Solar Control Techniques

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ABSTRACT

The paper is structured in four sections. The introduction sets the notion of solar control as a fundamental issue in deciding the priorities of climate-responsive design for different building types and locations in Europe. The second section presents an overview of application contexts and means of solar control, and discusses design priorities and threshold conditions for different space functions and environmental design requirements. The third section focuses on specific solar control techniques identifying particular areas which appear problematic or where further work might be relevant. The fourth section summarises recommendations for further work to improve the understanding and application of these techniques.

1.0 INTRODUCTION

The focus of this review is on the selective exclusion of solar radiation from building surfaces and from spaces inside or around buildings, Fig. 1. Such exclusion may be required:

- as a *preventative* measure aimed at avoiding absorption of solar radiation on building or landscape surfaces, occupant clothing or skin;
- as a *regulatory* measure for daylight control, and for protection of occupants and room contents from glare and ultraviolet radiation.

In either case, reduction of the incoming solar radiation will also have an effect on cooling loads, the size of cooling plant (if any) and the use of artificial lighting.

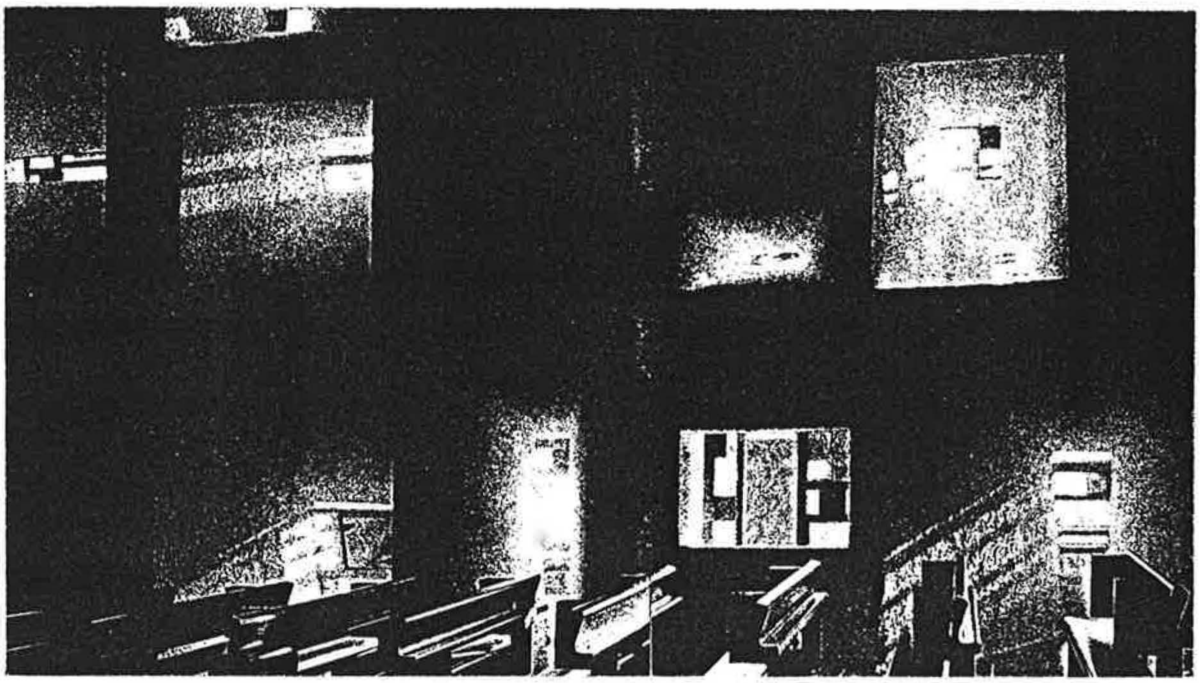


FIG. 1 Internal view of south wall, Notre-Dame du Haut, Ronchamp (Le Corbusier)

For any space inside a building, Fig. 2, the point in time at which the need to exclude solar heat gain may supersede the desirability for such gain, depends on :

- use of the space;
- occupant activities and comfort expectations;
- internal loads;
- enclosure design and thermal properties;
- ambient and site parameters.

On the other hand, the controlled use of natural illumination is an all year objective the benefits of which have been always widely recognised (though not always achieved) by architects. These are now also increasingly the subject of numerical and qualitative evaluation in terms of energy savings, lighting load reduction, occupant comfort and environmental quality.

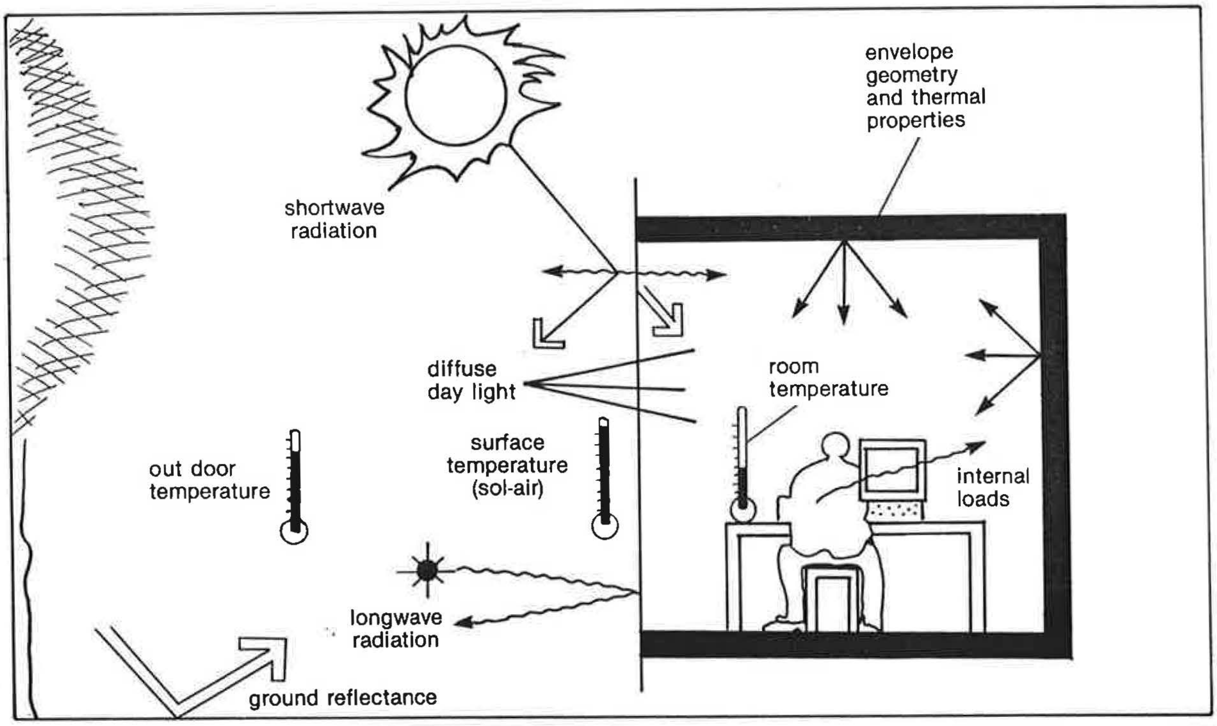


FIG. 2 Design considerations for solar control

The notion of solar control thus lies at the intersection of the three main objectives of climate-responsive design: the displacement of mechanical heating; the disposal of cooling loads, or displacement of mechanical cooling; and the provision of daylight. The objective of solar control is an open-ended question at the starting point of climate-responsive design. Depending on the context, the design objective may range from all year admission to all year exclusion of direct radiation as a source of heat with, where required, the provision and regulation of diffused daylight. As such, the measures adopted for solar control represent the common loci between thermal and lighting objectives as circumscribed by our understanding of the priorities of climate-responsive design for a given location and design brief. How we define these priorities, -by seeking to identify the relative importance of heating, cooling and lighting in the energy balance; by establishing the respective importance of energy saving, occupant comfort and environmental quality; and by attempting to resolve the conflicts that may emerge between these and other design requirements (for example, contact with outdoor through view and the provision of fresh air for ventilation)-, is one of the key issues discussed in this paper.

2.0 DESIGN CONTEXT AND MEANS OF SOLAR CONTROL

2.1 General Principles and Overview

Solar control is the most widely accepted and applied among the strategies of climate-responsive design. The range of design applications of solar control is very wide. External elements which may require some form of temporary or permanent application of solar control include:

- Outdoor spaces;
- Ground adjacent to buildings;
- Windows, clerestories, rooflights;
- Atrium and conservatory glazing;
- Non-view glazed elements (glazed walls, roofspace collectors, roofponds).
- Opaque external walls and roofs.

There are three fundamental modes of solar control that may be applied individually or in combination:

- Manipulation of geometric coordinates of surfaces, and aperture sizes of openings, in relation to the sunpath;
- Raising (or removing) obstructions to the sunbeam;
- Manipulation of the solar-optical properties of glazed and opaque surfaces.

FIG. 3 Combination of solar control modes

The basic typology of techniques that emerges when these three modes are considered with respect to typical design contexts is illustrated in Table 1, and is further discussed in the next section of the paper. The choices made in practice will often combine more than one mode, as part of a multi-layered approach or in the form of corrective action, Fig. 3. The latter is often dictated by the need to compensate for some unfavourable previous choice (with respect to site layout, building form, orientation, tilt, size of aperture

TABLE 1. TYPOLOGY OF SOLAR CONTROL TECHNIQUES

Mode	Scope	Option
GEOMETRY + APERTURE REGULATION	ORIENTATION	South North
	TILT	Downward Vertical
	OPENING SIZE	Minimum "Optimum" Variable
SUNBEAM OBSTRUCTION - SHADING	SITE	Siting Adjacent Buildings Trees + Vegetation
	BUILDING FORM	Roof Shape and Overhang Plans Form and Section Protected Plan Extension (arcade, veranda, balcony)
	APERTURE COMPONENTS	External Fixed Horizontal / Light shelves Vertical Combined (Eggcrate) Slanted opening External Adjustable/Retractable Louvres, jalousies Blinds, shutters Awnings, canopies External Mixed Internal Louvres, shutters Blinds, curtains
SOLAR-OPTICAL PROPERTIES	GLAZING + FENESTRATION SYSTEMS	Clear Glass Tinted Glass Multi-layered Systems Interpane blinds or louvres Low-e coatings Translucent Glazing Controllable Transmission (mainly electrochromic materia
	OPAQUE SURFACES	Reflectance Emittance

etc.). Where not critical, the function of solar control is sometimes carried as a secondary function by a component installed for a different purpose (e.g. for privacy, security or night insulation).

