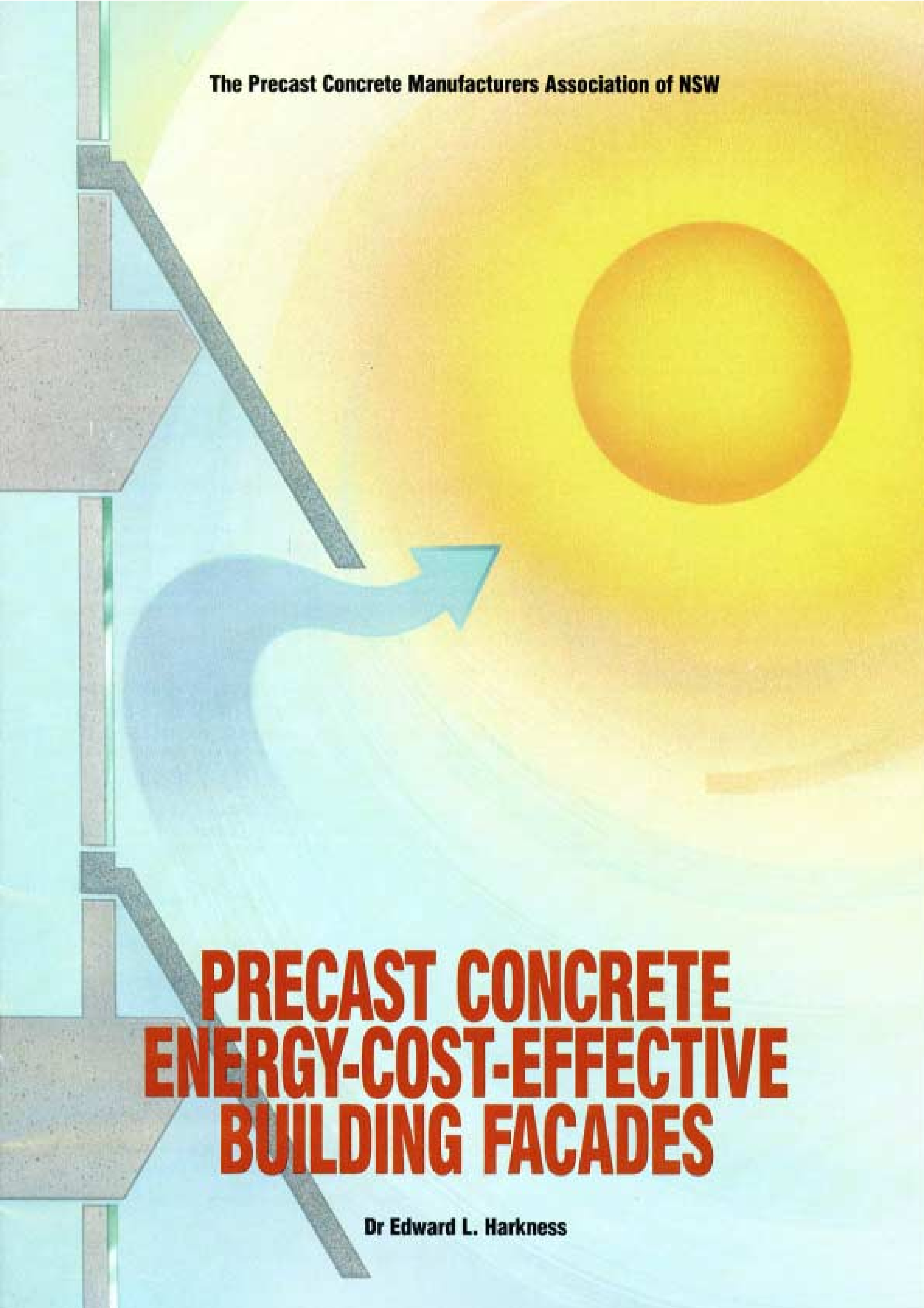
The Precast Concrete Manufacturers Association of NSW



PRECAST CONCRETE ENERGY-COST-EFFECTIVE BUILDING FACADES

Dr Edward L. Harkness

FOREWORD

There is a common saying that you cannot get something for nothing. This booklet proves that this is not true. By using geometry and the known data of the location of the sun in the sky to design the precast concrete sunscreens, one can save a great deal of energy, or improve the interior thermal environment of the building, or both.

We want daylight inside the building, partly because it is a pleasant and free method of lighting, and partly because it reduces the need for artificial lighting which generates also quite a lot of heat. We do not want the thermal solar radiation inside the building in summer. We can get good daylight from diffuse radiation from the sky. Radiant heat is a problem if it comes in a direct line from the sun. The solution is therefore simply to block the direct component of solar radiation by a sunscreen, while admitting diffuse daylight.

Dr Harkness advocates this approach together with the use of relatively small, clear-glass windows. He points out that while the use of heat-absorbing or heat-reflective glass without sunshading reduces solar radiation, it also reduces daylight.

Dr Harkness has a distinguished record of performance in architectural research. His book "Solar Radiation Control in Buildings", published in London in 1978, has become a standard work in its field. The sunscreens which he designed since establishing his consulting firm have generated considerable interest. He has, of course, one great advantage in his chosen field: the altitude (vertical angle) and azimuth (horizontal angle) of the sun on any given day and at any given time of day can be predicted with great accuracy and with complete certainty.

Henry J. Cowan AO
DEng PhD MArch MSc HonFRAIA FRSA FIEAust FASCE FIStruct E
Professor Emeritus of Architectural Science University of Sydney

THE AUTHOR

Dr Harkness, for many years an academic teaching the Building Sciences to Architecture students and an author of books and papers on Solar Energy, established, in 1984, a special service to other architects and mechanical engineers for quantifying the energy cost effectiveness of building design options.

He numbers among his clients private and government mechanical engineers and architects in Australasia and South East Asia.

In the period 1984/87 he carried out energy studies on projects valued at $350m.

His innovative and incisive application of physics to the analysis of architectural problems has resulted in his being in demand to give guest lectures in universities, workshops to government departments, and papers to conferences, in Australia and overseas.

Some of his papers include: "Energy Costing and Budgeting", presented to a Conference on Effective Building Maintenance Management in Kuala Lumpur, Malaysia, November 1984; "Radiation Effects in the Internal Environment", presented to an International Conference on the Indoor Environment of Buildings, in Singapore, January 1985; and "Energy Consequences of Building Design Options" to the Australian and New Zealand Architectural Science Association Conference, the University of Auckland, New Zealand, August 1986.

His book entitled "Solar Radiation Control in Buildings" co-authored by Madan Mehta (now Professor of Architectural Engineering in Saudi Arabia), was first published in London in 1978 and republished in a Russian Language Edition in 1984.

Energy savings and improved thermal environment conditions resulting from shading the glass of buildings have been important in his work which has generated national and international interest.

These principles form the underlying theme of this booklet.

INTRODUCTION

Architects know that windows should be shaded in the Australian environment, but may have difficulty in convincing their clients to do so. This booklet will assist by providing examples of the reduction in peak airconditioning loads, size of air-conditioning plant and environmental temperatures achievable by shading windows.

Precast concrete facade systems may be readily designed to provide shading by moulding their surfaces. Two case studies are included in this booklet.

An Australian Government Department(1) recently issued design briefs to building design consultants, expressly forbidding comfort cooling below 25°C.

Note, however, that occupants exposed to the direct solar beam behind **any** type of transparent glass will require the air temperature to be less than 25°C if thermal comfort is to be achieved, because of the heat contribution to the thermal environment of solar radiation.

The only way, therefore, that summer comfort can be achieved for occupants seated near windows is to ensure that they are not exposed to the direct solar beam.

Edward L. Harkness
BArch(Hons)(Syd) MBdgSc(Syd) MArch(Newcastle) PhD(Syd) MASA MAAS FAIA

PRECAST CONCRETE ENERGY-COST-EFFECTIVE BUILDING FACADES

CONTENTS

1 FACTORS AFFECTING THE THERMAL ENVIRONMENT WITHIN A BUILDING

INTRODUCTION

Environmental temperature, which is the effective temperature perceived by an individual, is affected by the air temperature, the rate of air movement and radiation effects.

The radiation component has an important influence on our sense of thermal comfort and is usually not accounted for when architects and mechanical engineers compute heating and cooling loads for buildings, because of the difficulties associated in quantifying that influence.

TEMPERATURE CONTROL IN VARIOUS PARTS OF A BUILDING

Occupants of office buildings sitting in the direct solar beam behind any type of glass know that the environmental temperature is higher there than in areas of the office remote from the windows. The reason is that although the air temperature may be controlled by the airconditioning system, such control does not alter the radiant heat loads. The number of occupants affected will depend upon the orientation of the glazing. For example: the direct solar beam will penetrate 4 metres into a west-facing room at 4.00 pm in February in Sydney; at which time the intensity of solar radiation is 790 watts/m² under clear sky conditions.

Thermometers fail to reveal true environmental temperatures for occupants near windows because their bulbs are usually silver which reflects much of the radiant component.

A more accurate measure of environmental temperature would be to use a thermometer with, say, a bulb of skin colour. Black-globe thermometers are sometimes used to measure radiant effects. However, these do not take into account the complex interchange of heat at the surface of the skin nor indicate the subjective response of the occupants.

SUBJECTIVE TEMPERATURE OF THE SKIN

A recently devised method of estimating the subjective temperature of the skin[2] brings together the physiological studies of radiation effects on thermal comfort by Drysdale[3] and Olgyay[4] with the Sol-air temperature concept used by mechanical engineers for decades as a means of estimating the equivalent heat load on a building. The Sol-air temperature combines the air temperature with an equivalent-air-temperature-effect of the radiant solar energy incident on a building. Figure 1.1 shows the reduction in air temperature required to achieve thermal comfort as the level of radiant heat load is increased.

Applying this method, calculations of subjective temperatures of the skin of occupants behind various facade systems in an airconditioned building were made for the month of December in a building facing west in Sydney.

Figure 1.2 shows subjective temperatures of the skin of occupants behind building facades fitted with (a) unshaded clear glass, (b) unshaded, green, heat-absorbent glass and (c) shaded clear glass — ie shaded against the direct component of solar radiation but exposed to the diffuse component of solar radiation.

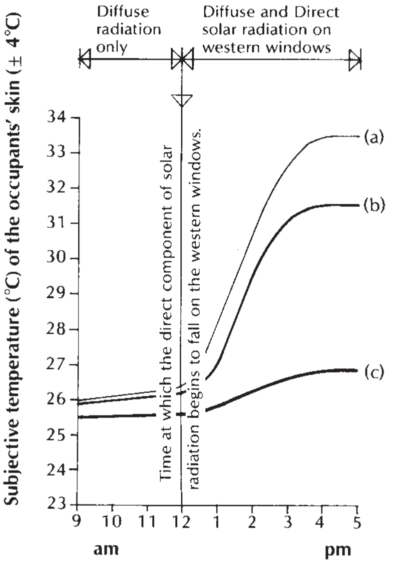


Figure 1.2
Subjective temperature of the skin of occupants sitting near windows:
(a) exposed to direct solar radiation through unshaded clear glass;
(b) exposed to direct solar radiation through unshaded green, heat-absorbent glass; and
(c) clear glass shaded from the direct component of solar radiation,
in a Sydney office facing west in December.

These subjective temperatures have been calculated assuming that the internal air temperature will be held constant at 23°C.

This figure also shows that even for glass shaded against the direct component of solar radiation, the subjective temperature of the skin is 3°C higher than the conditioned air at 23°C due to diffuse radiation from the sky.

