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ENVIRONMENTAL SUSTAINABILITY AND ARCHITECTURAL DESIGN

Educational buildings in Europe

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SÍNTESE

A concepção arquitectónica ambiental. consiste na manipulação intencional da localização, da forma do edificio, da organização espacial interna e dos parâmetros construtivos, que tem como propósito a consecução de objectivos desejáveis em relação ao ambiente e ao conforto do utente com o mínimo recurso a energias não-renováveis. Esta comunicação coloca a tônica sobre a relação próxima e directa que existe entre o programa do projecto e os requisitos de uma concepção arquitectónica ambiental para aquecimento, ventilação, arrefecimento e iluminação. Os princípios da concepção arquitectônica anibiental são universais, no entanto, a sua aplicação deve ser desenvolvida em estreita relação com a especificidade do tipo de edificio e do contexto. A tônica desta comunicação refere-se aos edificios educacionais e o contexto geográfico é a União Europeia. A comunicação está estruturada em cinco secções. A primeira secção introduz as características distintivas do tipo de edificio e mostra como estas influenciam os requisitos de uma concepção arquitectónica ambiental para aquecimento, arrefecimento, ventilação e iluminação. A segunda, terceira e quarta secções concentram-se na concepção arquitectónica que trata respectivamente de questões de localização e implantação, forma do edificio e organização espacial interna, e da concepção de elementos. A secção final considera questões de avaliação do desempenho ambiental. A comunicação conclui que as características funcionais e de ocupação dos edificios educacionais proporcionam oportunidades excelentes para a utilização dos recursos energéticos naturais, exploração da relação entre o interior e o exterior, e para o desenvolvimento da consciência espacial e ambiental desde muito cedo.

SUMMARY

Environmentally-sustainable architectural design is an intentional manipulation of siting, building form, internal planning, and constructional parameters, aimed at achieving desirable targets of environmental performance and occupant comfort with the minimum expenditure of non-renewable energy. This paper highlights the close and direct relationship that exists between the architectural programme of buildings and the environmental design requirements for heating, ventilation, cooling and lighting. The principles of environmental design are universal; however, their application must develop in close relationship with the specificity of building type and context. The focus of this paper is on educational buildings and the geographic context is that of the European Union. The paper is structured in five sections. The first section introduces the distinctive characteristics of the building type and shows how these influence the environmental design requirements for heating, cooling, ventilation and lighting. The second, third and fourth sections focus on building design dealing respectively with issues of siting and site layout, building form and internal planning, and with element design. The final section addresses issues of environmental performance assessment.

1 ENVIRONMENTAL OBJECTIVES AND ARCHITECTURAL PROGRAMME

The following are distinctive characteristics of educational buildings which have an important bearing on environmental design :

- ***Occupancy patterns*** : a highly intermittent pattern of occupation
- ***Density of occupation*** : some spaces are very densely occupied (e.g. classrooms)
- ***Types of spaces and occupant activity*** : a wide range of spaces and activities with different spatial and environmental requirements
- ***Outdoor spaces*** adjacent to buildings and other spaces used for play and recreation
- ***Building Trends***: owing to the low population growth in Europe the rate of new school building is low, but there is a large stock of existing buildings in need of extension, rehabilitation and environmental improvement.

Occupancy Patterns

The demands for heating, ventilation, cooling and lighting closely relate to the daily and seasonal patterns of building occupation. Although occupancy patterns can vary significantly, the occupation and usage of educational buildings is generally confined to a relatively small proportion of the total hours in a year. Within the ***daily*** cycle, school hours coincide with daylight and sunshine hours and will commonly avoid the coldest period of the day in winter and the warmest in the summer. At the ***seasonal*** level, long vacation periods between school terms and over summer further shorten the need for environmental conditioning, as does weekend closure. Thus compared to other building types (e.g. housing or commercial buildings) any need for mechanical heating and cooling, and for artificial lighting is considerably lower and can be potentially eliminated altogether. However, the validity of the low utilisation of buildings (the working hours of many school buildings are commonly confined to around 15-20% of the total hours in a year) should be questioned. Use of educational buildings outside traditional school hours can provide a means for making their facilities available to the local community. Where this is the case the extension in the hours of occupation and use should be taken into account as an important consideration for environmental design.