Coverage of the topic in the literature has tended to fall into three categories: conventional textbook material; experimental and/or analytic work on specific techniques;

and references listed under a related topic, commonly daylighting. Published some thirty five years ago, Aladar and Victor Olgyay's "Solar Control and Shading Devices" [1], is still the most comprehensive and most widely quoted work on the subject. With small variations its vocabulary and design procedures, Fig. 4, are reproduced in most textbooks published since, including the still influential book by Mazria [2] and the preliminary version of the CEC Passive Solar Handbook [3].

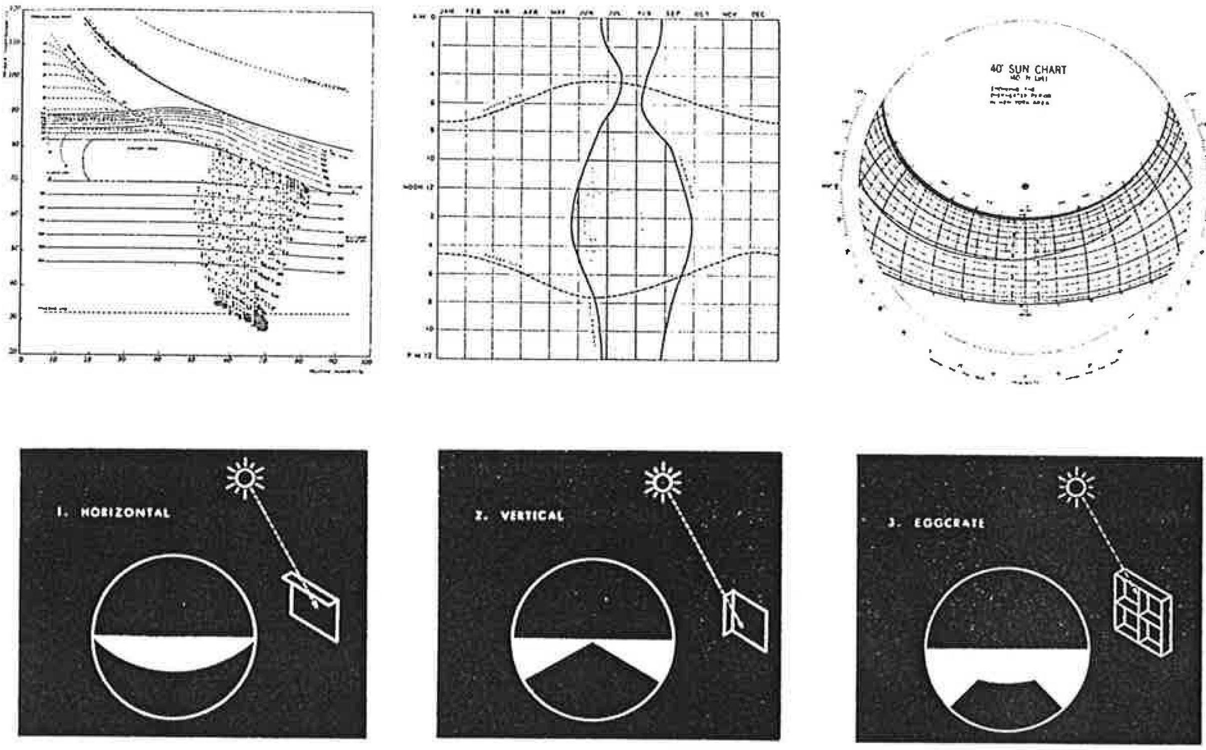


FIG. 4 Shading period and basic types of shading devices after Olgyay and Olgyay [1]

Notwithstanding the technique developed by Shaviv [4], which provides an alternative way of visualising a solution domain for shading devices, little progress has been made since Olgyay either in design methodology or the means of disseminating information on the topic of solar control. A number of gaps in knowledge and design procedure have remained unresolved. There has been much duplication of effort in the development of computer programs aimed at predicting the shadows cast on facades by different types of obstructions, but little in the way of evaluation of such software and its capabilities for design support. The modelling of shading devices and other solar control techniques and their effects on daylight, ventilation and occupant comfort remains among the major weaknesses of most building performance evaluation models. The "shading coefficient", commonly used in the literature to characterise total transmission through glazing or through glazing and shading configurations, is both a misleading term and an inadequate and unreliable index. Use of the bioclimatic chart in conjunction with a fixed threshold outdoor temperature for the definition of shading periods is also inadequate and misleading especially in the light of continuing trends toward higher thermal insulation standards, increasing inputs from internal gains in the energy balance of buildings, and frequent use of highly glazed spaces.

The weaknesses in present knowledge and design support are reflected in practice. Most architects assume rather than possess knowledge on the subject. The considerable potential of shading techniques as a form of architectural expression has led to a number of imaginative, though not always technically satisfactory, applications. There has been very little critical evaluation of performance in practice or of interactions with other aspects of architectural or environmental design. The Olgyay book provides a useful inventory, but it is mainly descriptive and many of the examples appear dated. Earlier experimental work reported by Givoni [5] is limited to the geographic conditions of Israel and is not comprehensive enough. More recent experimental work, mainly in the US, has been increasingly concerned with issues of daylighting in non-residential buildings.

Considerable developments are expected in glazing technology, both through improvements in thermal properties and through applications of optically controllable materials. These could have an important effect on the kind of design advice we give regarding orientation and glazing areas as well as on the appearance of buildings. It will be important to ensure that appropriate conditions for solar control are established in developing specifications for such materials. A useful and detailed review of the physical processes and properties with respect to current glazing and fenestration systems was completed recently under IEA Annex XII [6], and a study on the properties and application issues of optical switching films, multilayer low-emissivity coatings and transparent insulation materials is the next objective of research conducted under IEA Task 10.

2.2 Space Functions, Design Considerations and Solar Control Objectives

The priorities between the objectives of admission or exclusion of solar heat gain and daylight are best established before design. It is generally recognised that the design measures adopted for solar control will have a considerable effect on the energy requirements of buildings; on occupant thermal and visual comfort; on fabrics, materials or objects indoors; and may also have a bearing on ventilation and heat dissipation mechanisms, and on view. Consequently, the application of solar control techniques tends to be circumscribed by a number of design considerations, environmental as well as architectural, economic and behavioural. These are summarised in Table 2.

TABLE 2. SOLAR CONTROL ISSUES AND DESIGN CONSIDERATIONS

Environmental Design Objectives and Interactions
- Relative weight and switching criteria between admission and exclusion of solar gains.
- Relative weight between solar heat gain control and adequate daylight provision.
- Interaction with other heat gain attenuation techniques and with mechanisms of heat dissipation; possible trade-offs.

Interaction with other Design Objectives (where appropriate);
- View
- Privacy
- Security

Application and Use Considerations
- Control strategies (automatic/manual)
- Ease of operation
- Durability, flexibility, adaptability; solar control function combined with other functions.
- Capital and maintenance costs.

Potential
- Architectural expression
- Innovation
- Energy Savings
- Thermal/Visual comfort
- Environmental quality (including effects on neighbouring buildings and outdoor spaces)

A starting point for ordering the confusing array of possible design considerations might be through a matrix relating the objectives of solar control with specific uses of space in different building types and locations. This is illustrated in Figure 5 which identifies four generic categories of design objectives relating solar heat gain, daylighting and outdoor view requirements:

1 Solar heat gains, daylight and view (nearly) always desirable.
2 Solar heat gains desirable at times, undesirable at others; daylight desirable, view requirement variable.
3 Solar heat gains (nearly) always undesirable, daylight essential or desirable, view potentially negotiable.
4 Solar heat gains always undesirable; daylight, view not of interest.

The ways in which the other factors listed in Table 2 might affect the design priorities, or help in formulating performance targets, are discussed in the following section of the paper in conjunction with questions of threshold conditions and design procedure. Such classification, perhaps further elaborated by consideration of occupancy schedules and internal gains, can form the basis of formulating design targets and performance criteria for use at pre-design stage. It can be noted from Fig. 5 that the issue of a temperature threshold as a criterion for exclusion of solar heat gains only arises with space type category 2; in category 3 the limiting conditions are a function of daylight requirements and view.

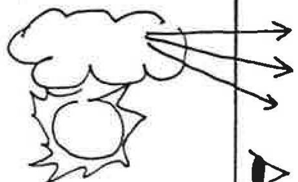
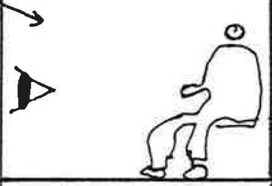
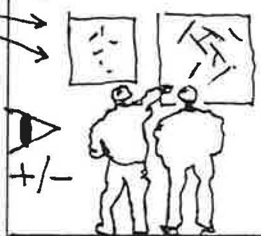
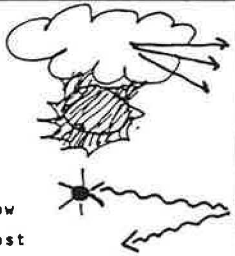
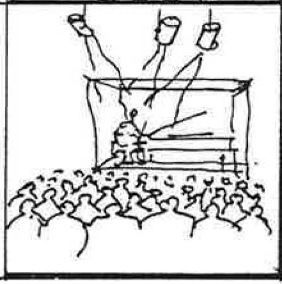
Heavily insulated spaces with high internal gains, or spaces with low exposure to the outdoor (e.g. located on an intermediate floor and having one external surface only) might fall under category 3 instead of category 2 depending on climatic region and site conditions. Designers should have advance information to judge whether the design priority for such spaces should be geared toward all year exclusion of solar radiation, or whether trade-offs between insulation (or other means of heat loss reduction) and solar control might be available. Daylight rather than passive solar heat gain may become the main criterion for design of openings in these cases; it may become appropriate for Building Regulations to incorporate provisions on daylight where no allowance exists at the present time.