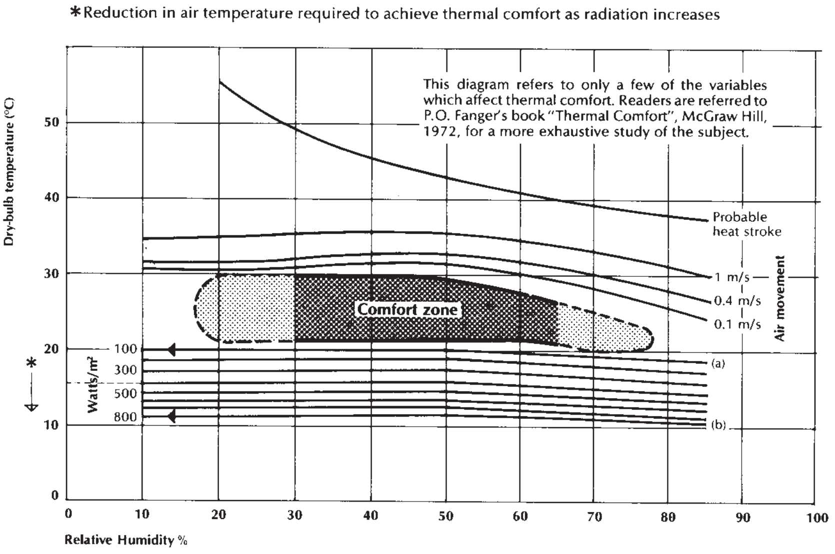


Figure 1.1
This bioclimatic chart shows the reduction in air temperature required to achieve thermal comfort as the level of radiant heat load is increased. (After Drysdale and Olgyay. Reproduced from 'Manual of Tropical Housing and Building' Part 1, Climatic Design by Koenigsburger et.al.) (With additional annotations.)

(a) and (b) above indicate the intensity of solar radiation incident upon west-facing windows that are shaded and unshaded from the direct component of solar radiation respectively, at 4 pm in Sydney during February.

The reduction in air temperature required in an attempt to achieve thermal comfort within the room behind the window may be estimated by attenuating the radiation levels in accordance with the solar exclusion characteristics of the particular glass used and projecting the transmitted levels horizontally across to the left-most scale.

For example, given 800 watts per square metre of solar radiation on the outside of the glass and solar characteristics of glass which exclude 50% of radiation, the transmitted radiation will be 400 watts per square metre. Projected across to the left-most scale, it may be seen that the air temperature needs to be reduced by 4°C in an attempt to achieve thermal comfort. (See text for qualification.)

The subjective temperatures of the skin behind unshaded clear glass reach more than 33°C and behind unshaded, green, heat-absorbent glass, 31°C — temperatures exceeding thermal comfort zones even though the airconditioning held the air temperature at 23°C in this particular study.

Using the same procedure outlined above[(2)], the air temperatures required in an attempt to achieve thermal comfort for those portions of occupants exposed to solar radiation have been computed and summarised in Figure 1.3.

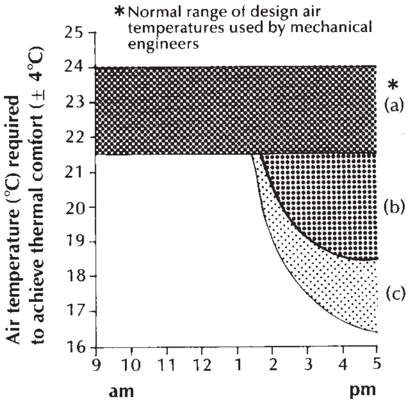


Figure 1.3

In order to achieve thermal comfort in December, for occupants sitting in the direct solar beam in a Sydney office facing west:

- (a) *where unshaded clear glass is used, the air temperature may need to be reduced to 16°C or less, for individual preferences, in the late afternoon;*
- (b) *where unshaded, green, heat-absorbent glass is used, the air temperature may need to be reduced to 18°C or less, for individual preferences; and*
- (c) *where shaded clear glass is used, the normal range of design air temperatures (21.5 to 24°C) is appropriate.*

Note that individual preferences occur and it is therefore unwise to speak in terms of specific temperatures. The purpose of these calculations and figures is to illustrate that as exposure to solar radiation is increased, so also is the occupant's sense of discomfort increased.

In a west-facing office in Sydney during a summer late afternoon, for unshaded clear glass, the air temperature may need to be reduced to 16°C or less. For unshaded, green, heat-absorbent glass the temperature may need to be reduced to 18°C or less. Where shaded clear glass is used, the normal range of air temperatures 21.5 to 24°C is appropriate.

Supplying cooler air will help to cool the hotter side of the body but will, at the same time, chill the shaded side of the body. Supply of cooler air is not an acceptable solution.

Thermal comfort, therefore, cannot be achieved for occupants sitting in the direct solar beam. **The correct solution is to shade the glass from the direct component of solar radiation.** This will make the airconditioning designer's task easier, ensure greater occupant satisfaction and reduce recurrent energy consumption.

Examples of buildings designed by Australian architects who have used precast concrete facade elements to provide shading are analysed in Section 2, the Energy Case Studies section of this booklet.

CLEAR v. SPECIAL GLASS HEAT ADMISSION FOR REQUIRED DAYLIGHT

Following experiences in Singapore (see Appendix I) in which building owners retrofitted buildings with special glass types for the purpose of complying with OTTV (Overall Thermal Transfer Value) regulations only to find little or no energy savings, but a need to increase electric lighting of interiors; a review of the heat gain through various types of glass has been made[(2)] holding constant a required level of admitted daylight.

Table 1 shows a comparison of the daylight and heat admitted through various types of glass. The light transmittance and shading coefficients are those supplied by the manufacturer.

Highly reflective glass types, by definition, admit less light than other types of glass and therefore require a larger area of glass to be used to admit equivalent daylight. The result is admission of more heat to the detriment of the thermal comfort of occupants near windows.

An effective means of admitting daylight and excluding solar heat, is to shade the windows and use clear glass in smaller windows.

Table 1 COMPARISON OF HEAT GAIN THROUGH VARIOUS TYPES OF GLASS FOR A REQUIRED LEVEL OF ADMITTED DAYLIGHT.

TYPE OF GLASS (6 mm thick)	LIGHT TRANSMITTANCE	AREA OF GLASS REQUIRED TO ADMIT EQUIVALENT DAYLIGHT AS CLEAR GLASS	SHADING COEFFICIENT	SOLAR GAIN COMPARED TO CLEAR GLASS (%)
Clear	0.87	1.00	0.95	100
Spectrafloat	0.51	1.71	0.75	135
Antisun — green	0.75	1.16	0.70	85*
grey	0.41	2.12	0.69	154
Reflectacoat — silver	0.33	2.64	0.60	167
Coolray — silver blue (6.4 mm)	0.14	6.21	0.38	248

*Of the glass types reviewed above, the only type that is superior to clear glass with respect to the admission of daylight *and* the exclusion of heat, is Anitsun — green.

2 FACTORS AFFECTING THE SIZE OF AIRCONDITIONING PLANT AND RECURRENT ENERGY LOADS

ENERGY CASE STUDIES

The energy case studies presented in this section have applied program TEMPAL(†) in computer modelling the energy consequences of various building-envelope design options. Summer conditions only, in air-conditioned office buildings in Sydney and Brisbane have been reviewed.

† Written by A & E Coldicutt, Department of Architecture, University of Melbourne.

ENERGY CASE STUDY A

Westfield Office Building, Sydney

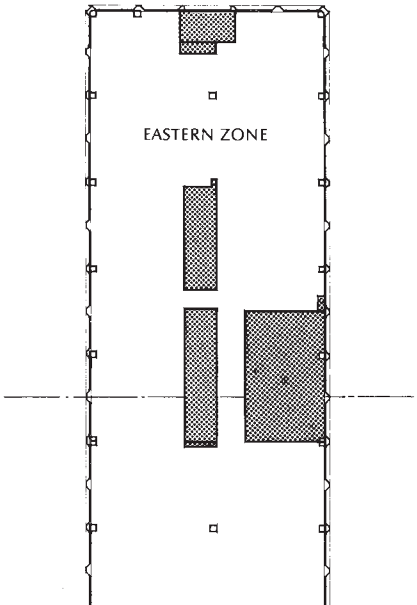


Figure 2.A.1
Typical floor plan of the Westfield Office Building, William Street, Sydney.

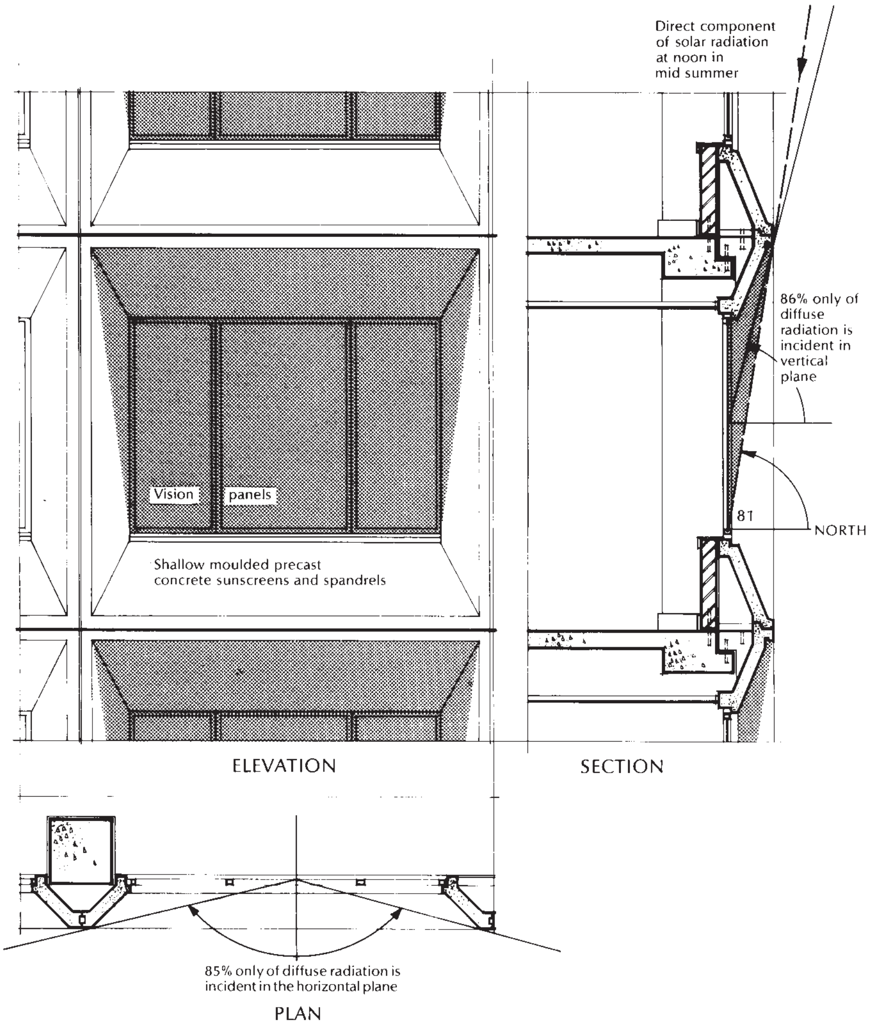


Figure 2.A.2
Details of the precast facade system showing the shallow moulding which provides a 20% reduction in recurrent cooling loads for a four month summer period compared to a flush all-glass facade system using the same type of glass

Computer modelling of the recurrent energy consumption consequences of various building-envelope design options for the Westfield Building in Sydney are summarised as follows.

The building has been modelled with vision panels in each variation (a) to (f) fitted with the glass as specified in (a).

(a) A flush glass facade fitted with double glazing: 6 mm Cool-ite + 6 mm Clear float glass + 12 mm air space; without sunscreens.
*Horizontal void-to-solid ratio = 1:0 (Continuous strip glazing)
Percentage vision glass in the facade = 55%

(b) 100 mm solid concrete walls
*Horizontal void-to-solid ratios = 1:1 & 1:2
Percentage glass in the facade = 27% & 18%

(c) 150 mm solid concrete walls
*Horizontal void-to-solid ratios = 1:1 & 1:2
Percentage glass in the facade = 27% & 18%

(d) Flush facade with cavity concrete walls and cavity fitted with 120 UF insulation
*Horizontal void-to-solid ratios = 1:1 & 1:2
Percentage glass in the facade = 27% & 18%

(e) Flush facade with cavity concrete walls
*Horizontal void-to-solid ratios = 1:1 & 1:2
Percentage glass in the facade = 27% & 18%

(f) Shallow recessed precast concrete facade
*Horizontal void-to-solid ratio = 1:0.33
Percentage of glass in the facade = 41%

*Horizontal void-to-solid ratio refers to the plan dimensions of the vision and wall panels in the facade, assuming that the head and sill heights are consistent and that the windows are rectangular.

