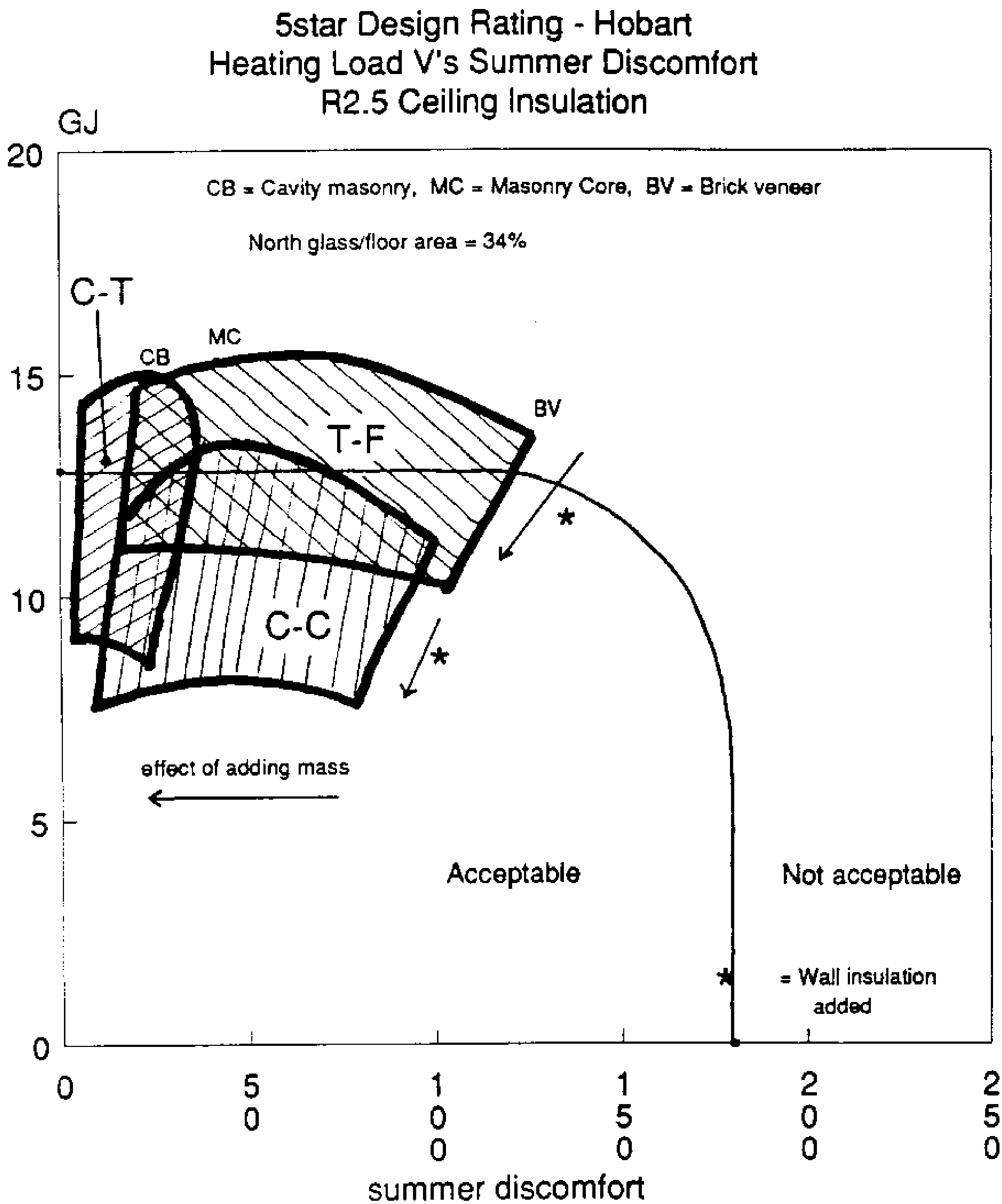


Figure XI.2 5–star design rating appraisal graph for Hobart

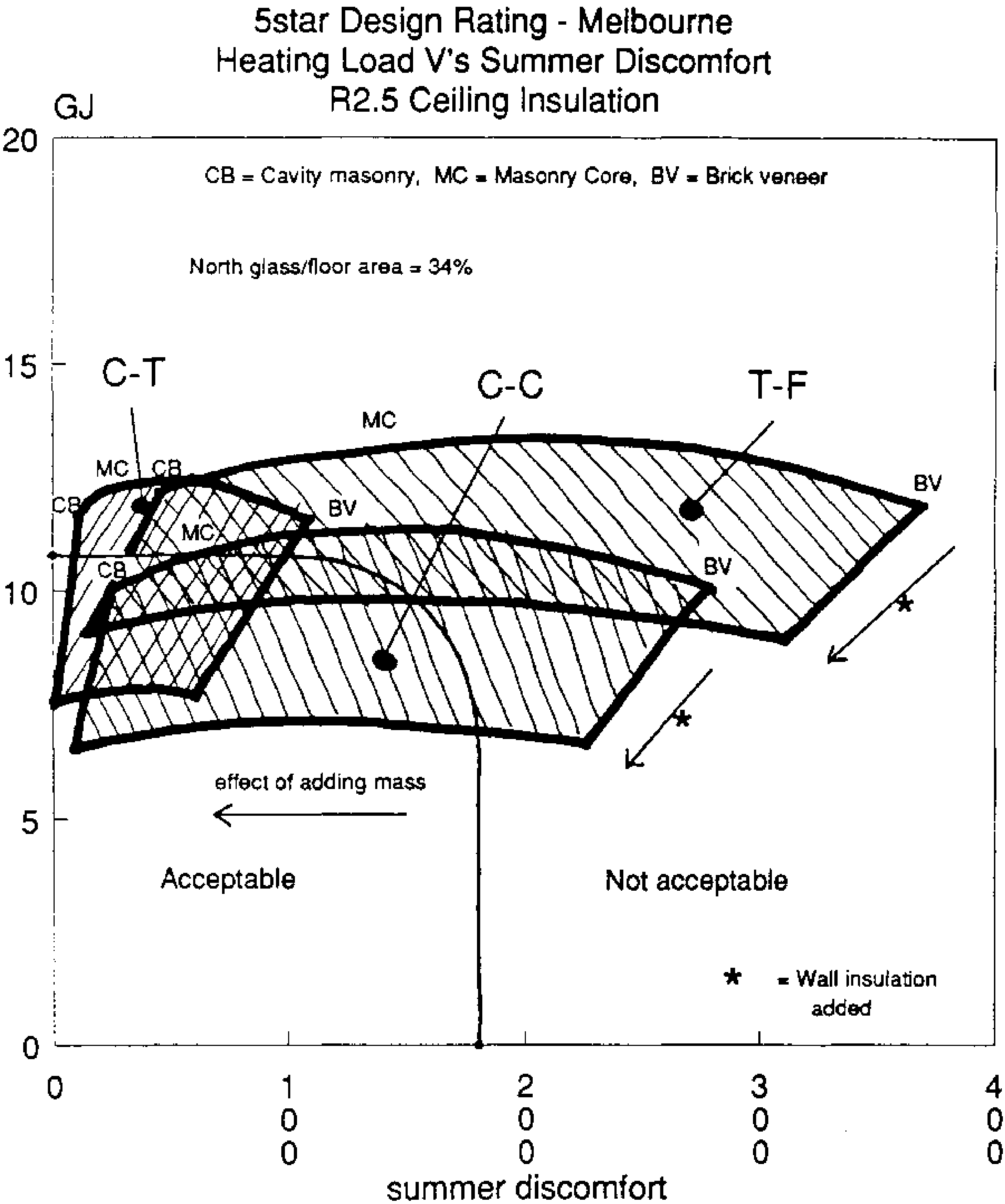


Figure XI.3 5−star design rating appraisal graph for Melbourne