In the south of Europe, outside the heating season, the use of space extends to various "shades" of indoor, semi-indoor, protected outdoor, and unprotected outdoor spaces. Individuals tend to move from one type of space to another several times in the course of the day. Such movement is essential for environmental comfort, but also an aspect of cultural behaviour and a means of enjoying the distinctive environmental qualities of these spaces. Neither simulation nor the criteria of HVAC engineering can help provide insights on this; however, much insight might be gained by simple measurements and observation of spontaneous patterns of behaviour.

There is wide speculation about global warming and its implication on heating and cooling requirements in buildings. In the UK, recent scenarios by the Department of Energy suggest a rise in mean annual outdoor temperature of between 1.5 and 4.5 ^{o}C , which could lead to reductions in heating requirements of 15-45 %, and (at the high range) to a doubling of full load hours of refrigeration plant operation for air-conditioned buildings [7]. Were such changes to take place the importance of solar control would increase for the north of Europe, while the reduction in the duration of the heating season may diminish the usefulness of passive solar heat gains in the south.

Table 3 provides a tentative review of the applicability of different solar control techniques with respect to the four categories of design objectives and space types presented in Fig. 5.

FIG. 5 SOLAR CONTROL MATRIX

DESIGN OBJECTIVES (what ?)	SPACE TYPES (where ?)	SCOPE AND MEANS OF SOLAR CONTROL (how / how much ?)	CONDITIONS (when ?)
1   Solar heat gain, daylight view desirable	(in Northern Europe only): - most rooms in residential buildings (except perhaps kitchen and highly glazed rooms) - many outdoor spaces.	Internal aperture components (curtains, louvres or blinds) or external blinds when installed for winter heat loss control.	June-August at occupant discretion.
2   Daylight essential Solar gain desirable at times View requirement variable	- Most offices (*) - All conservatories and atria In Southern Europe: - most rooms in housing (*) - many outdoor and semi-outdoor spaces	- azimuth /tilt/ aperture - site options - External aperture components - Glazing/ fenestration systems	Outdoors: Jun- Sep Indoors: see threshold criteria
3   Daylight desirable Solar gain undesirable View negotiable	- Museums, art galleries (*) - classrooms, lecture halls - gymnasia, sports halls - many commercial/ industrial spaces; some laboratories (*)	as above and Building Form	All Year
4   Heat gain undesirable; Daylight/ view not of interest	- Concert Halls - projection rooms, darkrooms - some laboratories	- azimuth /tilt/ aperture - site options - Building form - Opaque Surfaces	All Year

(*): Wrong design choices will push this space type to next category.

TABLE 3. SOLAR CONTROL TECHNIQUES : ASSESSMENT MATRIX FOR DIFFERENT SPACE TYPES

SOLAR CONTROL TECHNIQUES			SPACE TYPES			
Mode	Scope	Option	1	2	3	4
	ORIENTATION	South	+	+	-	-?
		North	-	?	+	+
GEOMETRY + APERTURE REGULATION	TILT	Downward	-	-	+	+
		Vertical	+	+	+	+
	OPENING SIZE	Minimum	?		+	
		"Optimum"	+	+		
		Variable	+	+		
	SITE	Siting	-	-	?	+
		Adjacent Buildings	-	-	?	+
		Trees + Vegetation	-	-?	+	+
	BUILDING FORM	Roof Shape and Overhang	-	+	+	+
		Plans Form and Section	?	+	+	+
		Protected Plan Extension	-	+	+	+
SUNBEAM OBSTRUCTION - SHADING	APERTURE COMPONENTS	External Fixed	-	+		
		External Adjustable/Retractable	-	+		
		External Mixed	-	+	+	
		Internal	+	-	?	
	GLAZING + FENESTRATION SYSTEMS	Clear Glass	+	?		
		Tinted Glass	-	-	-	
		Multi-layered Systems	?	?	+	
SOLAR-OPTICAL PROPERTIES		Translucent Glazing	-	?	+?	
		Controllable Transmission	-	?	?	
	OPAQUE SURFACES	Reflectance	-	+		+
		Emittance	-	+		+

Key:

+ : Desirable or Neutral
_ : Undesirable
? : Depends on other considerations

Olgyay proposed the use of a threshold outdoor temperature around 21 °C (70 °F) as the criterion for identifying the times in the year when shading might be required. This threshold temperature corresponded with the shading line, as the lower limit of the comfort zone on the bioclimatic chart. The geographic context for the 21 °C threshold was given by Olgyay as 40 °N latitude with the suggestion that the threshold temperature might be raised by 0.4 °C (0.75 °F) for every 5 degrees decrease in latitude to account for acclimatisation. Following a similar reasoning, Szokolay [8] suggested adjustments to the threshold temperature as a function of the annual range in outdoor temperature and relative humidity. Making such adjustments would result in the range 18-21 °C for European locations.

In Olgyays' method for shading design the threshold temperature provides a criterion for defining the "overheated period", as the locus of hours during the year when the threshold temperature is exceeded outdoors. Transferred onto a sunpath diagram, the contour of the overheated period represents the shading requirements and can be related directly to the geometry of particular types of shading devices. The advantage of a fixed threshold based on outdoor temperature is that it is only location-dependent; Olgyay's assumption was that once the overheated period is determined for a given location it could then be used for any building design in that location. This may be a fair assumption as long as the relationship between internal gains and the heat loss characteristics of the enclosure remains constant. At the present time, however, the variations in thermal characteristics and resulting temperature rise due to internal gains and diffuse solar radiation admitted for daylight, can be very substantial between different spatial functions and building designs. On the criterion of 70 °F the overheating period throughout much of Northern Europe would be confined to an insignificant number of hours in the year; however, in practice, cooling plants are used for much of the year in many commercial buildings.

It is suggested that this issue of threshold should become an area of further study. One approach might be to derive the threshold as a balance point temperature, T_{bp}, Fig. 6, from a balance equation:

$$T_{bp} = T_{oh} - G/HLC$$

where,

T_{bp}= balance point temperature (or shading line on a bioclimatic chart), representing the threshold outdoor temperature above which exclusion of solar radiation is required, °C;
T_{oh}= critical indoor temperature representing an indoor overheating threshold, °C;
G = heat gains from occupancy and an allowance for diffuse radiation admitted for daylight in the spaces being considered, W;
HLC = building heat loss coefficient including ventilation conductance, W/K.

The indoor overheating threshold for T_{oh} may be open to debate, but it is likely to lie between 24 °C and 29 °C depending on space functions, occupant activities, clothing level and acclimatisation, with perhaps the midpoint of 26-27 °C as more commonly accepted limit for summer conditions in non-air conditioned offices and classrooms. In any case the balance point temperature should be estimated for different values of T_{oh}, internal gains and heat loss coefficient. Internal gains will tend to vary according to space functions, while values of the heat loss coefficient are affected both by design parameters (glazing areas, insulation and airtightness standards), and by the building typology (for example, low-rise detached, high-rise attached, etc.).
The balance point temperature T_{bp} is equivalent to a signal from an external sensor to switch on shading or other solar control devices (e.g. optically switchable materials).
The periods in time when the outdoor temperature exceeds this value would then provide a revised contour of the overheating period for the design of shading devices and the assessment of desirable shading effects from vegetation, building form and siting. Conversely, solar heat gains would be desirable at outdoor temperatures below this value and depending on the intensity of the heating load in these periods measures to avoid overshadowing might then be required. On the other hand, the critical indoor temperature