Note: The solar load reduction graphs in Appendix III show how estimates may be made of the reduction in solar loads by reducing the percentage of window area in the facade and by increasing the depth of sunscreen projections or recesses to windows.

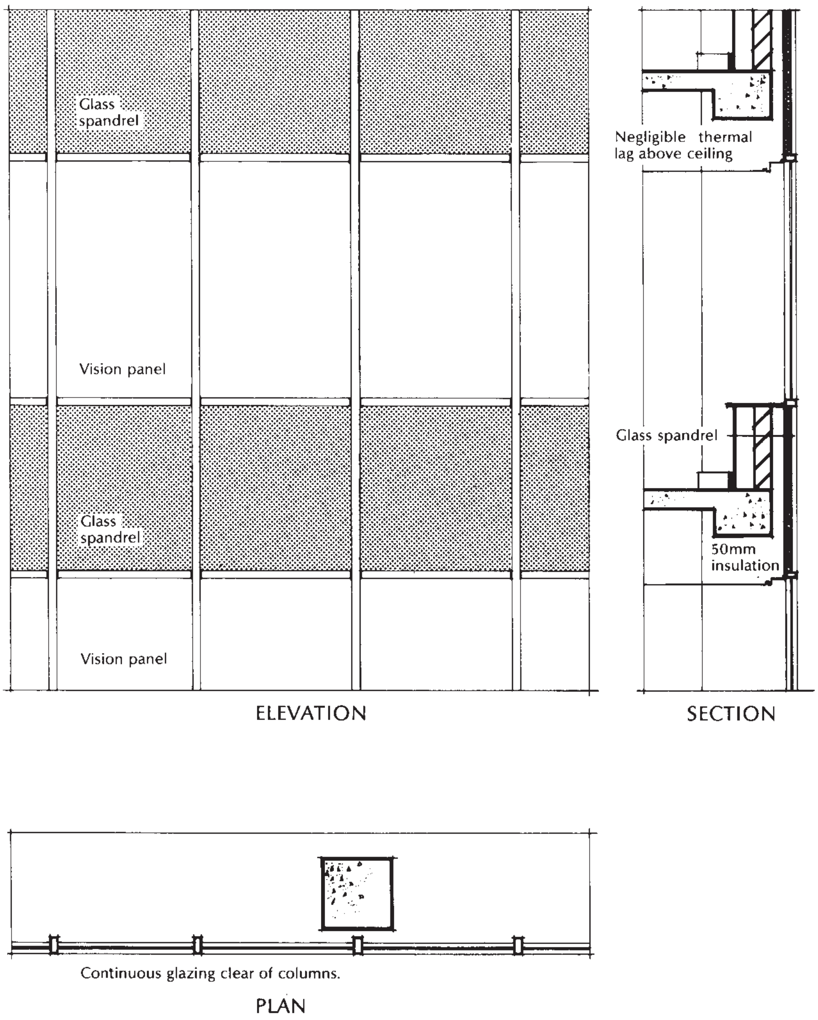


Figure 2.A.3
Details of the flush-glass box facade option considered, but rejected, as a possible building envelope system for the Westfield Office Building, William Street, Sydney.
This system is thermally very sensitive to high solar radiation loads and requires a chiller with a large capacity. (See Fig. 2.B.4.)

The computer modelling was carried out for a four-month summer period from December to March using CSIRO weather data for the year 1971. Note, however, that high solar loads can occur in winter on northerly oriented glazing.

Figure 2.A.1 shows a typical floor plan of the Westfield Office Building.

Figure 2.A.2 shows a part plan, section and elevation of the precast building envelope design option with its integral shallow moulded sunscreens. These shallow sunscreens are effective in shading against the diffuse component of solar radiation in addition to the direct component. For example, in the vertical section, only 86% of the diffuse component is incident on the glass. In the horizontal plan section, only 85% of the diffuse component is incident on the glass.

The horizontal and vertical shading of this precast system reduces the diffuse component of solar radiation by 27%. Applied to noon in mid summer on a north-facing window, this reduction of diffuse radiation is 150 watts/m^2 × 27% = 40 watts/m^2.

Note, however, that at this time the glass is also completely shaded from the direct component of solar radiation by the recessing of the mullions in the precast unit. With the precast system, the radiant solar load on the glass at noon is 110 watts/m^2, compared to approximately 300 watts/m^2 on the glass in the flush systems.

The effectiveness of profiled wall panels in reducing radiant solar loads is evident.

Energy savings can be best achieved by designing sunscreens for the specific orientation of a building. This is discussed further in Appendix II.

Figure 2.A.3 shows a part plan, section and elevation of the flush-glass building envelope design option.

Figure 2.A.4 shows a photograph of the southern facade of the Westfield Office Building as built in its precast version. The horizontal void-to-solid ratio is 1:0.33 and the percentage of glass in the facade is 41%.

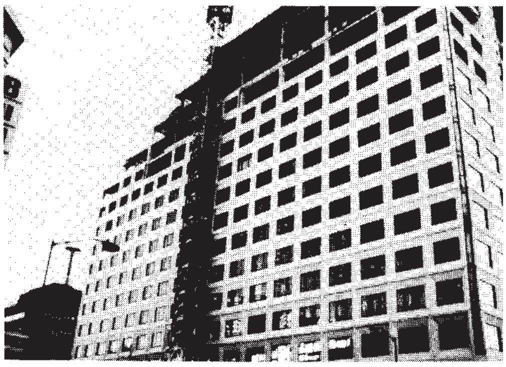


Figure 2.A.4
View of the Southern facade, Westfield Office Building, Sydney

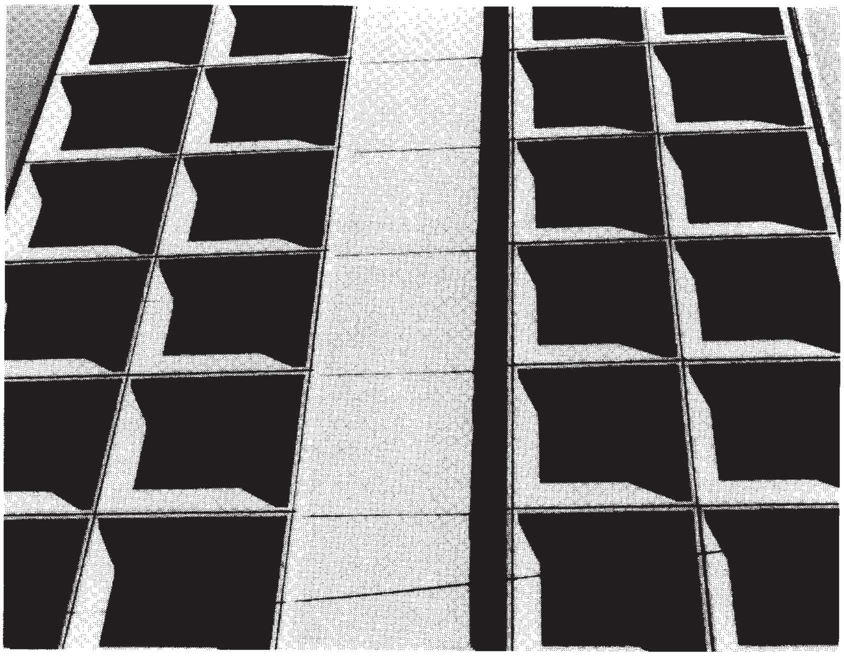


Figure 2.A.5
View of the Eastern facade, Westfield Office Building, William Street, Sydney, illustrating that even quite shallow sunscreens can be effective in reducing loads from the direct component of solar radiation for portion of the day

Figure 2.A.5 shows a photograph of the eastern facade of the Westfield Office Building. Note that the precast moulding forms shallow sunscreens which effectively shade the glass for a portion of the day.

The cooling loads for any particular day can be calculated.

Thus, Figure 2.A.6 shows the cooling loads in the Eastern Zone (see Fig. 2.A.1) of a typical floor for (a) the flush-glass-facade building envelope design option, and (b) the precast facade system which incorporates integrally moulded shallow sunscreens on 9 January 1971 (weather tape) which was a day of high air temperatures. At noon, for example, the precast system effects a 16% reduction in cooling loads compared to the flush facade system.

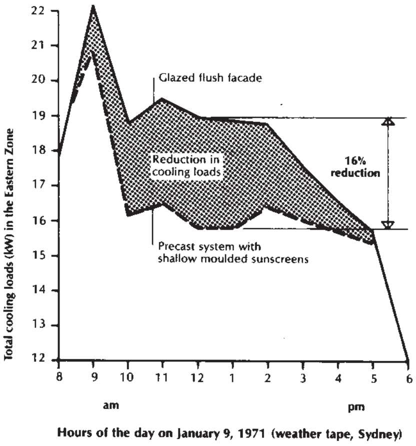
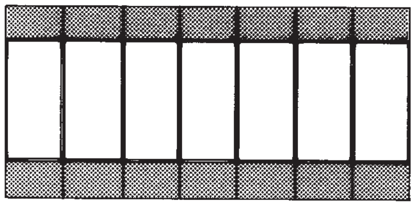


Figure 2.A.6

Comparison of total cooling loads in the Eastern Zone of a typical floor of the Westfield Office Building, Sydney: (a) fitted with a glazed flush facade and (b) fitted with the precast facade system with shallow integrally moulded sunscreens illustrated in Figures 2.A.2, 2.A.4, and 2.A.5

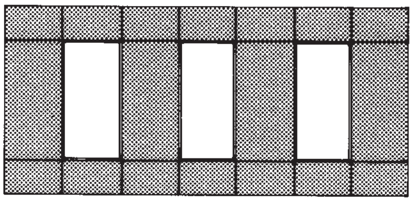
At midday there is a 16% reduction in cooling loads by using the precast system compared to the glazed flush facade.

FLUSH FACADES



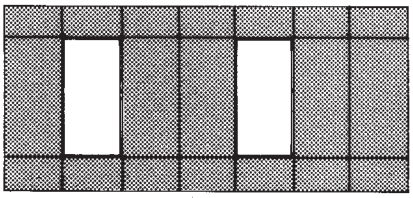
Horizontal vision panel :
opaque panel ratio = 1:0 (Continuous glazing)

Vision panel = 55% of facade area.



Horizontal vision panel :
opaque panel ratio = 1:1

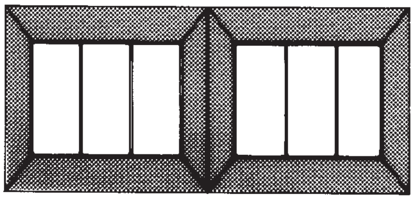
Vision panel = 27% of facade area.



Horizontal vision panel :
opaque panel ratio = 1:2

Vision panel = 18% of facade area.

PRECAST CONCRETE FACADE WITH SHALLOW MOULDED SUNSCREENS



Horizontal vision panel :
opaque panel ratio = 1:0.33

Vision panel = 41% of facade area.

Figure 2.A.7

The various percentages of vision panels in the facades studied

Note that although the vision panels in the precast concrete facade with shallow moulded sunscreens were larger, at 41% of the facade area, than the 27% flush facade system, the recurrent cooling loads were less due to shading against solar radiation.

Figure 2.A.7 illustrates the various percentages of vision panels in the facades studied.

Thus, for nominated recurrent cooling loads, larger vision panels are possible in facades fitted with sunscreens — even quite shallow sunscreens. These may be readily moulded integrally with the precast concrete spandrel and/or wall panels.

The results of the study are summarised in Figure 2.A.8 which shows the total of the energy cooling loads. These were calculated at hourly intervals throughout the hours of operation of the airconditioning plant, for the entire four-summer-months period modelled.

From Figure 2.A.8 may be seen the advantage of the precast system with its shallow sunscreens, which provides a 20% reduction in the total recurrent summer cooling loads compared to the all-glass flush facade.