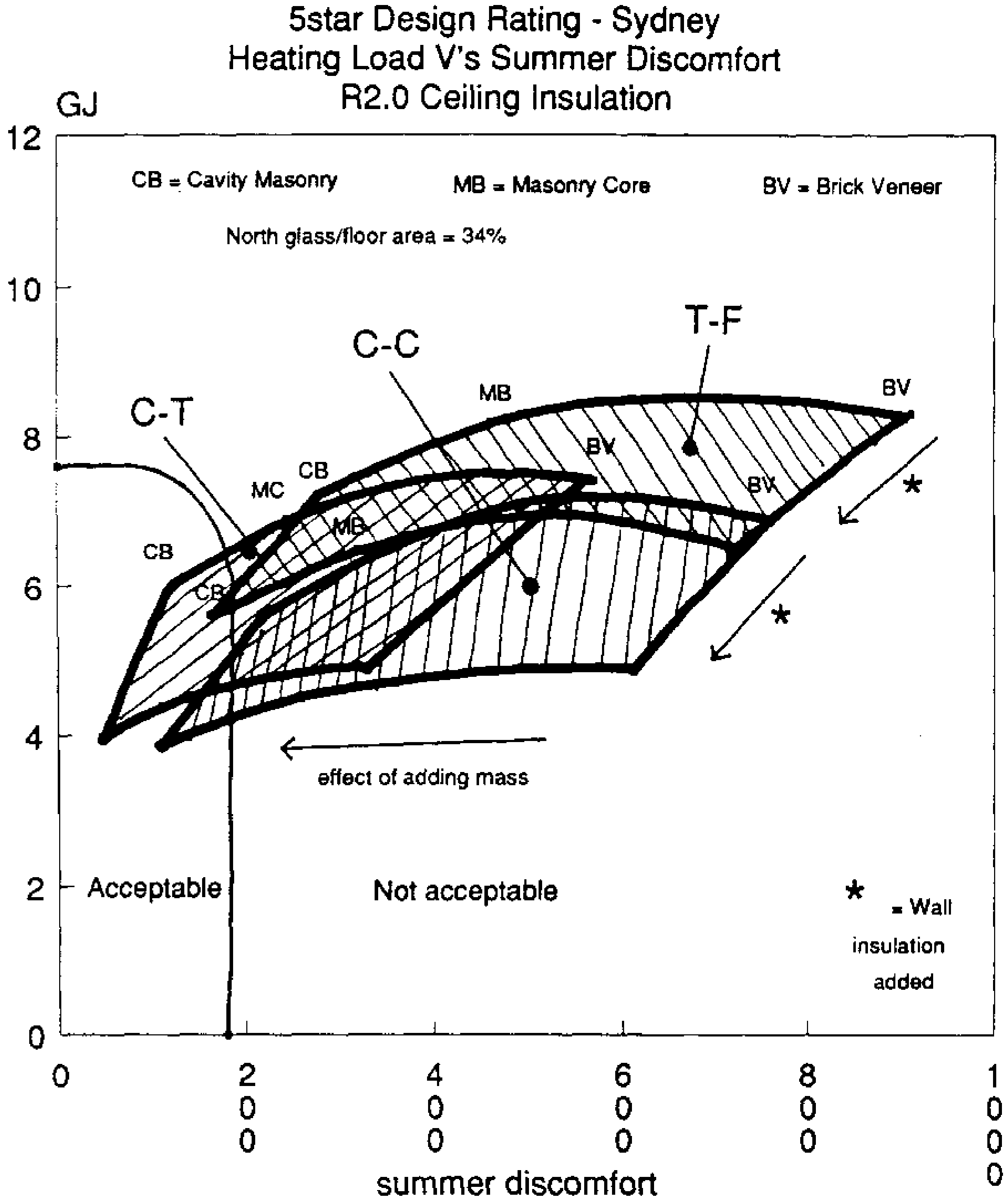


Figure XI.4 5–star design rating appraisal graph for Sydney

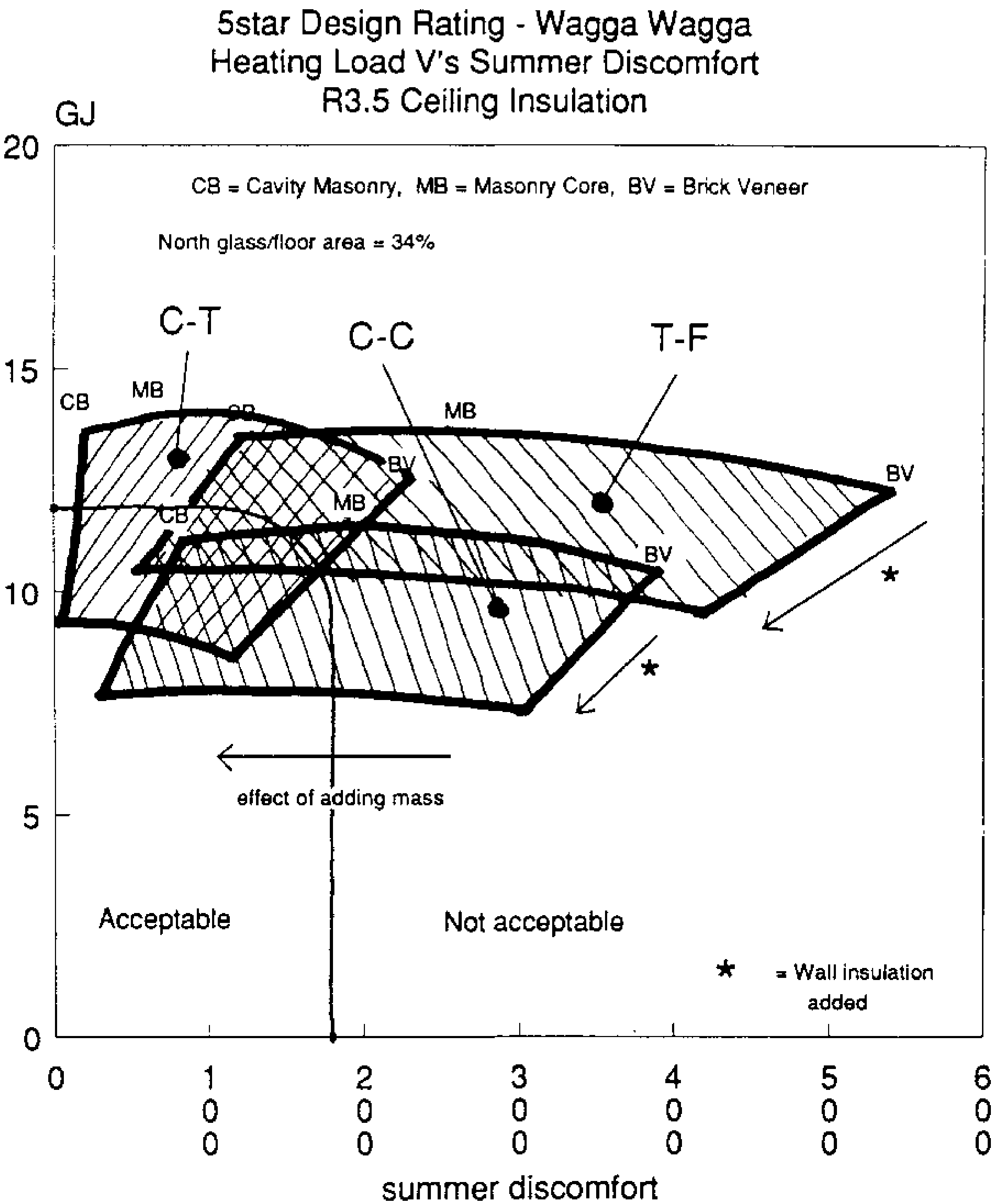


Figure XI.5 5–star design rating appraisal graph for Wagga Wagga

Annex XII: Sun position charts for Australian capital cities

The following sun–charts are a selection of those developed by David N.H. Hassall. B.E.. M.Bdg.Sc., M.I.E. (Aust.) of the School of Building at the University of New South Wales. The full collection of charts for many centres in New South Wales and all capital cities of Australia were published by the School of Building' as Report No. 2, November 1984.