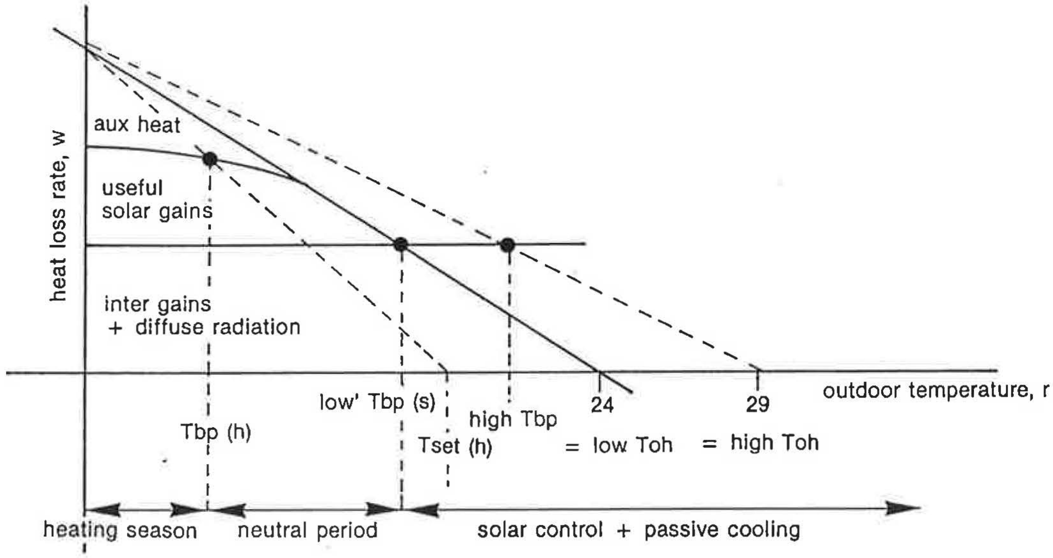


FIG. 6 Balance Point Temperature for shading

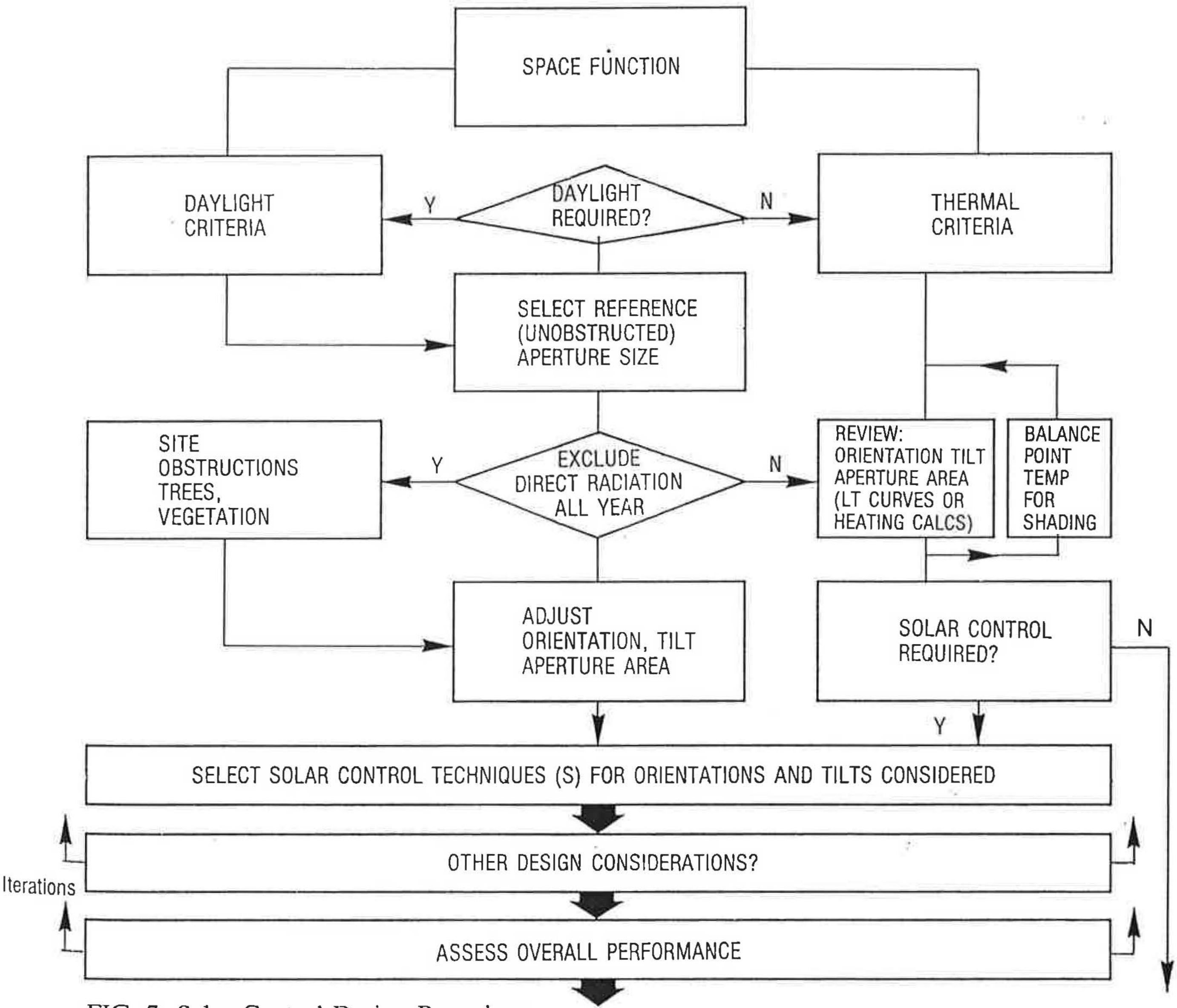


FIG. 7 Solar Control Design Procedure

T_{oh}, in conjunction with a threshold daylight datum, are also relevant parameters for controlling the action of adjustable blinds and louvres, manually or automatically, and may perhaps also apply as switching criteria for variable transmission glazing systems.

Estimates for a wide range of values for the above parameters indicate that mean values of T_{bp} could range from below 10 °C to over 25 °C (for values of T_{oh} between 24 and 29 °C). At the lower extreme of T_{bp}, spaces sited in the south of Europe will require almost all year exclusion of solar radiation under prevailing outdoor temperature patterns, while at the higher extreme most spaces in northern European regions will scarcely require any solar control. The balance point temperature can thus be a criterion in deciding design priorities. Clearly, the thermal capacity in the building structure will have a moderating influence, and depending on different values of thermal capacity the actual balance point at any given moment may be higher than the mean value. Parametric studies using dynamic simulation or the empirical concept of thermal admittance can be used to allow for this, and threshold temperatures for different space functions and values of the above parameters can be tabulated for use at pre-design stage. The LT curves [9] could be used to determine starting values for glazing areas.

For spaces where solar heat gain is permanently undesirable the temperature criterion is still useful as an indication of overheating threshold but not a sufficient design criterion for sizing the aperture of openings. Daylight factors or other illumination targets can be used for sizing. Where shading devices are also to be applied, the area of opening could be adjusted to allow for the target illumination values. Baker [10] has suggested transmission factors for diffuse radiation with respect to louvres which can be related to target Daylight Factors.

Figure 7 is an attempt to systematise the operations that need to be encompassed by a design procedure aimed at defining overall priorities as well as providing design support on solar control. Most current software developed for the purpose of shading assessment do little more than emulate an heliodon. For design support there is considerable scope to combine shadow and sunpatch prediction with daylight and thermal analysis and the possibility of accessing typological inventories of solar control techniques.

3.0 REVIEW OF SOLAR CONTROL TECHNIQUES

3.1 Solar Control By Geometry and Aperture Regulation

Scope:

Choice of orientation, tilt and aperture of surfaces as means of:
- optimising annual influx of solar radiation; or,
- minimising the incidence of global radiation at certain periods; or,
- affecting the ratio between the direct and diffuse components of the irradiance reaching a surface.

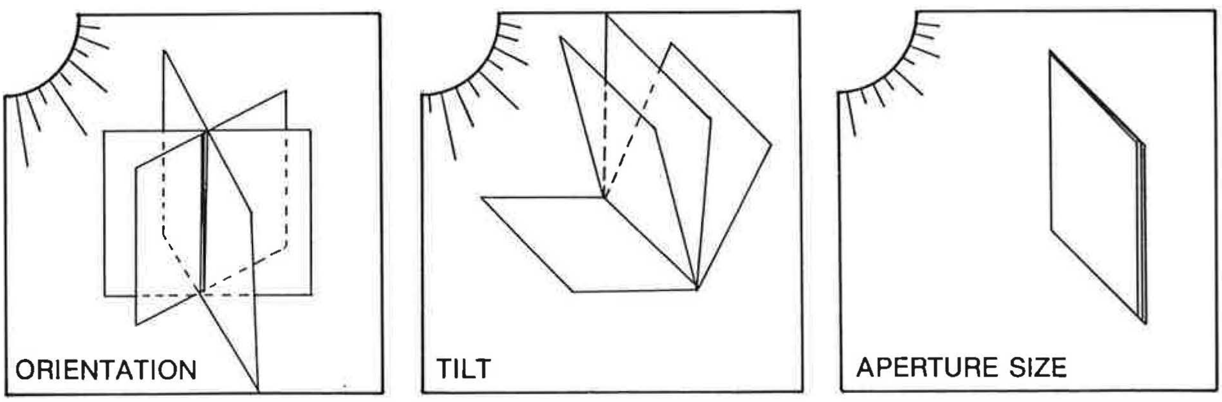


FIG. 8 Orientation, tilt, aperture

Means of Solar Control:

- Option of southern orientation as optimum where solar heat gain is required at times; option of northern orientation as optimum where solar heat gain not required.
- Option of downward tilt of aperture (outward from building interior) to increase exclusion of irradiance;
- "Optimum" aperture size (e.g. using the LT curves as a starting point) on the criterion of a minimum total annual energy cost (heating, cooling and lighting, or cooling and lighting only; for non-airconditioned buildings indoor overheating threshold as upper comfort limit criterion).
- Concept of a variable aperture, with minimum area based on daylighting criteria and maximum on solar heat gain considerations.

Regional Variations and Topics for Study:

The considerable variations between the north and south of Europe with respect to geographic latitude, outdoor temperature, and the magnitudes of incident solar radiation suggest the likelihood of significant differences in optimum values and appropriate design strategies for different building types. These differences have not been clearly identified in the literature so far, while many recent building projects across Europe appear to reflect homogeneity rather than differences in their "passive" design characteristics.

There is scope for investigating the relative importance of orientation and aperture size, and to a lesser extent tilt, for southern European locations, both as means of solar control and for the overall environmental performance of buildings. Results would also provide a basis for comparing and assessing other means of solar control. Some hypotheses that appear to deserve study are given below:

- The high gains to loss ratio that characterises south-facing glass in the south of Europe is often wasted by the recent trend in combining large glazing areas with low U-values for the opaque envelope, thus creating conditions of low solar utilisation and high risk of overheating. In principle, there could be a number of trade-offs between orientation, aperture area, and thermal properties; it may well be that improvement of thermal properties is more relevant for glazing than for opaque envelope. Such trade-offs are likely to vary according to building type, as well as between mechanically conditioned and free-running buildings, and this is also an important area for study. The notion of variable aperture may be envisaged as using components combining the functions of solar/daylight control with night insulation (and security), the latter being also applied selectively during daytime to partly contract the area of exposed glazing. This is equivalent to traditional use of shutters in southern Europe.

- North facing glazing has been anathema in recent years and this is clearly justified by the sort of energy balances that it yields under high heating load conditions. However, in the conditions of southern Europe the gross energy balance of north glazing in mid-winter is not substantially worse than that of south-facing glazing in some of the cool cloudy regions. For spaces which have low (or no) heating loads, but which require daylight, moderate sizes of north glazing can have cost and energy (and possibly, comfort) advantages over other orientations.

- The relative disadvantages of west (and to a lesser extent, east) orientations are not clearly appreciated. These probably apply throughout Europe, though from the viewpoint of solar control the problem is more serious in the South, while in the North it is more an issue of unfavourable energy balance in winter resulting from relatively poor incidence of radiation and the high likelihood of overshadowing on glazing. Lack of choice on orientation, or an exceptional outdoor view, or other design considerations will require that openings of varying size are used on these orientations in some cases and it would be useful to study aperture characteristics for these situations.