Reducing the vision panels to an area of 27% of the facade in a flush-facade system, does not lower the cooling loads as effectively as the precast system with its integrally moulded shallow sunscreens even with its larger vision panel area of 41%.

Reducing the vision panels from 55% of the facade area to 27%, and using cavity concrete wall panels for the remaining 73% of the flush facade, produced only an 18% reduction in total cooling loads for the four-month summer period studied. With the shallow precast concrete sunscreens, 20% reduction in total cooling loads was achieved with a vision panel of 41%.

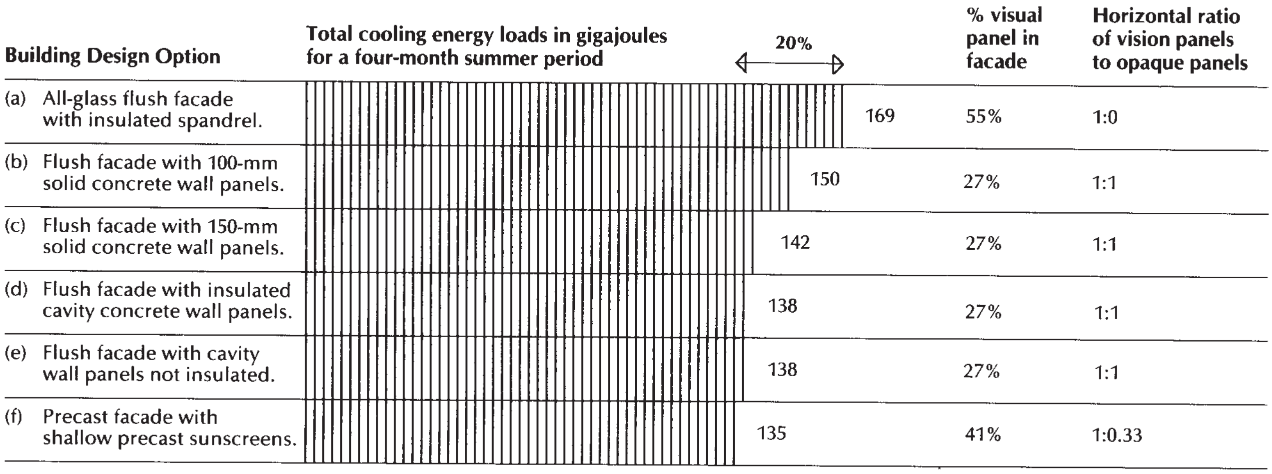


Figure 2.A.8

Comparison of total cooling energy loads of five building design options in the eastern zone of a typical floor in the Westfield Office Building, Sydney, for a four-month summer period. A 20% reduction in cooling is achieved using the moulded precast system.

Where the vision panels in the flush-facade system were reduced to 27% of the facade, the cooling load reductions using cavity concrete were 8.2% (over 100-mm solid concrete) and 2.6% (over 150-mm solid concrete).

Where the vision panels in the flush-facade system were reduced to 18% of the facade, the cooling load reductions using cavity concrete were 9.8% (over 100-mm solid concrete) and 3.1% (over 150-mm solid concrete).

Insulating the cavity-concrete wall areas in a flush-facade system produces almost insignificant (0.07%) cooling-load reductions because, without sunscreens, the heat gain through the vision panels is, in comparative terms, very great.

The conclusions to be drawn from this study are that the most significant factors in achieving recurrent energy savings are:

(a) reducing the areas of windows; and

(b) shading the glass from the direct component of solar radiation.

More detailed appraisals of reductions in airconditioning-plant size and peak cooling loads are presented in Energy Case Study B.

ENERGY CASE STUDY B

200 Mary Street, Brisbane

Architect Geoffrey Pie, in his design for a high-rise office building at 200 Mary Street, used simple precast concrete spandrels that extended in an inclined plane to shade the windows below.

In this Energy Case Study, computer models were made for the following building envelope design options:

(a) Flush glass facade with single clear glazing and no sunscreens

(b) Flush glass facade with double-glazed, green, heat-absorbing glass and no sunscreens

(c) Precast facade with the sunscreens formed integrally with the spandrel panels and using clear glazing.

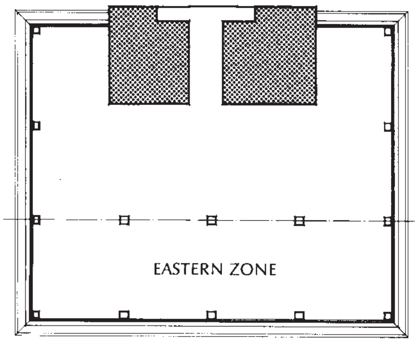
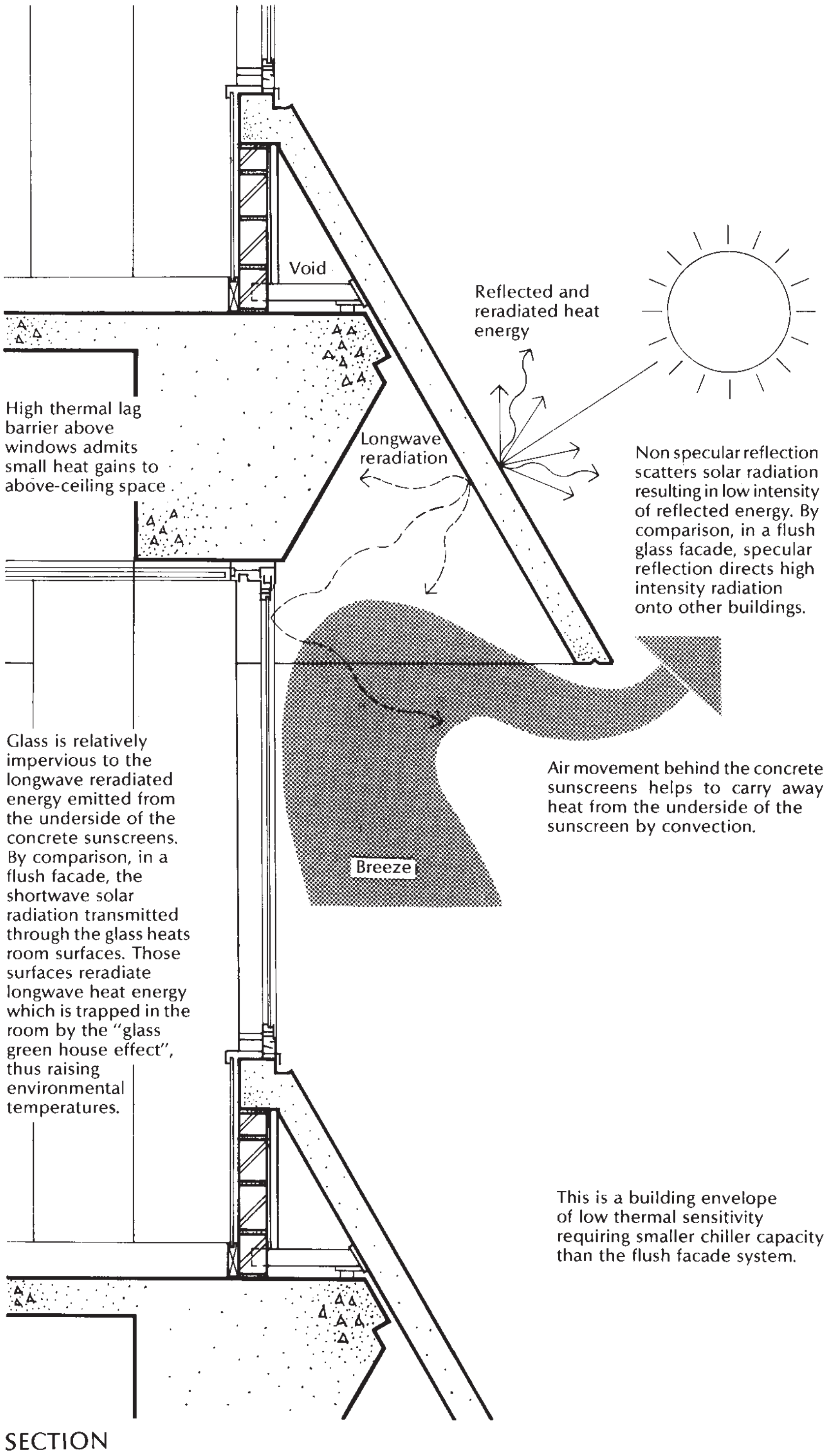


Figure 2.B.1
Typical plan of the twenty-storey office building at 200 Mary Street, Brisbane showing the Eastern Zone which is the subject of this energy study



High thermal lag barrier above windows admits small heat gains to above-ceiling space

Non specular reflection scatters solar radiation resulting in low intensity of reflected energy. By comparison, in a flush glass facade, specular reflection directs high intensity radiation onto other buildings.

Air movement behind the concrete sunscreens helps to carry away heat from the underside of the sunscreen by convection.

Glass is relatively impervious to the longwave reradiated energy emitted from the underside of the concrete sunscreens. By comparison, in a flush facade, the shortwave solar radiation transmitted through the glass heats room surfaces. Those surfaces reradiate longwave heat energy which is trapped in the room by the "glass green house effect", thus raising environmental temperatures.

This is a building envelope of low thermal sensitivity requiring smaller chiller capacity than the flush facade system.

Figure 2.B.2
Typical detail of the precast concrete spandrel and integrated sun shading system used on the office building at 200 Mary Street, Brisbane

Figure 2.B.1 shows a typical floor plan of 200 Mary Street and Figure 2.B.2, a typical section. Figure 2.B.3 shows the energy totals of cooling loads for a four-month summer period from December to March on a typical floor for each of the building envelope design options (a), (b) and (c).

Double-glazed, green, heat-absorbing glass in a flush facade reduced the energy totals of cooling loads for the four summer months by 20% compared to using clear glass. The precast facade with moulded shading elements and single clear glass, reduced the total cooling loads for the four summer months by 50%.

Figure 2.B.4 shows the percentage frequency of cooling loads computed for the hours of operation of the airconditioning plant over the four-month period studied.

These percentage frequency of loads have been expressed within ranges of loads, ie 0-9, 10-18, 19-27, 28-36, 37-45, 46-54 and 55-63 kW.

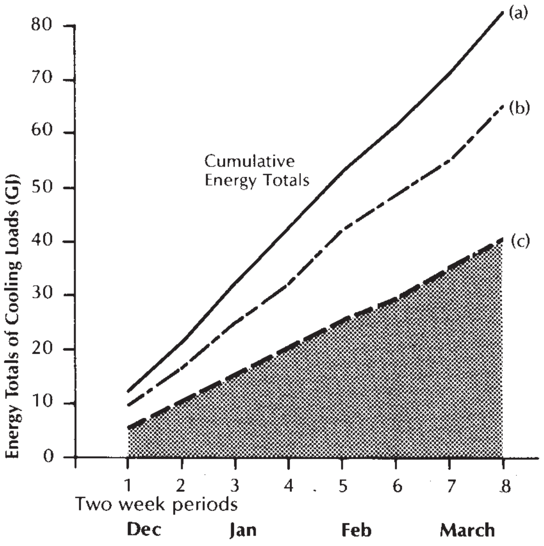


Figure 2.B.3
Eastern-zone energy totals of cooling loads on a typical floor throughout the months of December, January, February and March for various building-envelope design options:
(a) Flush facade, clear glass, no shading; (b) Flush facade, double, heat-absorbent glass, no shading; and (c) Shading with clear, single glazing.