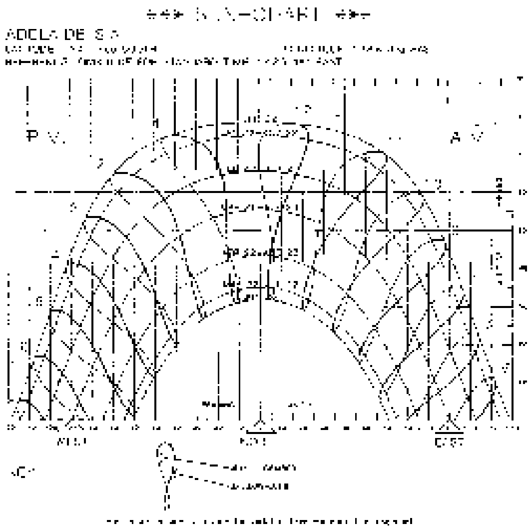


Figure XII. 1 Sun position charts for Adelaide

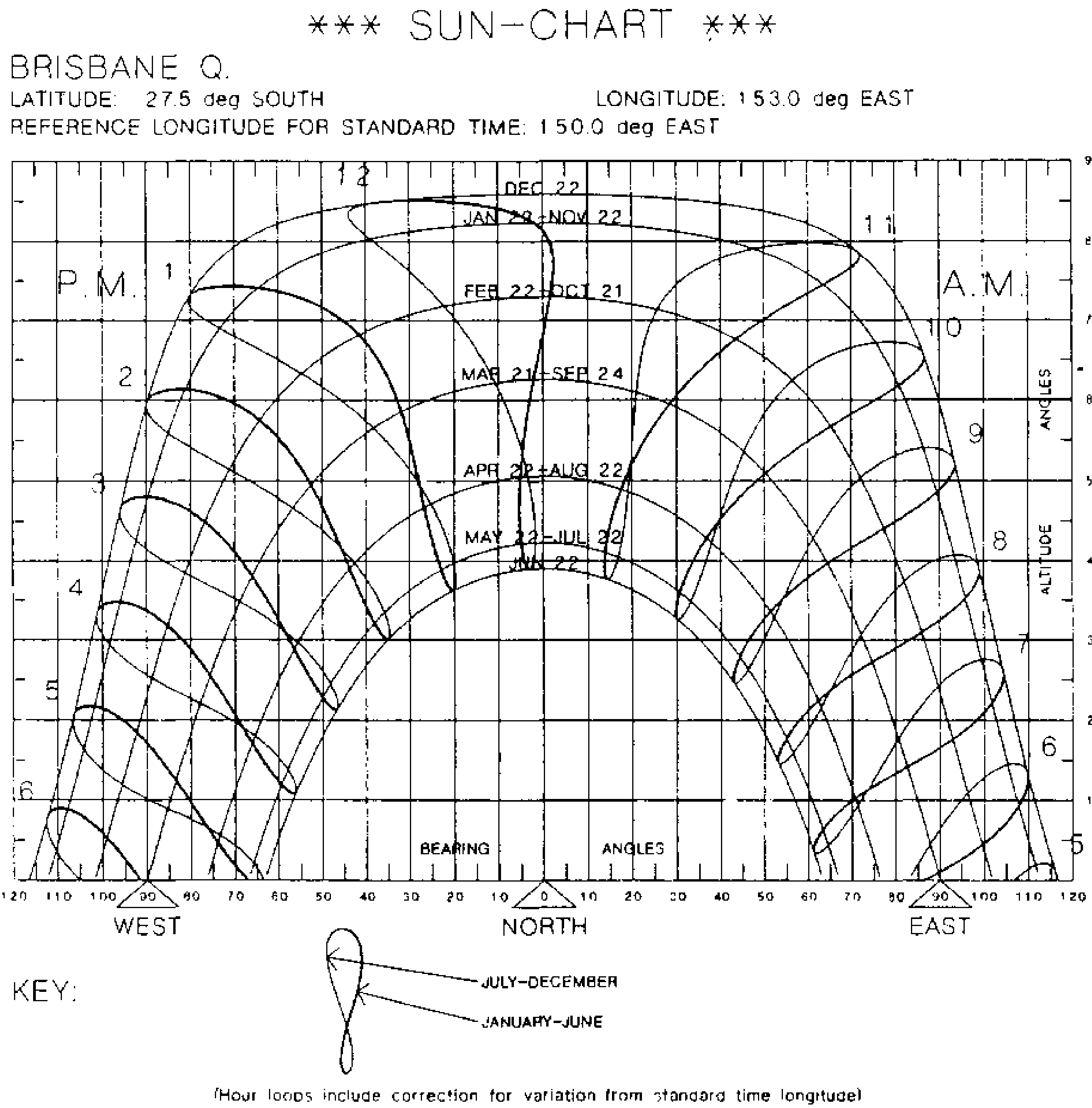


Figure XII.2 Sun position charts for Brisbane

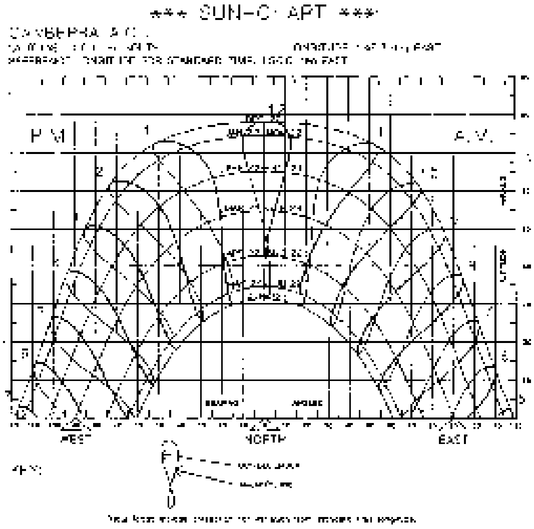