- The relative properties of tilted rooflights and atrium glazing of southern and northern orientation are an important topic for study, as these options emerge very frequently in the design of many spaces. It is suggested that for these configurations the issues of solar/daylight control should be considered in relation to possible night cooling potential through longwave radiation to the sky, as well as in terms of the possible role of such rooflights in the ventilation strategy for a building.

3.2 Sunbeam Obstruction - Shading

Scope

Elimination of the direct beam and part of the diffuse component of the irradiance directed toward a surface, by obstruction along pre-selected parts of the daily and annual sunpath.

Means

- Site topography and site layout;
- Trees and vegetation;
- Building form;
- Aperture components encompassing fixed and adjustable/retractable shading devices, internal blinds or shutters and combinations;

The means to be chosen need to be considered in conjunction with daylight and the desirability of solar heat gains at other times.

Accepted Knowledge

- The need for shading varies in time and with sky conditions, space functions, and design characteristics of the building enclosure.
- The geometric aspects of shading are a function of geographic latitude, the azimuth and tilt of surfaces to be shaded, and time.
- Generally, controlling solar radiation before it reaches a surface is a more effective way than the use of internal solar control devices.
- For spaces which may require solar access at times, adjustable or retractable means of shading are more effective and flexible than fixed (or permanent) devices, as they allow better control over diffuse as well as direct radiation and glare, and are likely to cause less overshadowing in the heating season;
- Combinations between permanent and retractable components may offer advantages in many cases.

Topics for Study - Southern Europe:

- The high solar altitudes in summer in conjunction with prevailing clear sky conditions allow effective shielding from direct radiation with very modest overhang depths on southerly orientation. Combination of overhangs with awnings or adjustable louvres, or contraction of the exposed aperture using opaque panels, provides the flexibility to exclude sun at certain times while admitting solar gain in the cool period with the corresponding sunpath (e.g. exclude in September, admit in March.) However, for many spaces provision of adequate shading may be more important than ensuring completely unobstructed solar access in the heating season. Where all year solar control is required the choice between fixed and adjustable devices and the means for control become a function of daylight requirements and criteria.

- The requirement for shading is not confined to the boundaries of a building, but will encompass surrounding outdoor spaces, Fig. 9: arcades, roof overhangs, balconies, verandas and pergolas have useful functions as shaded semi-outdoor spaces, and also as moderators of ground reflectance and of longwave radiation directed toward the parent building. While these functions may double-up with the shading of walls and openings on the parent building it would be wrong to compare these applications to single-purpose shading devices. Their environmental properties are more analogous to those of a conservatory in a colder climate. Trade-offs between design parameters can be sought depending on the desirability of such spaces and the relative importance between the requirement for shading and solar heat gain for a given building design.

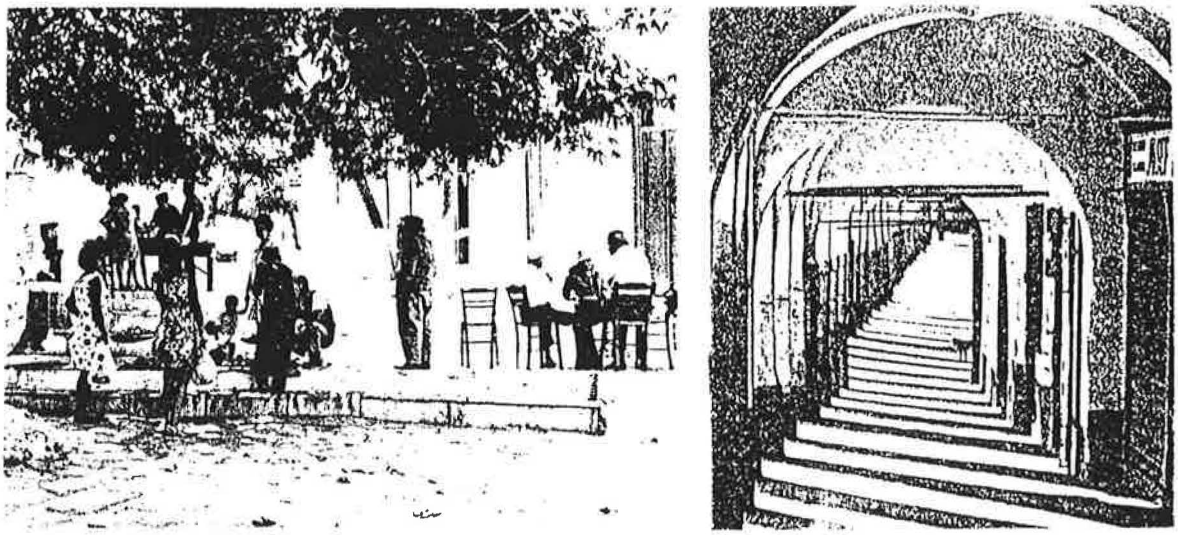


FIG. 9 Shaded outdoor and semi-outdoor spaces are of crucial importance in S. Europe

Topics for Study - High latitudes:

- The relatively low solar altitudes and the need to avoid overshadowing in the heating season point strongly toward retractable external louvres for daylight and sun control, and simple internal blinds and curtains where solar heat gain is not a problem.

- In cool and cloudy regions there is generally more advantage in preserving solar access to outdoor spaces than in providing them with shade.

Shading from site obstructions and adjacent buildings

During the heating season, overshadowing of windows and other glazed elements from site obstructions and adjacent buildings is a common source of considerable loss in useful solar gain. The effect becomes more pronounced on the lower floors of multi-storey buildings in dense urban regions, and with increasing geographic latitude. A recent study for France has expressed the effect of a wide range of such obstructions, including balconies and overhangs in the form of shading coefficients over the heating season for use in heating energy calculations [11]. In the south of Europe, high built density is a common feature of both traditional and contemporary urban development. In some cases the shading on building surfaces by adjacent buildings, in conjunction with shadows cast on walls and windows by balcony overhangs and vertical elements, may extend to most times of the year for the lower floors, Fig. 10. It may well be that close spacing could be desirable on an all-year basis in some cases, for example where the street direction is North-South. The value of the shading provided on the ground for pedestrians and circulation is another consideration; this urban canyon situation requires study of both the shortwave and longwave effects of reflected radiation, Fig. 11, [12]. There is scope for comparing the effect of different street widths to block height ratios with respect to both winter and summer requirements, including loss of daylight, and assessing differences in insolation and overshadowing between upper and lower floors.

Trees and Vegetation as means of solar control

The interest of using trees and vegetation as means of microclimatic control extends beyond their potential for shading and is an important topic for study. Depending on the design objectives, both deciduous and evergreen vegetation may be of interest, either with respect to the shading of outdoor spaces or for building facades. The latter is mainly of interest with respect to east or west facing surfaces. A number of computer programs are available to aid with the prediction of shadows cast by trees of various size and shape [13] [14]. These usually approximate the shape of trees as a combination of generic geometric forms and treat it as a solid. Another line of ongoing work is based on scanning and computer digitising of photographs of actual tree species for the purpose of characterising foliage and branch properties in the form of shading coefficients [15] [16]. It would be useful to have such typological characteristics.

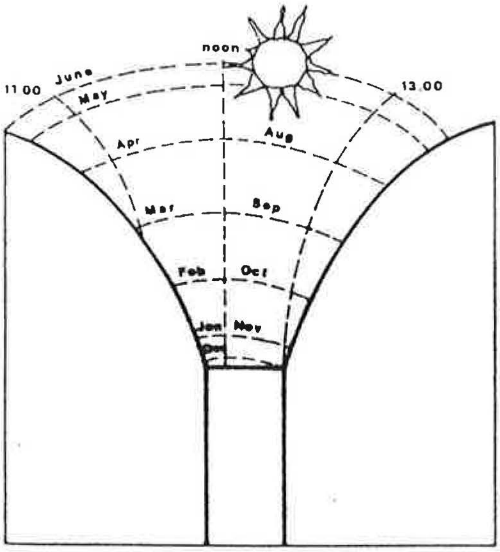


FIG. 10 Shading of walls and ground by adjacent buildings

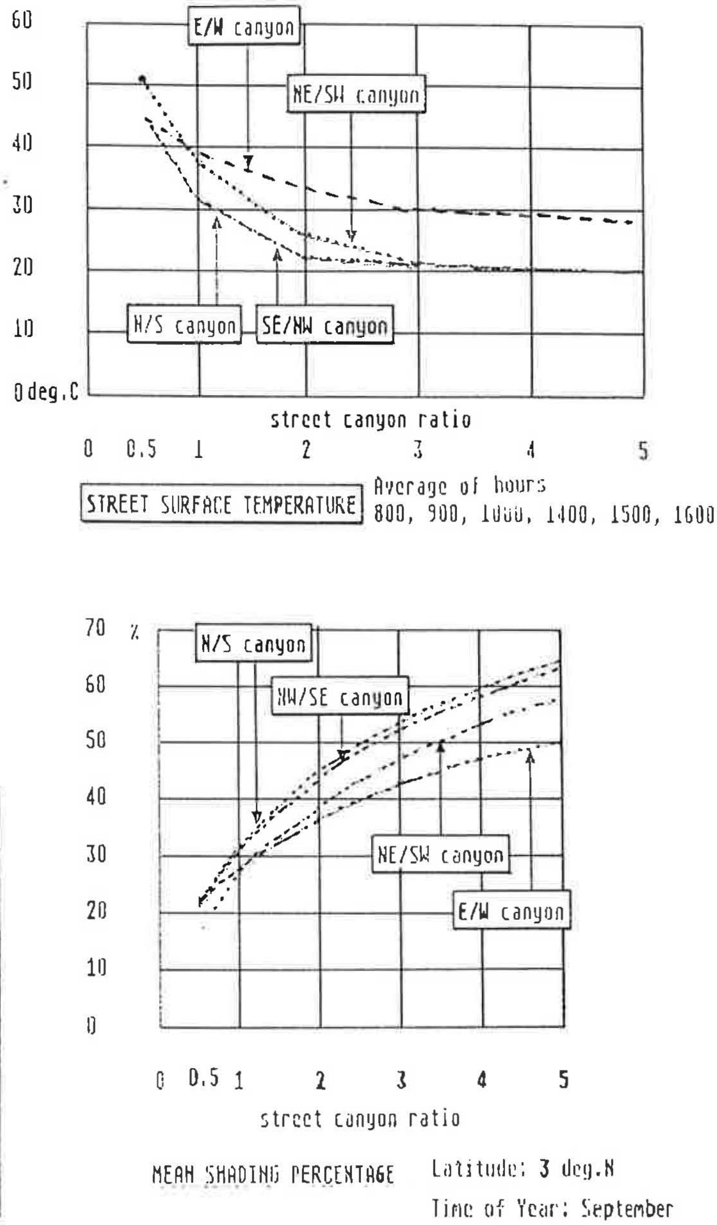


FIG. 11 Street surface temperatures and shading as function of building height to street width ratio, [12].