Density

The density of occupation (i.e. the floor area available per person) affects the rate of air exchange required for ventilation, as well as the total rate of internal heat generation (from metabolic activity and use of appliances). In school buildings some spaces are very densely occupied most of the time, and others only intermittently. Classrooms, commonly occupied by 20-50 pupils, are the most densely occupied spaces.

- ***Ventilation and indoor air quality*** : With a fresh air supply in the range of 15-30m^{3}per person per hour, which is commonly required in schools, ventilation is by far the largest component of heating and cooling loads for classrooms and other densely occupied spaces.
- ***Internal Heat Gains*** : At an average occupancy of 30 pupils per classroom, internal heat gains from metabolic processes alone are equivalent to a 3 kW heater (or some 24 kWh per day for an eight-hour school day). The use of lights and appliances adds a further source of heat which may be welcome in winter, but may contribute to uncomfortable temperatures in summer.
- ***Solar Heat Gains***: A classroom with 10m^2 of south-facing windows located in the south of Europe receives up to 30 kWh per day of heat gain from solar radiation. In conjunction with internal heat gains incoming solar radiation can lead to high temperatures even in winter.

Where the density of occupation is high, direct exposure to solar radiation can be undesirable.

Activity

Occupant activity affects the rate of metabolic heat generation which is in turn an indicator of the required comfort conditions, as well as contributing to internal heat gains. In educational buildings occupant activity varies from sedentary (in classrooms), to moderately active (laboratories) to very intensive (gymnasium). In the cool part of the year, desirable indoor temperatures may range from as low as 14°C for gymnasia and sports hall, up to 24°C for shower rooms and medical rooms. In summer the tolerable range can vary greatly, but it is generally accepted that room temperatures should not exceed 27°C for long periods. Occupant activity is also a determinant of lighting requirements. In classrooms, illumination requirements are commonly of 300-500 lux on the working plane.

Outdoor Spaces

Both contact with, and access to, outdoor spaces are important design considerations, Fig.1. Outdoor spaces immediately adjacent to classrooms are commonly used as an extension of classroom space. Protection of outdoor and semi-outdoor spaces, used for recreation or other activities, from wind in the cool period and sun in the warm period is an important design consideration.

Improvement of Existing Building Stock

Many school buildings in Europe date from the 1950's and 1960's, when new schools were built in large numbers to accommodate the growing child population of the post-war years, Fig. 2. These are highly glazed on all elevations, and poorly insulated. They have high running costs in energy, poor thermal and visual comfort, and problems of indoor air quality. With the low population growth rates that characterise most parts of Europe in recent years, few new school buildings are being built, but the adaptation and improvement of the existing stock is an important objective.