Figure XII.3 Sun position charts for Canberra

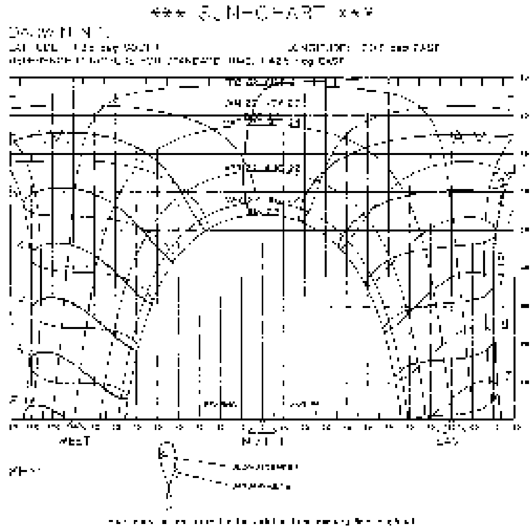


Figure XII.4 Sun position charts for Darwin

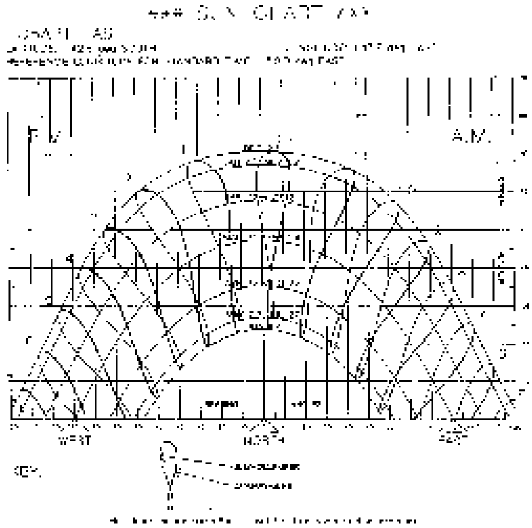


Figure XII.5 Sun position charts for Hobart