Building Form

As architects we will probably master the principles of bioclimatic design only when we acquire the ability to conceive form that is in itself an embodiment of explicit qualities of positive adaptation to, or exploitation of, ambient characteristics. In terms of solar control this may be through the way in which we might manipulate the roof, Fig. 12, in shape as well as properties; through the control of exposure on selected orientations, or through an overall surface to volume ratio, Fig. 13; through plan form and sectional arrangement as means of protecting certain surfaces or spaces at certain periods; or by the extension of the plan in the form of balconies, courtyards and other semi-outdoor spaces that can play the dual role of shading device and usable space, Fig. 14.

The questions of whether or when to glaze a courtyard or the gap in an L-shaped plan, thus creating permanent, or perhaps movable, glazed atria or conservatories, do not yet have clear answers for southern European regions and deserve more study.

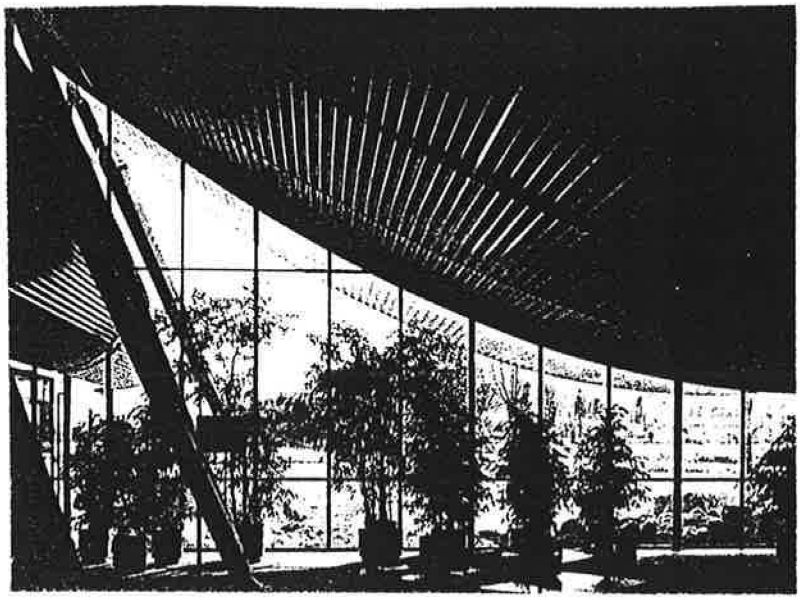


FIG. 12 Roof shape (top left, Atelier Piano).

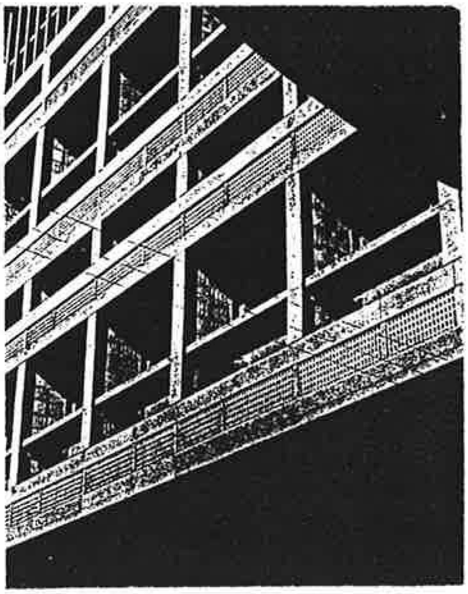


FIG. 13 Balcony extensions (top right, Le Corbusier)

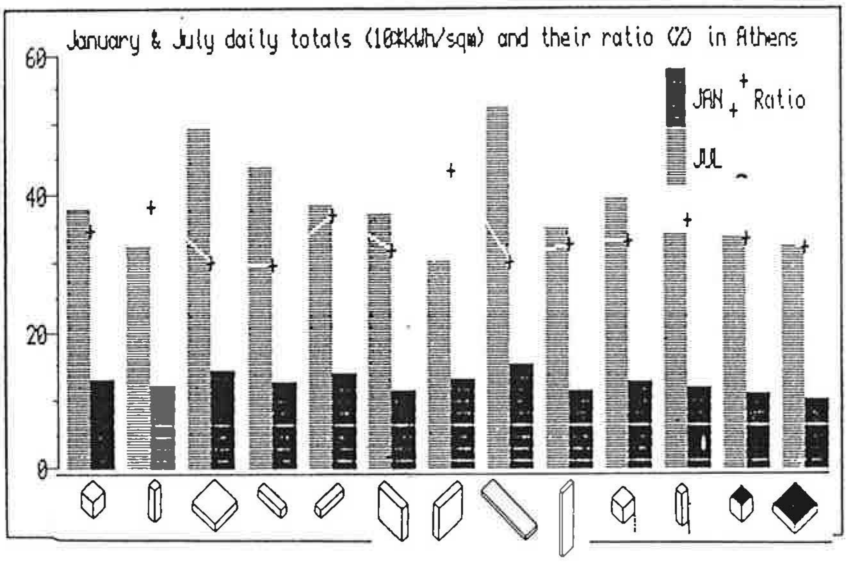
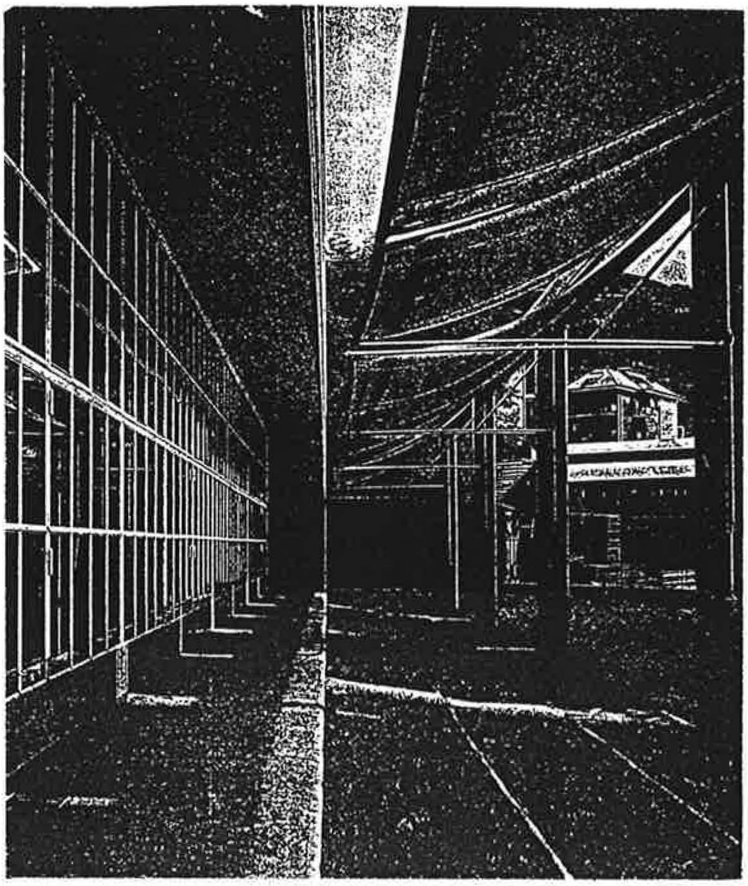


FIG. 14 Effect of building shape on insolation (left, T. Stassinopoulos, MPhil research, AA School,London)

Aperture Components/ Shading Devices

The range of possibilities is very wide both in terms of shapes, and with respect to materials, constructional techniques, and combinations between different types of devices and controls. Clearly, this is (and has been) an area both for demonstrating architectural ingenuity through context-responsive designs, Fig. 15, and for the production of standardised components for mass application, Fig. 16. It is all the more important to have fairly reliable comparative criteria and procedures for characterising and assessing performance of possible applications, and this should be an area of study (see also "shading coefficient" in next section). Increased recognition of the advantages of daylight as means of artificial lighting and cooling load reductions, as well as for its quality and psychological value suggest that it should be a major performance criterion in such assessments and specifications; this is touched upon by several recent studies [10][17].



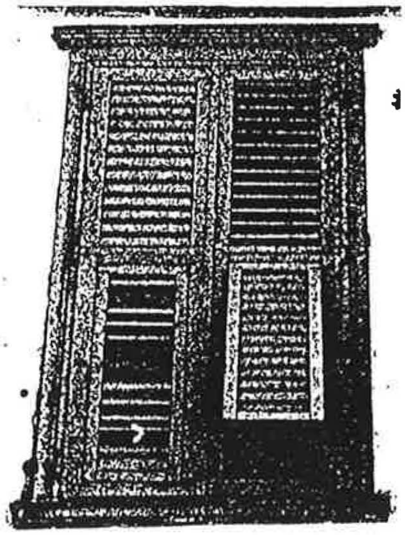


FIG. 16 Traditional multi-purpose louvred shutters

FIG. 15 Combination of fixed and movable shading at Asilo Sant'Elia (G.Terragni).