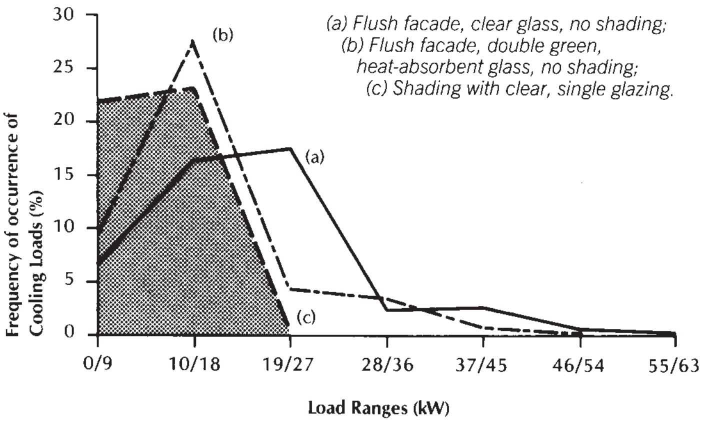


Figure 2.B.4
Frequency of occurrence of hourly cooling loads in the eastern zone of a typical floor over the total hours in a four-month summer period for various building-envelope design options: This data is useful for sizing airconditioning plant. For example, option (c) requires chiller plant capabilities in the range of 19-27 kW whereas option (a) requires chiller plant capabilities in the range 55-63 kW.
The aim of architectural design should be to design the building so that the greatest percentage frequency of loads occur in the lowest possible load ranges. This is possible where the glass is shaded from the direct component of solar radiation. Unless shading is provided, small percentages of high loads will require the installation of large-capacity chillers which will not be efficient because their coefficient of performance is poor in low load ranges.

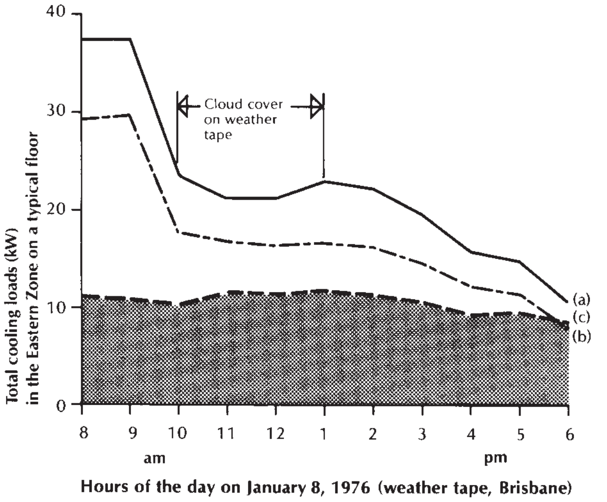


Figure 2.B.5
Total cooling loads in the Eastern Zone of the high-rise office building at 200 Mary Street, Brisbane, for various building envelope design options: (a) Flush facade, clear glass, no shading; (b) Flush facade, double, heat-absorbent glass, no shading; and (c) Shading with clear, single glazing.

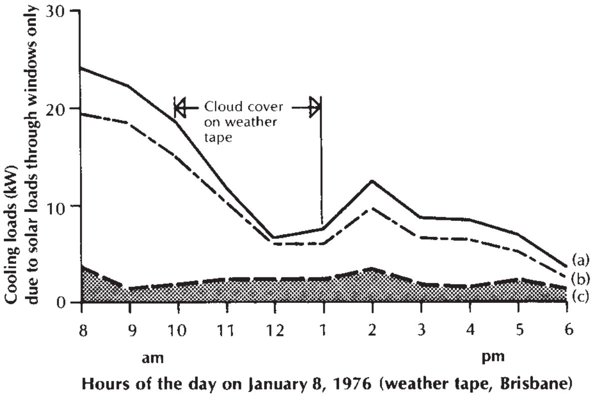


Figure 2.B.6
Cooling loads due to SOLAR loads transmitted through the windows in various building- envelope design options: (a) Flush facade, clear glass, no shading; (b) Flush facade, double, green, heat-absorbent glass, no shading; and (c) Shading with clear single glazing.
Note: Print out has been selected on this day to illustrate the detail contained in the weather tapes used (prepared by the CSIRO). Cloud cover from 10 am to 1 pm illustrates the effectiveness in reducing cooling loads of preventing the direct component of solar radiation from being incident on the windows.

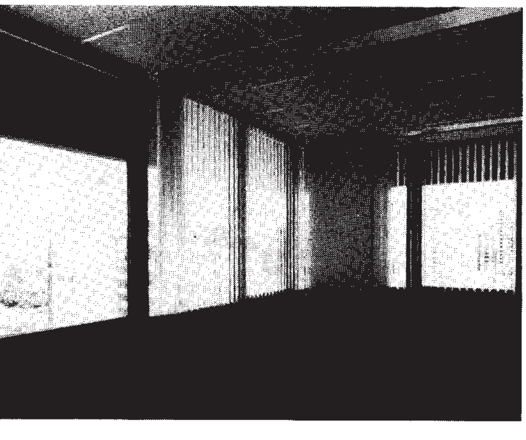


Figure 2.B.7
The interior of an office in 200 Mary Street, illustrating the use of internal blinds to control glare reflected off surrounding buildings

When the precast system with its integral sunscreens is used, the design loads which define the required airconditioning plant size are approximately half those for the flush-glass facade systems.

Figure 2.B.5 shows the total hourly cooling loads in the Eastern Zone on a typical floor for each of the building envelope design options (a), (b) and (c) on 8 January, 1976 of the CSIRO weather tapes used in the computer simulation.

Figure 2.B.6 shows the solar loads only through windows on the same day, also in the Eastern Zone. At 10.00 am, double, green, heat-absorbing glass in a flush facade compared to single glazing, produced a 19% reduction in SOLAR cooling loads through windows. Also at 10.00 am the precast facade with integral sunscreens and single clear glass, produced a further reduction of 70% in the SOLAR cooling loads through windows compared to the flush facade with double, green, heat-absorbent glass.

Simple shading elements are effective in reducing airconditioning plant size, recurrent cooling loads and in shielding occupants near windows from the direct component of solar radiation, making thermal comfort achievable. The daylight admitted is usable because glare that would otherwise be caused by direct sunlight penetration, is controlled. Note, however, that internal blinds have been provided to control glare reflected off surrounding buildings — Figure 2.B.7.

3 EXAMPLES OF PREFERRED CROSS SECTIONS FOR ECONOMICAL USE OF PRECAST CONCRETE AS SHADING ELEMENTS

PREFERRED CROSS SECTIONS

Figure 3.1 shows preferred cross sections for economical use of precast concrete as shading elements. Note that in each case:

(a) the spandrel and sunscreening elements are integral and may be lifted into place in one operation;

(b) the dead weight of the spandrel/sunscreen element is positioned on the edge beam as a compressive load and does not rely on metal fixtures in shear.

DESIGN OF SIMPLE SUNSCREENS

The depth of the overhang from the window plane, the height of the window opening and the size of the louvres may be designed to control sunlight penetration for the various facades. In temperate areas in the southern hemisphere:

(a) simple horizontal shading is effective on the northern facade;

(b) vertical louvres and mullions are effective on the southern facade and for a range of orientations in the quadrant south-east to south-west, provided the tops of the sunscreens are covered.

These sunscreens may be designed by the method described in the booklet "Sunshine and Shade in Australasia" by R.O. Phillips, Bulletin No. 8 of the Commonwealth Experimental Building Station — a popular booklet which was first published in 1948 and remains in print today.

Sunscreens facing due east and west may also be designed using R.O. Philips's booklet and will produce designs which give a view out to the south-east and south-west.

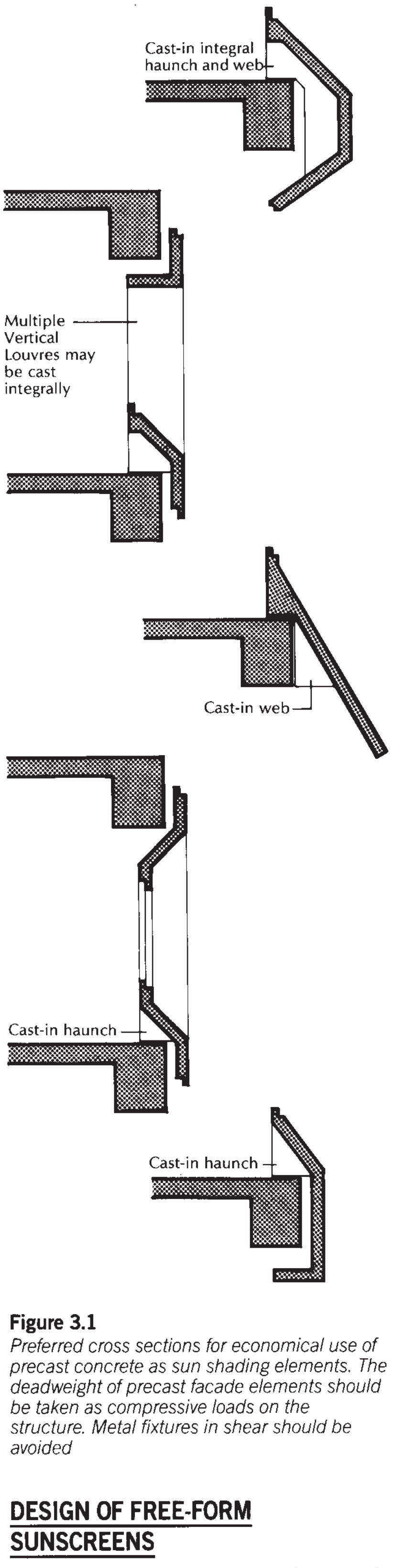


Figure 3.1
Preferred cross sections for economical use of precast concrete as sun shading elements. The deadweight of precast facade elements should be taken as compressive loads on the structure. Metal fixtures in shear should be avoided

DESIGN OF FREE-FORM SUNSCREENS

For orientations in the north-easterly and north-westerly quadrants, and if views are required towards the north-east or north-west from windows facing due east and west, the above-mentioned method will require sunscreens designed with redundancy, ie more material (dead weight) than is required. An improved method of designing these sunscreens is illustrated in Harkness and Mehta's book "Solar Radiation Control in Buildings"(5).

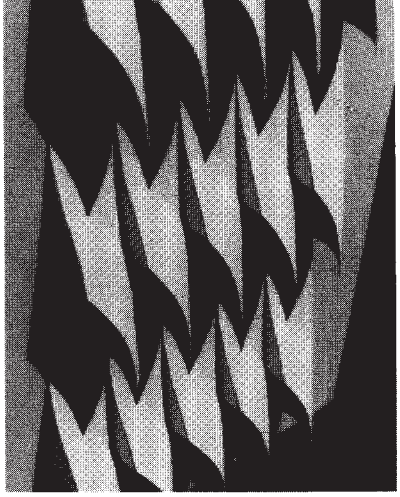


Figure 3.2
Sunscreens orientated asymmetrically to the equator

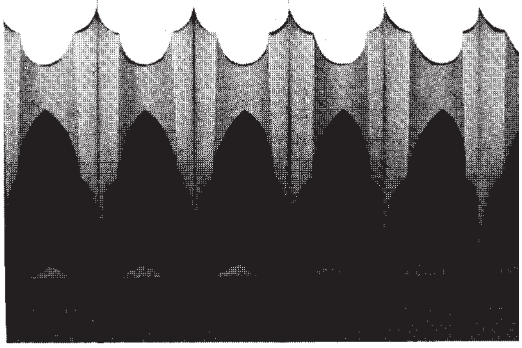


Figure 3.3
Sunscreens symmetrically facing the equator

Harkness and Mehta's book introduces design architects to a new free-form approach to sunscreen design that is both functional and aesthetically interesting. These sunscreens admit the maximum view out of the building for specified exclusion of the direct component of solar radiation. They may be designed to admit the direct component of solar radiation in winter and exclude direct radiation in summer for suitable orientations, with no moving parts.

The resultant sunscreens are of course different for each facade because the sun's relative movement is different with respect to each orientation. These sunscreens which may have an almost infinte variety of forms, have their shape scientifically defined.

Sunscreens have been designed using this technique for buildings in Australia and South East Asia, illustrations of which may be seen in the book "Architects of Australia" published by Images Australia, 1985. Figures 3.2 and 3.3 show models of sunscreens designed to trace the sun's path relative to building sites in Kuala Lumpur, Malaysia. Both designs integrate the spandrel panel and the sunscreen into one repeated element. The changing shadow patterns create a continuing character modification for the building throughout each day and season.

SUMMARY

1 Insulating the cavity of the concrete wall portion of building facades which are fitted with windows, is not energy cost effective unless the window areas are proportionally very small.