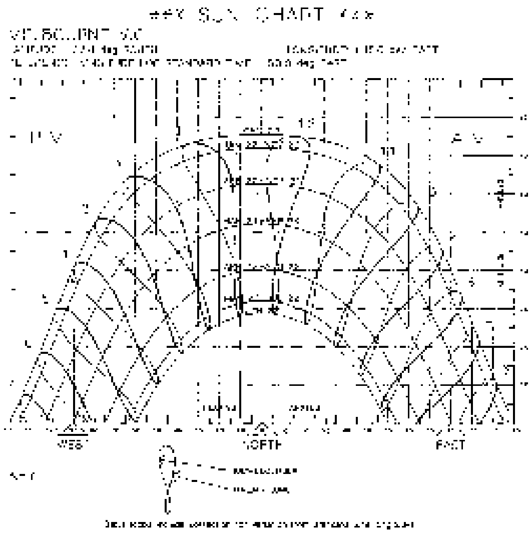


Figure XII.6 Sun position charts for Melbourne

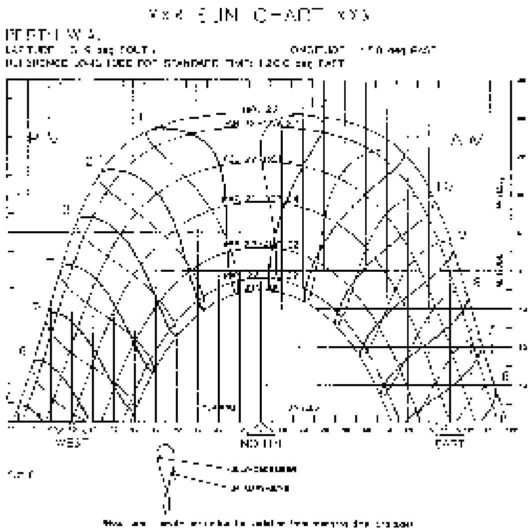


Figure XII.7 Sun position charts for Perth

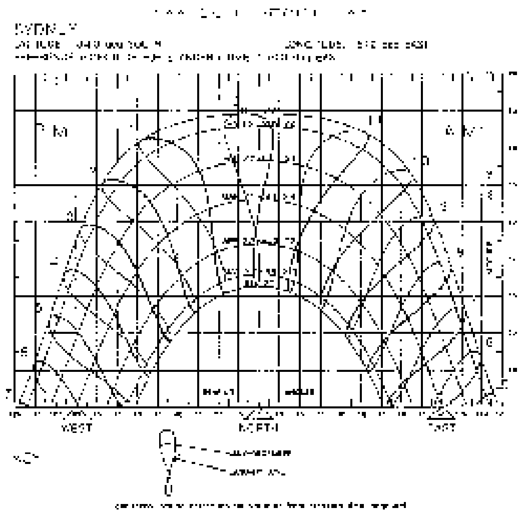