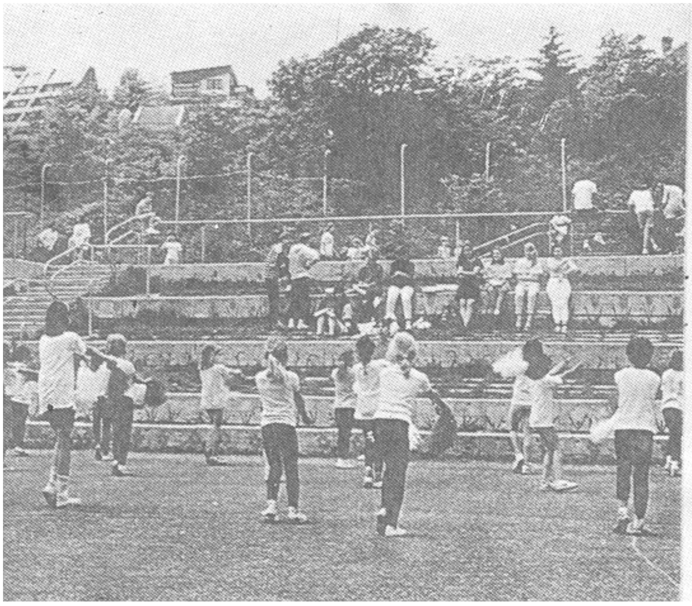


Fig. 1 Outdoor spaces for recreation

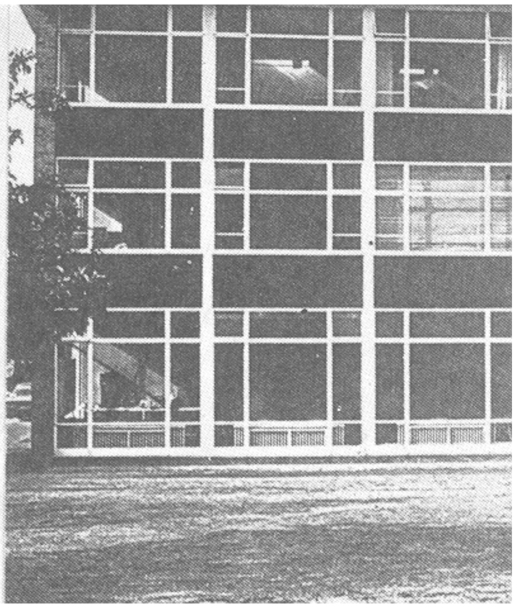


Fig. 2 Typical UK 1950's school building

2 SITING AND SITE LAYOUT

Important considerations in siting buildings are:

- access to sunshine and protection from wind in the cool period;
- shading and access to cooling breezes and other environmental heat sinks in the warm period.

These also apply to outdoor spaces used for recreation. The environmental opportunities and constraints presented by a site are conditioned by the following:

- **geographic location** and **site topography**: these characterise climate and site microclimate; there are important microclimatic differences between urban and suburban or rural locations.
- **built density and profile of adjacent buildings**: these affect solar access and air flow conditions on site
- the **orientation of streets** influences building orientation and building form
- **open spaces and landscaping** have an effect on the site microclimate
- **traffic, noise, and pollution** around the site may influence decisions on building orientation, spatial zoning and internal layout.

Orientation and Solar Access

In the northern hemisphere north-facing surfaces do not see the sun at all between September and March, and from March to September only for a very short period in the early morning and late afternoon. The amount of radiation reaching spaces with openings on this orientation is less than for any other orientation. Thus, this is a good aspect for spaces in which the admission of direct solar radiation is not desirable (see *Density* above). The advantage of a

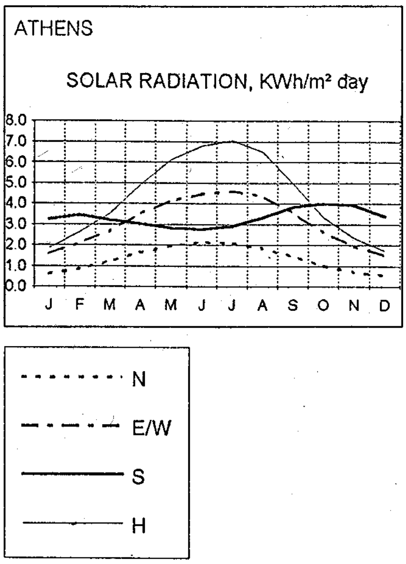


Fig. 3 Daily values of incident solar radiation on vertical surfaces of different orientation and on the horizontal in Athens, Greece.

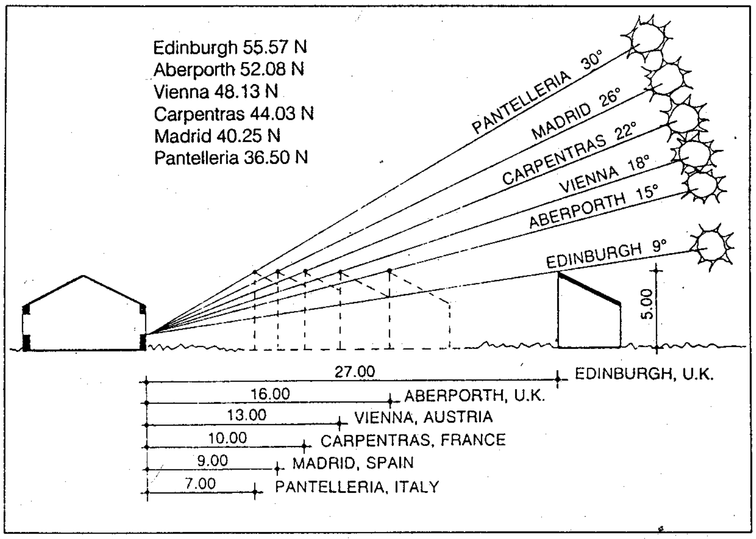


Fig. 4 Noon solar altitude angles in mid-winter, and relative distances to avoid overshadowing at different European latitudes.

southern aspect on the other hand, is that it receives the largest amounts of sunshine in the cool period and has a more even exposure to solar radiation than other orientations both seasonally, and within the daily cycle. In Southern Europe south *vertical* surfaces actually receive more radiation in winter than in summer, Fig. 3. Where sunshine is desirable for heating, a southern orientation should be preferred. Where off-south orientations are being considered, an easterly aspect is preferable to west.