2 The use of clear glass, shaded from the direct component of solar radiation requires smaller chiller plant and produces lower recurrent cooling loads than a flush facade fitted with double heat-absorbent glass without sunscreens.

3 Using heat-absorbent glass in windows which are effectively shaded against the direct component of solar radiation will yield small additional reductions in recurrent cooling loads compared to shaded clear glass.

4 Effective shading of windows can be achieved by the use of sunscreens moulded integrally with spandrel and wall elements resulting in requirement for smaller airconditioning plant, lower recurrent cooling loads and better thermal comfort than can be achieved in a flush glass facade system.

5 The final cost effectiveness in any building which is airconditioned, depends upon the sophistication of the mechanical engineer's design of plant and air-handling facilities.

REFERENCES

1 COMMONWEALTH DEPARTMENT OF HOUSING AND CONSTRUCTION, Design brief to mechanical engineers for the proposed Commonwealth Offices at Parramatta, NSW.

2 HARKNESS, E.L. "Radiation Effects in the Internal Environment", presented to an International Conference on the Indoor Environment of Tall Buildings, Singapore, January 24-26, 1985.

3 DRYSDALE, J.W. "Physiological Study No. 2", Technical Study 32. Commonwealth Experimental Building Station (Sydney), 1950.

4 OLGYAY, V. "Bioclimatic Approach to Architecture", Housing and Home Finance Agency (US), Report on Project 1-T-130.

5 HARKNESS, E.L. and MEHTA, M.L. "Solar Radiation Control in Buildings", Applied Science, London, 1978. Russian Language Edition, 1984.

BIBLIOGRAPHY

1 "Thermal Design of Precast Concrete Building Envelopes", Journal of the Prestressed Concrete Institute Vol. 23, No. 1, Jan - Feb 1978.

2 "Architectural Precast and Prestressed Concrete — the building material for all seasons", Prestressed Concrete Institute, Chicago.

3 "Handbook of Fundamentals", American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., New York, 1981.

4 "Energy Conversion in New Building Design", ASHRAE Standard 90-75, American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., New York, 1975.

5 HARKNESS, E.L. "Some Aspects of Fenestration Design in Modern Buildings" Architectural Science Review, Vol. 20, No. 1, March 1977.

6 HARKNESS, E.L., "Energy Consequences of Building Design Options", presented to the "Science and Architectural Form" conference of the Australian and New Zealand Architectural Science Association held in Auckland, New Zealand, August 1986.

7. FANGER, P.O., "Thermal Comfort" Analysis and Applications in Environmental Engineering, McGraw - Hill, New York, 1972.

APPENDICES

I THE SINGAPORE EXPERIENCE WITH ENERGY-SAVING GLASS

Six years ago, the owners of approximately 200 buildings in Singapore were instructed to retrofit their buildings to reduce energy consumption or face utility surcharges. The Development and Building Control Division (PWD) Singapore, prepared a handbook on energy conservation in buildings and building services within which a concept for Overall Thermal Transfer Value (OTTV) was presented as a guide to architects and building owners.

The OTTV concept accepted the claims of glass manufacturers that their special glass types were energy saving. The following excerpts of a report by Aleshire(†) raise serious doubts about those claims.

- ☐ Denmark House was retrofitted with $S230 000 worth of double glazing and roof insulation. Its monthly utility bills before and after retrofitment were approximately the same at $S20 000.
- ☐ The DBS Bank in Shenton Way spent $S500 000. The bank has been unable to quantify the results of the retrofitment but project that savings will be only approximately 1.6 per cent.
- ☐ $S1.5 million was spent fitting dark glass to the International Plaza in Anson Road with energy savings expected to be 3 to 5 per cent. These projected savings were lost when the building owners realised that they had to install additional lights within the building because of the reduced daylight transmission of the dark glass.
- ☐ The Oberoi Imperial Hotel in Jalan Rumbia spent $S1.0 million, with a resultant energy saving of zero.

Other buildings surveyed in Aleshire's report included Commercial Union Building, Hong Leong Building, Mandarin Hotel, Shaw Centre, Shaw Towers, United Overseas Bank Building and Overseas-Chinese Banking Corporation.

Aleshire reported that research carried out in Singapore under a joint Asean-American programme concluded that, with respect to designing for energy savings: heat conducted through windows and walls should be de-emphasised and **that encouragement should be given to increased use of shading the building against the sun and reduction in the area of windows,** ie reduction in the instantaneous heat gain of the direct and diffuse components of solar radiation.

The Energy Case Studies in Section 2 of this booklet confirm these recommendations.

II COMPUTING THE ENERGY COST EFFECTIVENESS OF BUILDING DESIGN OPTIONS

The Energy Case Studies in this booklet have been prepared using computer models of typical floors of a building, quantifying the recurrent energy loads for various building envelope design options, with or without sunscreens on various facades, types and quantity of glazing and insulation. The computer program accommodates complex shading of the building by other buildings, self shading of buildings and shading by complex sunscreens.

Energy data produced in these studies include:

- ☐ total gigajoules of heating and cooling loads over the period required — from one day to an entire year;
- ☐ print out on selected days of hourly heating and cooling loads in each zone;
- ☐ percentage frequency of loads which is useful for sizing air-conditioning systems;
- ☐ print out of the perimeter loads due to solar influences on the building envelope separate from occupancy loads and lighting loads - information required by mechanical engineers in designing dual supply systems for perimeter zones where one supply accommodates the change in solar loads and the other accommodates the constant loads.

The program used is TEMPAL written by A & E Coldicutt of the University of Melbourne. *Note: The program can also be used to predict the environmental temperatures in naturally ventilated buildings.*

Weather tapes used in these studies were prepared by the CSIRO and contain hourly data of all the relevant meteorological variables of the external environment such as air temperature wet-bulb temperature, wind speed, wind direction, solar radiation and cloud cover for entire years.

The purpose of this service is to provide data upon which quantification of the energy cost effectiveness of various building envelope design systems and resultant airconditioning systems can be made, enabling architects, mechanical engineers and owners to make informed economic decisions which will be a function of their short-term or long-term interest in the proposed building.

Commissioned by the Public Works Department of NSW to advise how the ward block of the $100m New Teaching Hospital, Greater Newcastle Area, could be designed to provide thermal comfort without airconditioning, program TEMPAL was used to predict environmental temperatures for various building design options. The capital cost of each variation was plotted against the percentage frequency of hours that the environmental temperature exceeded a nominated temperature. The results of that study are summarised as shown in Figure A.1(a) and (b).

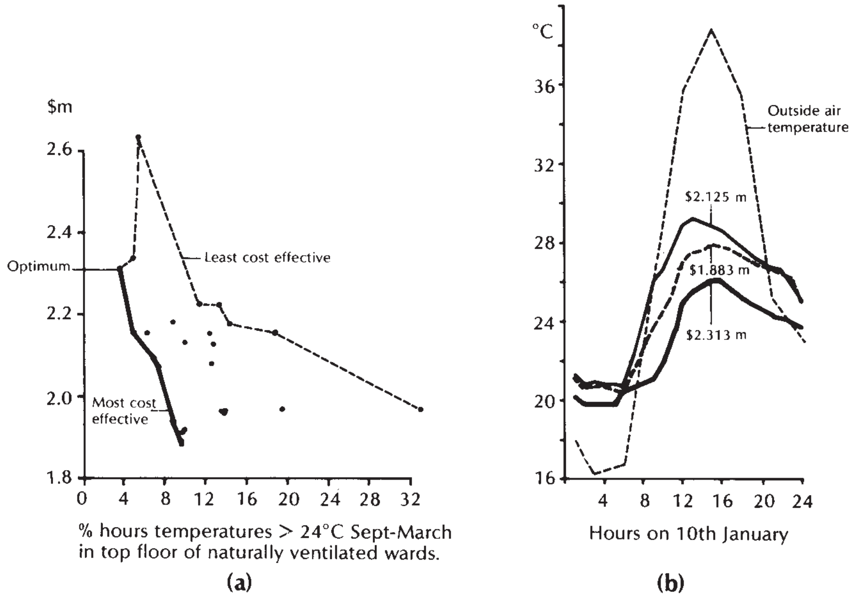


Figure A.1
Thermal comfort cost effectiveness studies for the $100m New Teaching Hospital, Newcastle.
(a) *Shows plots of capital costs and percentage frequency of hours the environmental temperatures exceeded 24°C.*
(b) *Shows plots of environmental temperatures for three of the design options (and their capital costs) plotted against the outside air temperature.*

(†) ALESHIRE, I. "Little Energy Saved". The Straits Times (Republic of Singapore), p2, Friday, 7 September 1984.

III SOLAR LOAD REDUCTION GRAPHS

INTRODUCTION

The solar load reduction graphs (published in this appendix for the first time) contain the following information at the latitude of Sydney in the months of December, March/September and June, for a range of orientations at which facades are subjected to the incidence of both the direct and diffuse components of solar radiation:

(a) Percentage reduction in solar load for increases in the projection of a simple sunscreen.

(b) Percentage reduction in solar load for reduction in area of window:
- ☐ without a sunscreen fitted;
- ☐ with sunscreens of various projections or window recesses.

(c) Total daily solar load in MJ for the variations described in (a) and (b).

Sizes of windows and projections of sunscreens used in preparing these graphs are as defined in Figure X.0.

HOW TO USE THE GRAPHS

Nomination of window area:

Holding the window height constant at **0.8H,** where **H** is the floor-to-floor height, the designer may nominate any width of window in each panel up to the dimension of **H**. This width is defined by the width of the precast mullions (**bH**).

Where **b** is zero, the window is the full width of the panel, providing continuous glazing. If the value 0.5 is given to **b**, there will be no window at all. Values of **b** which lie between zero and 0.5 will define windows bounded by mullions on each side. The values of **b** are shown on the second scale down from the top of each graph.

Nomination of sunscreen projection:

Values of **aH** define the projection of the sunscreen from the external face of the precast panel or the depth of window recess behind the face of the precast panel.

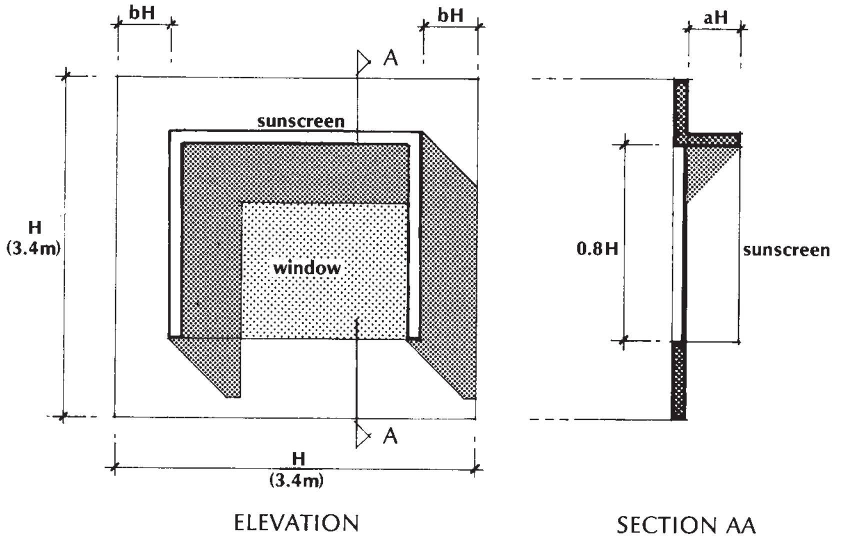
Values of **a** used in these graphs are 0.0, 0.05, 0.1, 0.2, 0.25, 0.3. The user may interpolate between the values.

The bottom scale:

The bottom scales in the graphs show the % **reduction in window area** which is directly related to the second top scale showing values of **b**. The user may interpolate between these values. Immediately above the bottom scale is shown the % **window area in the facade.**

The right hand vertical scale:

The right hand vertical scale shows the cumulative **total solar load in MJ** over one day in each month for the specific floor-to-floor height (**H**) of 3.4m.



ELEVATION

SECTION AA

Figure X.0 *Definition of sizes of windows and projections of sunscreens used in the solar load reduction graphs*

The remaining vertical scales:

All of the vertical scales except the right hand scale show the % **reduction in total solar load** on the day under consideration for the various combinations of values of **a** (sunscreen projections) and **b** (mullion size). The user may interpolate between these values.