Specific techniques, devices or issues which deserve further study (primarily for Southern European conditions) include the following :

- Recommendations on appropriate typical geometric parameters of fixed shading devices for different parts of Europe as function of latitude and orientation and for different definitions of shading period and degrees of coverage of the shading requirement; effect of surface finishing of shading devices on daylight and longwave transfer.

- Lightshelves, -fixed horizontal or tilted horizontal elements dividing the glazed aperture at selected points on the outside and/or inside, and which combine the function of shading with sunbeam reflection toward the ceiling for daylight penetration and distribution-, are of considerable interest as an alternative to, or combined with, overhangs on southern orientations. A recent study identified significant advantages for clear sky regions, Fig. 17, [18], [19].

- Slanted openings, a traditional technique which maximises skyview for a given glazed aperture while also providing shading, are a sort of natural form of lightshelf, Fig. 18; there is an ongoing European study testing a variant of this technique [20].

- Design characteristics of adjustable external louvres for solar heat/daylight control: materials, shapes, spacing to depth ratio; appropriate slat angles for solar admission, shading, light intensity control; types of controls and locations of sensors; possible improvements of optical properties by application of coatings, films, or mirrors on louvres [21].

- Evaluation of multi-purpose components combining function of solar control with movable insulation or other uses, for example, louvred shutters or blinds; "Beadwall" variants [22].

- Acceptable types of internal blinds or curtains that may be used for spaces of low solar control priority.

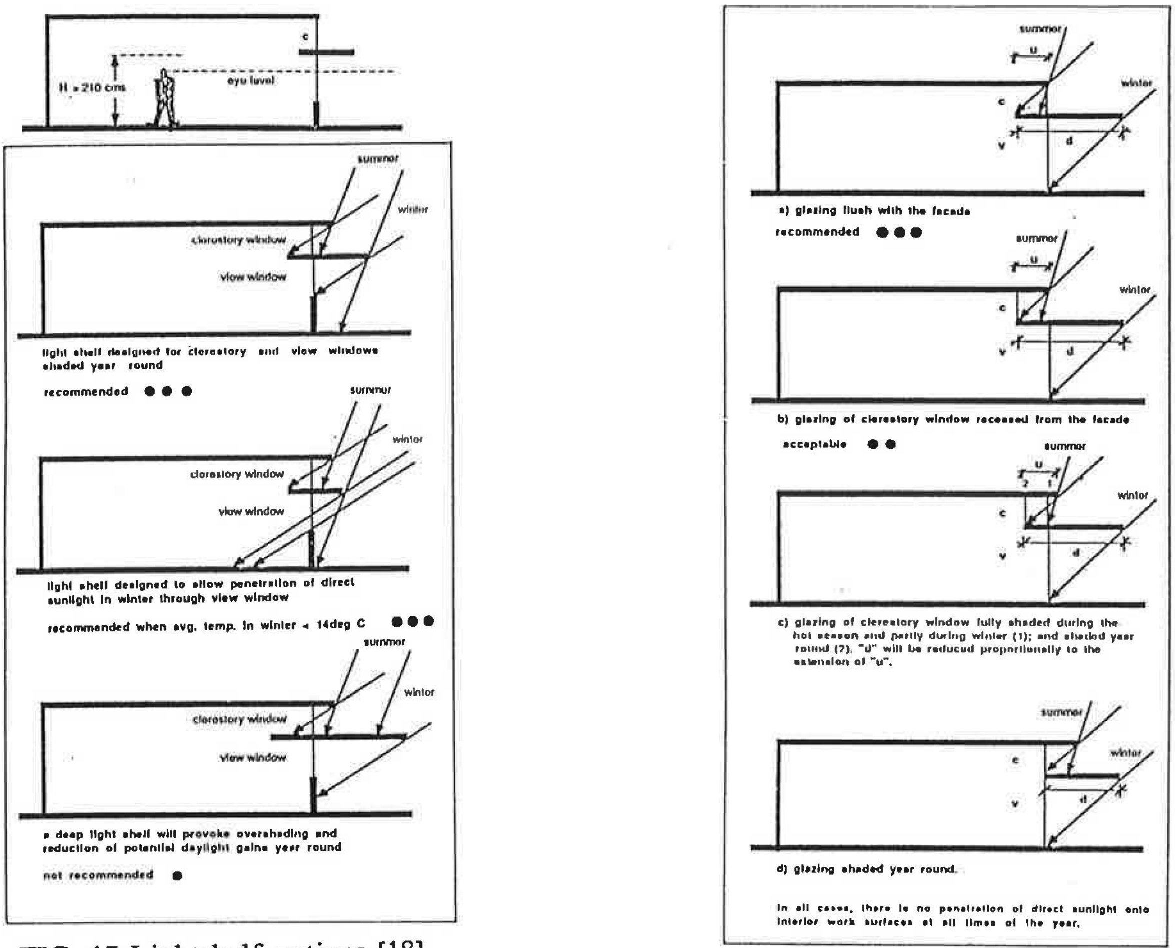
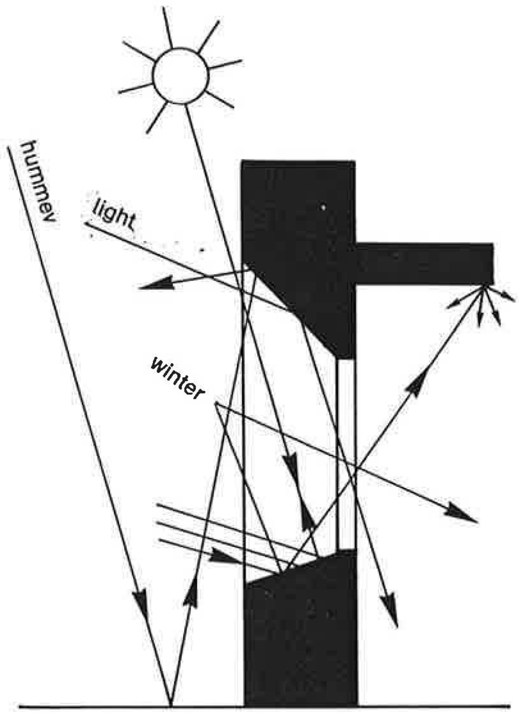


FIG. 17 Lightshelf options [18]



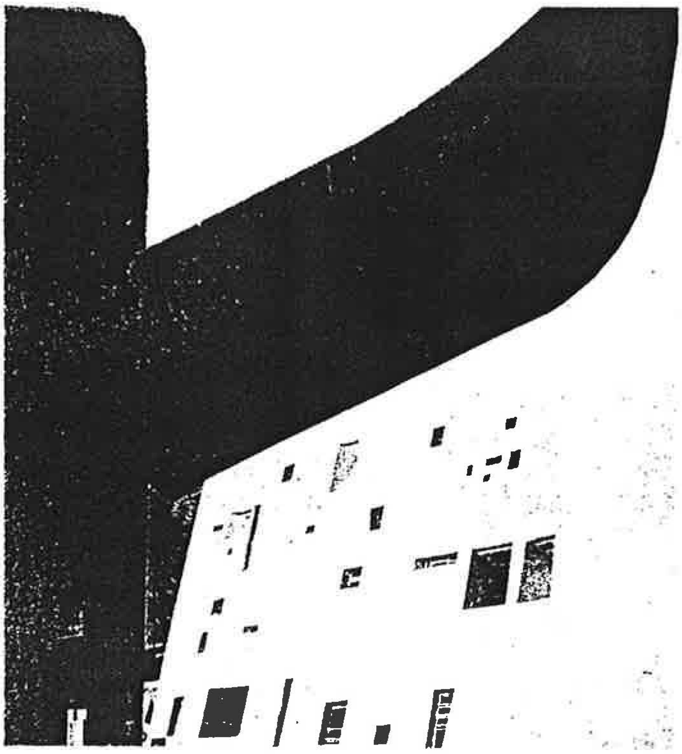


FIG. 18 Slanted openings

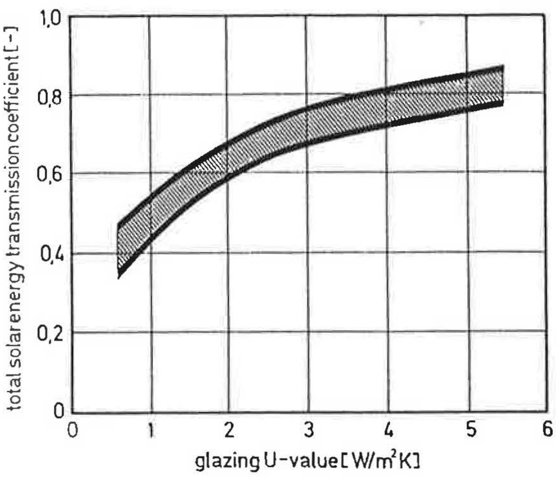


FIG. 19 Solar transmission as a function of thermal transmittance

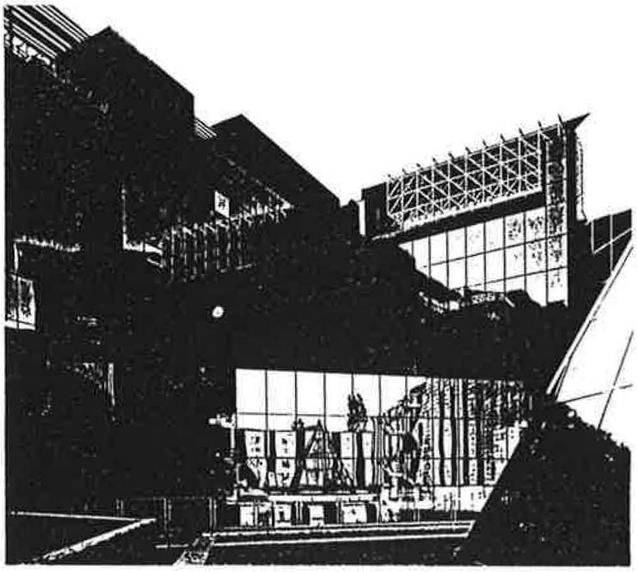


FIG. 20 Visual and radiant impact of reflective glass

3.3 Solar Control through Solar-Optical Properties

Scope:

Rejection of unwanted wavelengths of the spectrum.