Figure XII.8 Sun position charts for Sydney

Annex XIII: Bibliography and suggested reading

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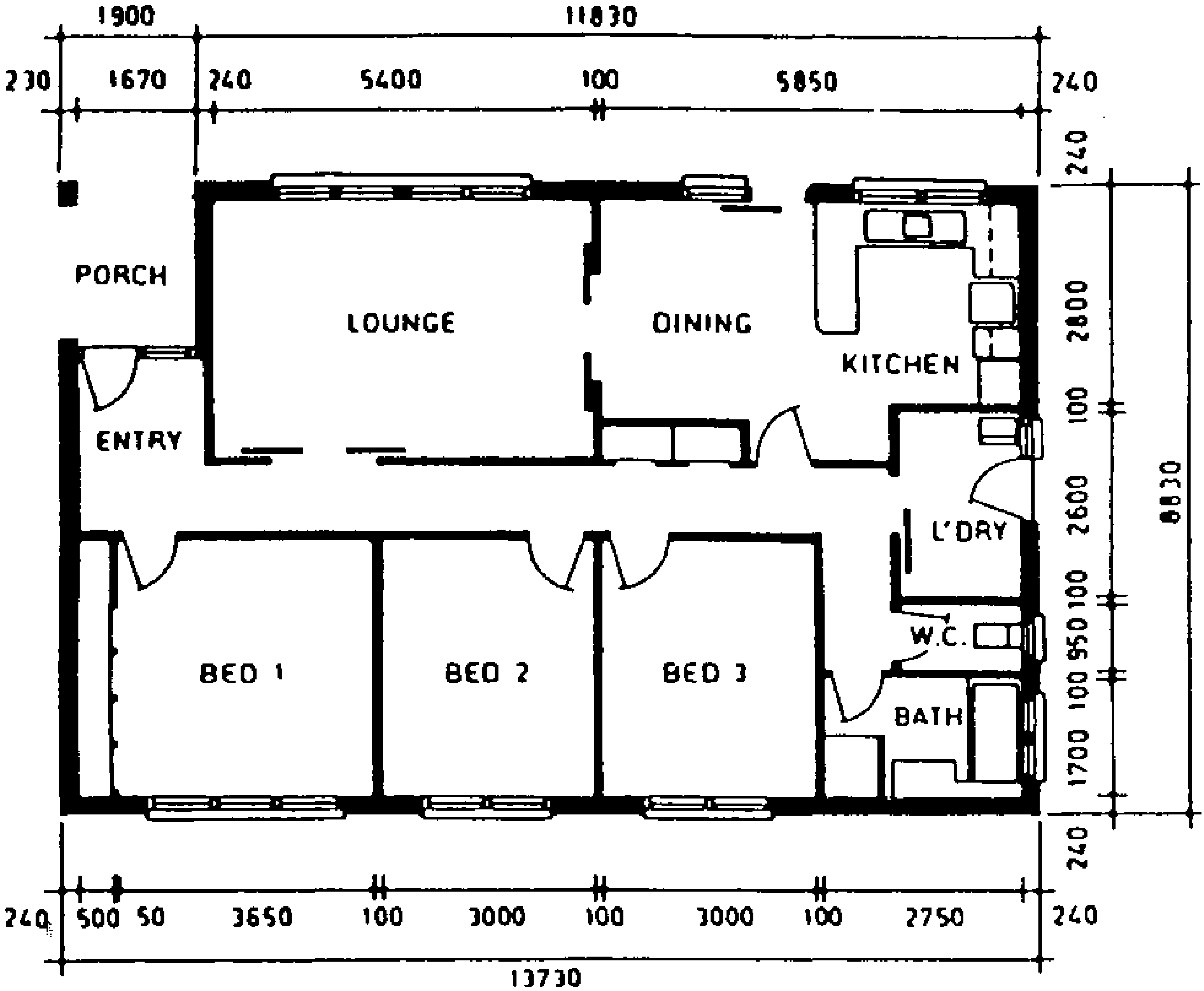

Floor plan of the house as the example building.