The actual and % reduction in total solar loads for various **combinations** of reductions in window areas and sunscreen projections where the floor-to-floor height is 3.4m may be estimated as follows:

This estimate may be made by locating the intersection of one of the inclined **a** lines with a vertical line projected from the top or bottom scales for a given combination of sunscreen projection and window area. From this intersection, project a horizontal line across to the right hand 'Solar Load' scale and note the number of MJ.

Repeat this process for another set of options for a and b.

The difference in MJ will give the quantitative reduction. This reduction may then be converted to a % reduction if required.

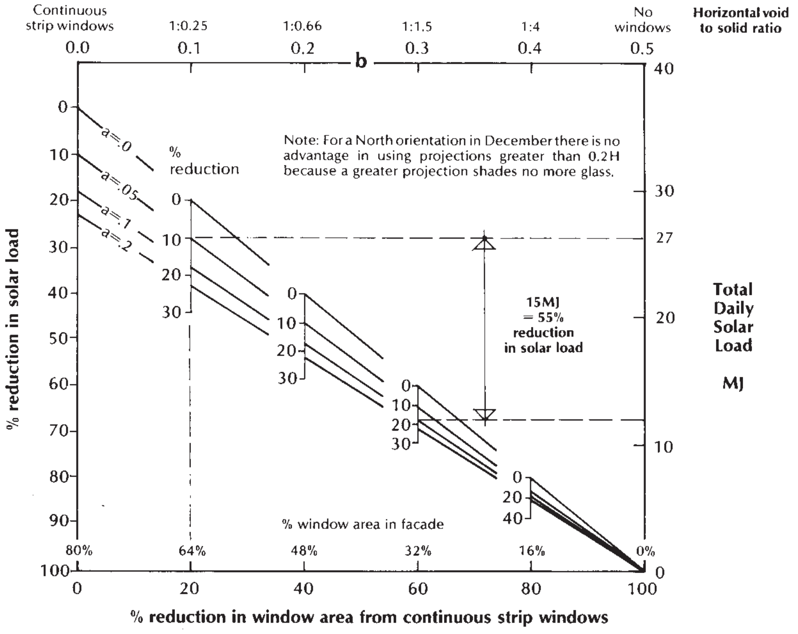
An example of solar load reduction calculation is illustrated by the broken lines in Figure X.1.

A window occupying an area of 64% of the facade, shaded by a 0.05H projection (170mm) permits a solar load of 27MJ; whereas a window with an area of 32% of the facade shaded by a 0.1H projection (340mm) permits a solar load of 12MJ; facilitating a 15MJ or 55% reduction in solar load.

Effects of other window height options:

On request, the author would be willing to produce graphs for other window heights, sunscreen options, latitudes and orientations.

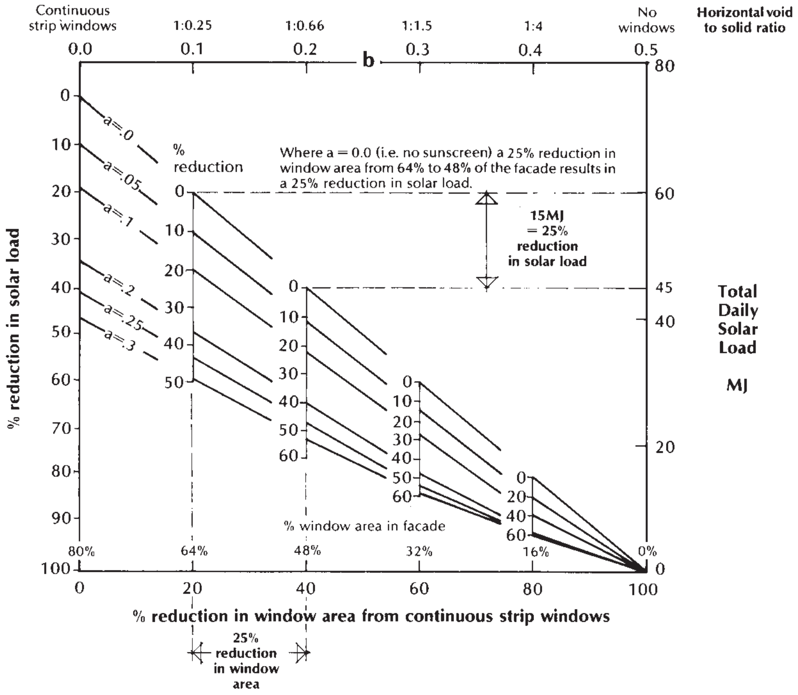
Figure X.1



Note: For a North orientation in December there is no advantage in using projections greater than 0.2H because a greater projection shades no more glass.

December
Wall Orientation: **N**

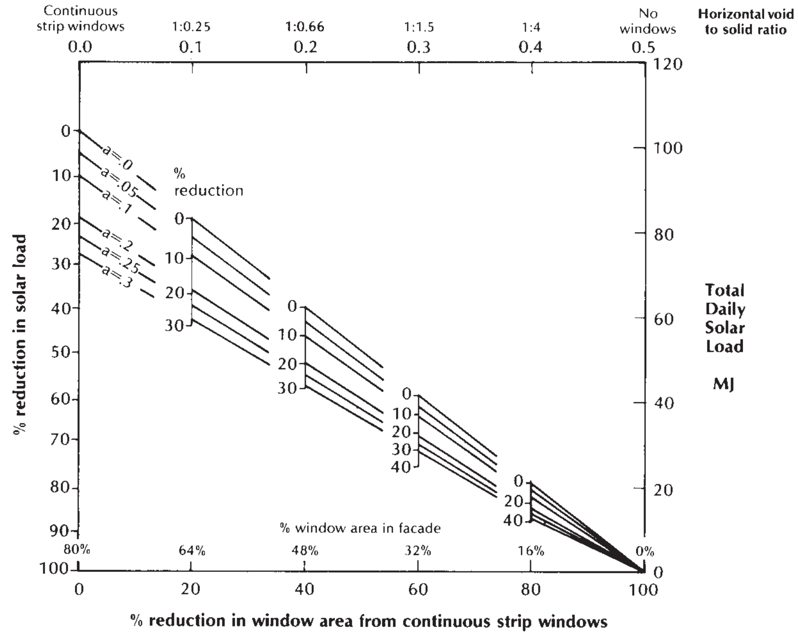
Figure X.2



Where a = 0.0 (i.e. no sunscreen) a 25% reduction in window area from 64% to 48% of the facade results in a 25% reduction in solar load.