Means:

- Reflective or absorptive glass.
- Double and multi-layered glazing in combination with interpane blinds, selective coatings or films.
- Use of translucent materials such as aerogel.
- Controllable transmission through electrochromic, photochromic or thermochromic materials.
- Opaque surfaces: reflection of shortwave and longwave radiation.

Topics for Study

Most of these applications will also tend to have a bearing on the thermal properties of glazing; the three issues of solar heat gain transmission, light transmission and thermal transmission need to be studied in close connection. The bewildering range of materials and glazing configurations reported in recent literature will require careful evaluation in terms of all year characteristics and regional relevance. Going back to fundamental principles it would appear that if solar gains are to contribute meaningfully in cool and low radiation regions it is desirable to maximise solar and light transmission per unit aperture during daylight hours, while providing thermal properties close to the equivalent of wall insulation at other times. These characteristics are best achieved by clear glazing and heavy night insulation on south orientations. On the other hand, in milder and sunnier regions, the heavy solar and thermal loads imposed on glazing for at least one third of the year, suggest that we might aim to achieve low thermal transmission during daytime, throughout the year, even if it is at the expense of some loss in solar transmission, Fig. 19, as the latter will help some buildings in the warm period and others throughout the year. As mentioned previously this "rebalancing" of glazing properties could be traded-off by reductions in thermal insulation of opaque elements and/or readjustments to the overall gains to loss ratio of a building.

Such reasoning leads to the following recommendations for topics of study:

- Conventional types of tinted glass can be a serious disadvantage due to high infrared absorption (35-75% of the incident radiation), and for the cool period high loss in total solar transmission. The mirror-like reflective variety of tinted glass is environmentally unacceptable due to disruptive effects, glare, and shortwave radiation increments it contributes to neighbouring buildings and outdoor spaces, Fig. 20; and its architectural expression is alienating. Use of absorptive glass as external layer of a double glazing unit with provision for ventilating the cavity and for reflecting infrared radiation by use of low-emissivity coatings could be a way of improving performance. Alternatively, Granqvist [23] has suggested a three layer coating to reflect at the 0.7-3 range as a line of development.

- Comparative effectiveness, durability, means of control and costs of interpane blinds [24] and other multi-layered glazing/coatings configurations, Fig. 21, in relation to other techniques;

- The potential of translucent materials with low thermal and solar transmission where clear glazing is not crucial for vision and view, for example, skylights atrium glazing.

- Among the type of materials which may provide the capability of controllable transmission, photochromic glasses appear to share some of the disadvantages of tinted glazing, while thermochromic glazings are said to lose transparency when activated; only electrochromic materials are considered as serious contenders for application on windows. Studies at LBL suggest that electrochromic glazings could outperform other glazing systems on capital and running cost reductions of lighting and cooling equipment, Fig. 22. The range of performance criteria quoted in the literature is from

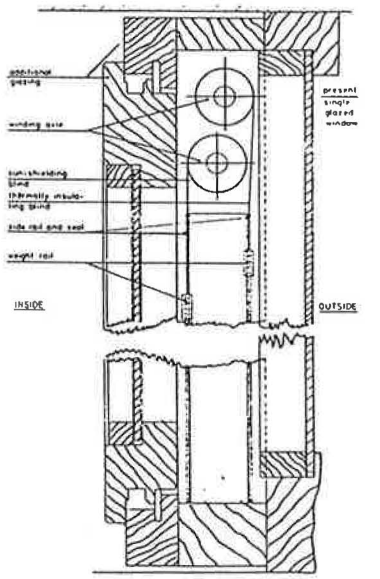


FIG. 21 Application of coated roller blinds in double-layered window [24]

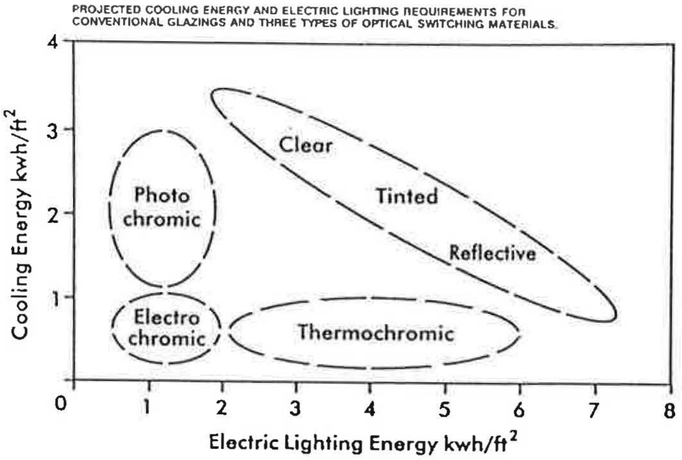


FIG. 22 Estimates cooling and lighting loads for different glazing materials [25].

10-20% light and total transmission at low range, up to 50-70% at high range with near infra-red varying from 10-20% to up to 70%, [25]. Clearly, care will be needed to avoid the disadvantages of tinted glazings. It is early to speculate how glazing with controllable properties might affect architectural design and the design advice we give on window size or orientation, and whether these materials will make other types of shading devices become redundant. However, they could provide an excellent retrofitting option for highly glazed International Style buildings.

- The Shading Coefficient is a misleading term, and the values commonly used in the literature based on normal transmittance for fixed orientation, location and time, do not provide a basis for a comparative assessment of solar control capabilities in practice. Work carried out in the context of the IEA study on Windows and Fenestration, [26], shows considerable differences in total transmission as a function of angle of incidence, orientation and period of the year. There is scope for further study of this issue, as well as for adopting a clearer terminology.

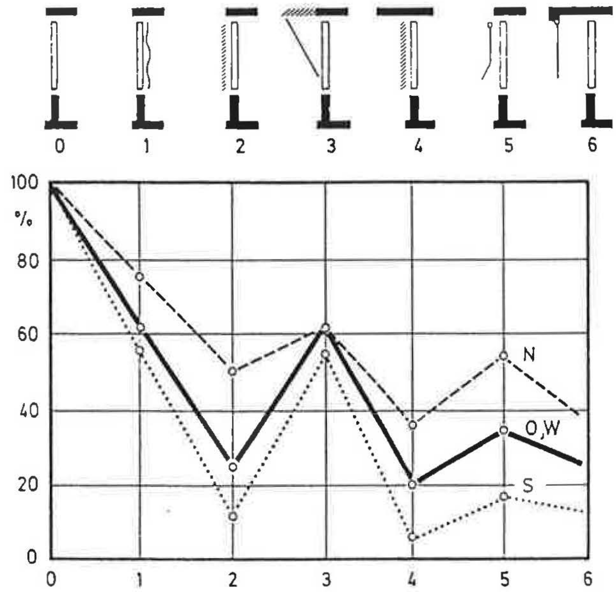


FIG. 23 Percentage reduction in shading coefficient as function of orientation and shade type [6]

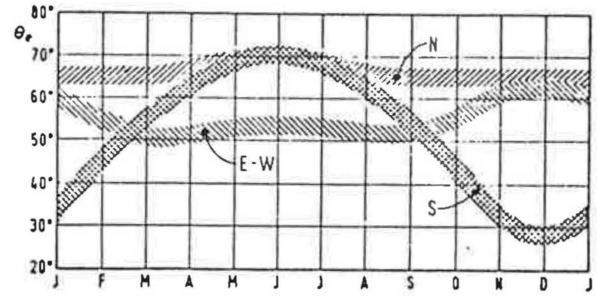


FIG. 24 Monthly variation in "effective" angle of incidence as function of orientation, after [26].

4.0 CONCLUSIONS AND RECOMMENDATIONS

The topics discussed in the main body of the paper are summarised below under four interdependent areas of recommended further work.

4.1 Experimental Studies

- Protected outdoor spaces: measurements, observations of patterns of use of typical configurations in S. Europe
- Evaluation of selected applications of solar control techniques in traditional and contemporary architecture.
- Adjustable louvres: assessment of solar and lighting control ranges, operating conditions, control strategies, and interactions with ventilation and heat dissipation mechanisms.
- Study of lightshelves and slanted openings.
- Specification of required solar-optical and thermal characteristics for "re-balanced" multi-layered fenestration systems with special reference to S. European conditions; extension to characteristics expected from electrochromic materials.
- Reassessment of notion and values of Shading Coefficient based on allowances for variations in angle of incidence, orientation, latitude, period of the year.

4.2 Analytic work and Parametric Studies

- Balance point temperatures for determining shading periods as a function of a range of critical indoor temperatures, internal loads and thermal properties of building envelope.

- Parametric studies on orientation, tilt and aperture size including notion of variable aperture for S. European locations.
- Urban canyon and site layout studies based on all year assessment of thermal and lighting requirements
- Assessment of shading effects of different tree species.
- Assessment of relative merits of glazed atrium/conservatory as opposed to the equivalent protected semi-outdoor spaces in S. Europe.
- Assessment of shading and lighting performance of horizontal, vertical and combined types of fixed shading devices on different orientations an locations.

4.3 European Book on Solar Control

Incorporation of current knowledge and results of the above studies into publication addressed to designers and aimed at updating and extending Olgyays' earlier synthesis. The book should present choices of techniques and design procedures with reference to different latitudes, site conditions, building types and space functions. It should include critical review of selected examples both from Europe and other relevant locations, covering aspects of solar heat gain/shading/daylight and interactions with other environmental objectives and design requirements.

Such a book can easily stand on its own since the subject matter is large enough, easily recognisable as a meaningful entity and its interest to architects is both established and considerable. It should be the entry point publication for newcomers to the field of climate-responsive design and would help to trigger interest on the other means of heat gain prevention and passive cooling most of which are less known to architects and have a lesser bearing on architectural expression.

4.4 Design Support Tools

- Computerised form of the above combining analytic capabilities for thermal/ lighting assessments with visualisation of shade and light intensity and iconic/textual database covering design principles and application examples.
- Improvement of modelling capabilities of building simulation tools with respect to different types of solar control techniques and interactions in terms of thermal, lighting and air flow.

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