December
Wall Orientations: **NE**
NW

Figure X.3



December
Wall Orientations: **E**
W

Figure X.4

December
Wall Orientations: **SE**
SW

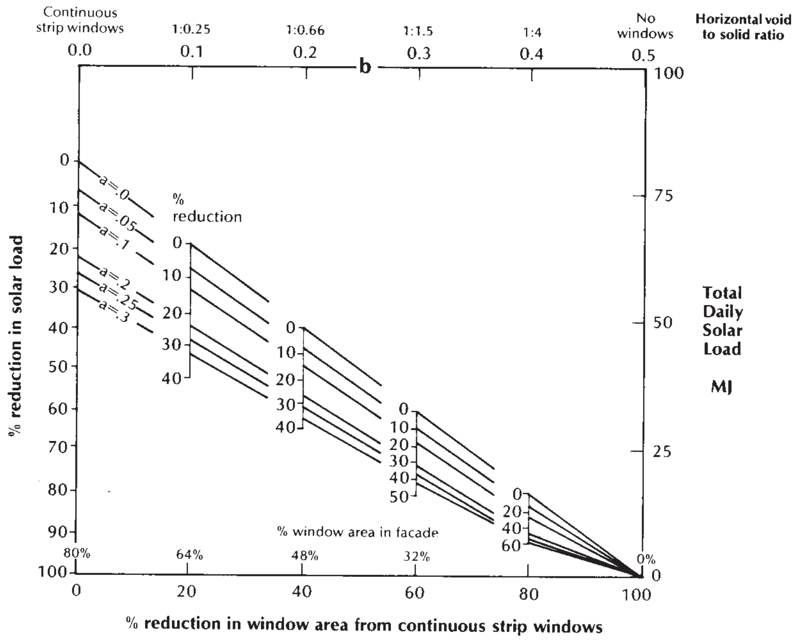


Figure X.5

December
Wall Orientation: **S**

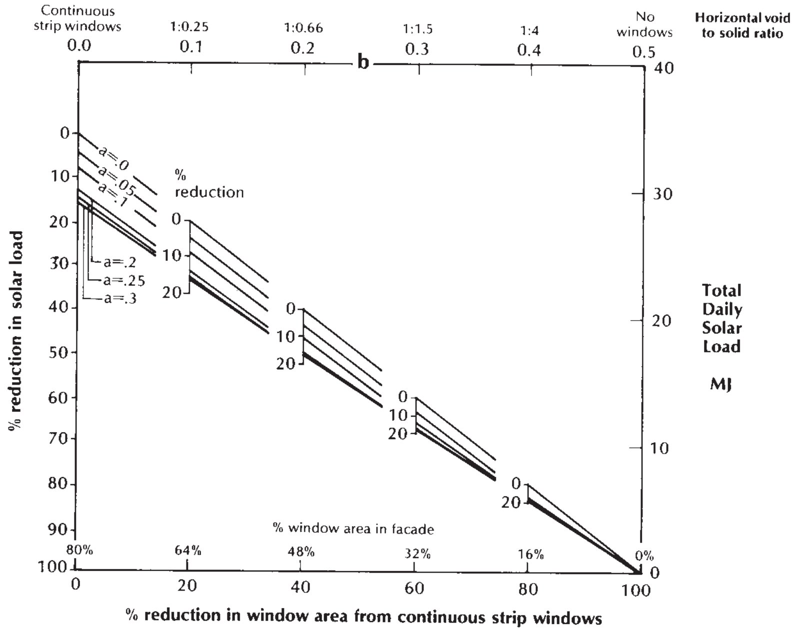


Figure X.6

March/September
Wall Orientation: **N**

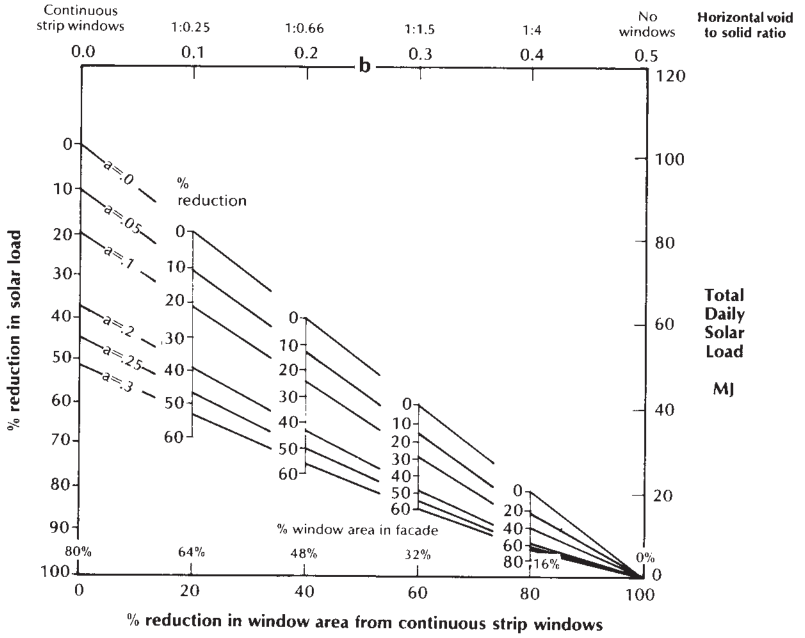


Figure X.7

March/September
Wall Orientations: **NE**
NW

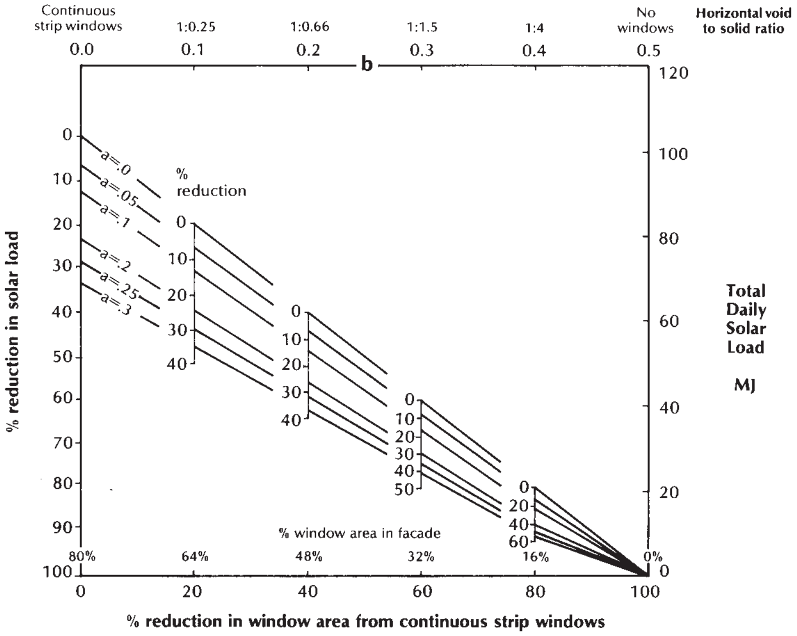


Figure X.8

March/September
Wall Orientations: **E**
W

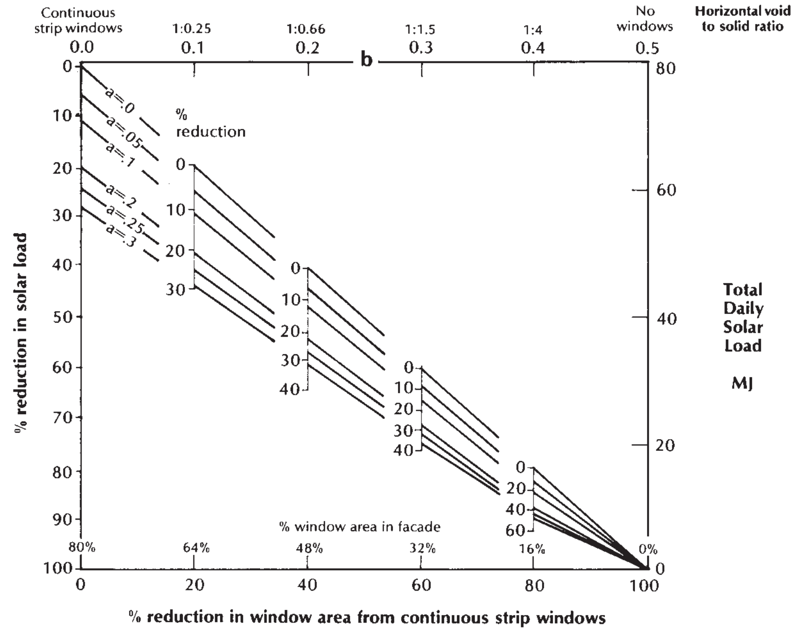


Figure X.9

March/September
Wall Orientations: **SE**
SW

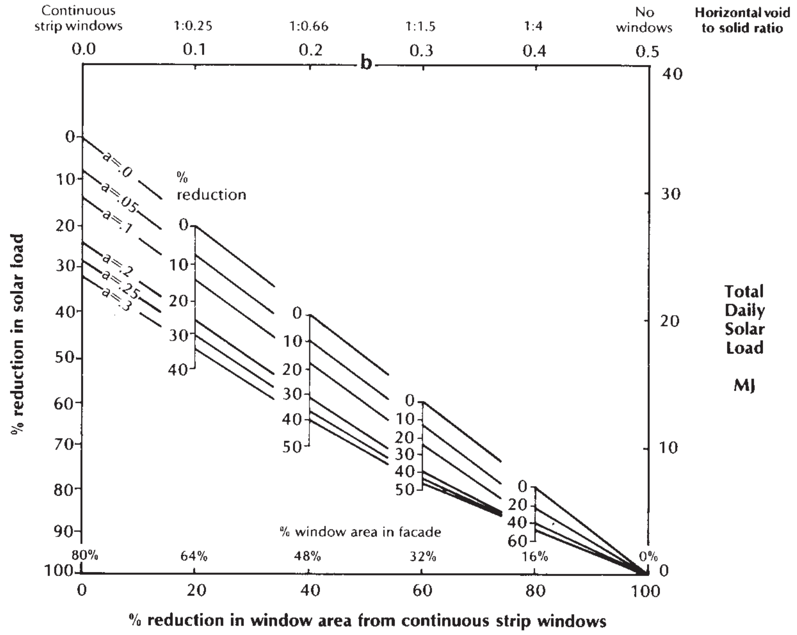


Figure X.10

June
Wall Orientation: N

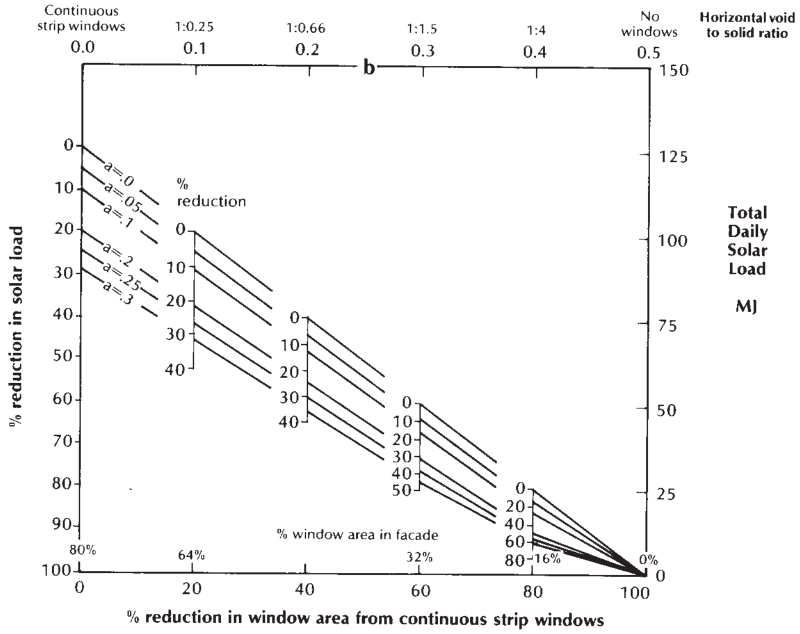


Figure X.11

June
Wall Orientations: NE
NW

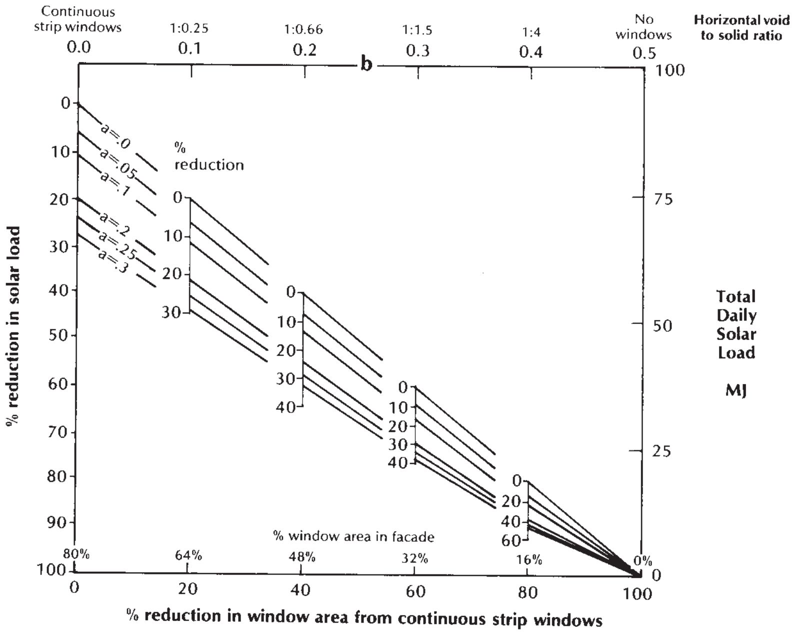
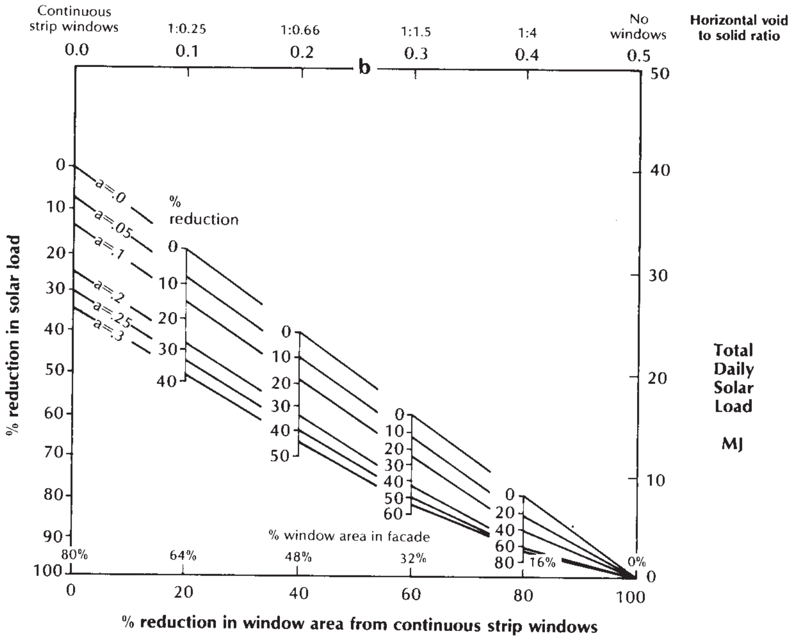


Figure X.12

June
Wall Orientations: E
W



GLOSSARY

Cooling loads: The heat energy required to be expelled from a space by the airconditioning system to maintain a nominated temperature within that space.

Diffuse solar radiation (d): Solar radiation reflected from particles in the atmosphere.

Direct solar radiation (D): Unreflected radiation from the sun.

Equivalent-air-temperature effect: See Sol-air temperature.

Gigajoules: A measure of energy (1 GJ = 277.78 kilowatt-hours).
(1 GJ = 1000MJ)

Heating loads: The heat energy required to be placed in a space by the air conditioning system to maintain a nominated temperature in that space.

Shading coefficient (SC): The ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar heat gain through a single light (pane) of the reference glass under the same conditions.

$$SC = \frac{\text{Solar heat gain of fenestration}}{\text{Solar heat gain of reference glass}}$$

(From ASHRAE Handbook, 1981)

Sol-air temperature (T_{sa}): A function of the solar radiation, air temperature and the thermal properties of the surfaces of that object.

$$T_{sa} = T_o + \frac{Ia}{f}$$

where:
T_{sa} = Sol-air temperature
T_o = Air temperature
$I = d + D$
d = Diffuse solar radiation
D = Direct solar radiation
a = Surface absorptivity
f = Surface conductance.

ACKNOWLEDGEMENTS

Acknowledgement is made of the contribution by Richard Jacombs and Andrew Tweedie who assisted in the preparation of the computer models; by David Malcolm who wrote the computer program to produce the Solar Reduction Graphs in Appendix III; by Norhisham Bin Mohamed Noori and John Bailey who assisted in preparation of the diagrams; by Shirley Byron who typed the manuscript; and by Professor Bill Lim, Dean of the Faculty of Architecture, University of Singapore, who commented on the text.

Precast Concrete Energy-Cost-Effective
Building Facades

ISBN 0 9588360 0 0

August 1987

Copies of this booklet may be obtained from the
Precast Concrete Manufacturers' Association of New South Wales
100 Walker Street
North Sydney 2060
Telephone (02) 929 5866

Back Cover
Office Building,
200 Mary Street, Brisbane

Geoffrey Pie, Architect Planners Pty Ltd

This building illustrates the use of precast concrete sunscreens moulded integrally with the spandrel panels to effectively reduce solar heat gain. See Case Study B.


G