Overshadowing, -the interception of the sunbeam directed toward a surface by an intervening obstruction-, erodes the advantage that a southern orientation has over eastern and western aspects in the cool period of the year. The likelihood and extent of overshadowing vary considerably depending on geographic location and site topography. These should be assessed at the design stage. The main considerations are the heights and shapes of any surrounding obstructions, and their distance from the spaces being considered for solar access. Figure 4 illustrates midday solar altitudes in mid-winter, and the spacing required to avoid overshadowing of a single-storey building on a flat site at different European latitudes.

Landscaping and Microclimate Modification

Landscaping can be used as means of solar and wind control and can also help reduce noise and pollution, and provide visual stimuli, Fig. 5. Microclimatic effects that might be sought through landscaping and external finishes include:

- modification of the direction and/or velocity of winds and breezes
- shading of building surfaces and ground around buildings
- control of surface reflectances and temperatures (through appropriate specification of paving materials and external finishes)
- cooling from plant evapotranspiration and water evaporation.

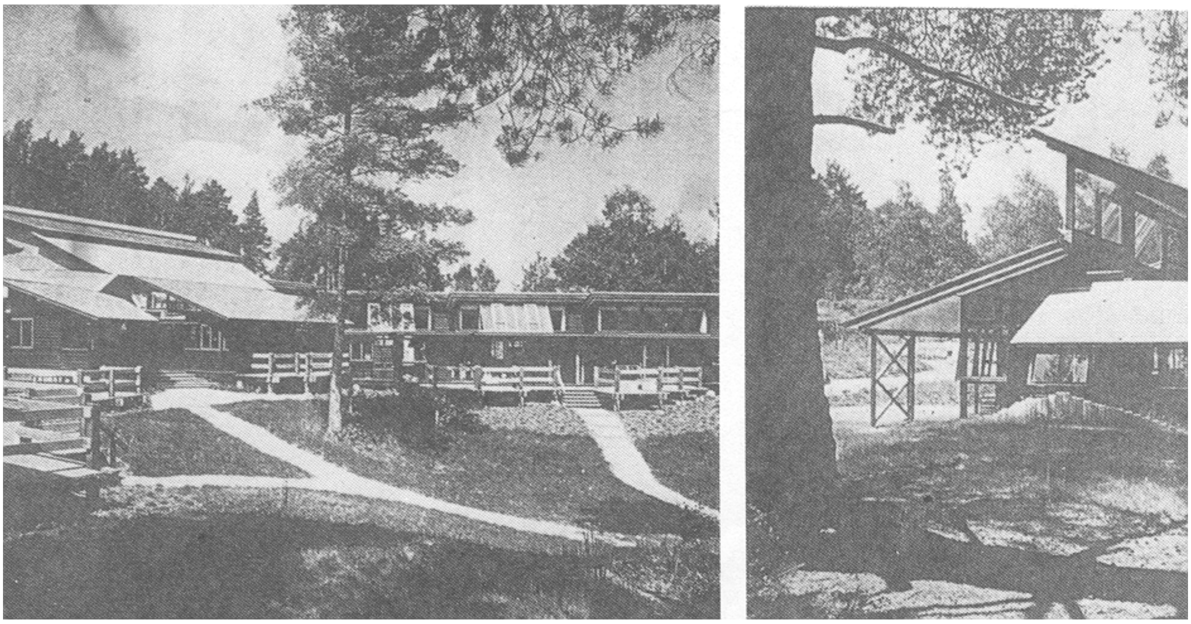


Fig. 5 Woodlea Primary School, Hampshire, UK (Architects: Hampshire County Architect's Dept.)

3 BUILDING FORM AND INTERNAL LAYOUT

Building form and spatial organisation affect daylighting and ventilation, wind exposure and heat loss, and the potential for passive heating and cooling.

The environmental attributes and implications of building form and spatial planning arise from:

- plan form, section and building shape;
- grouping of spaces and relationship with the outside;
- orientation
- the relative exposure of individual building elements.

The plan forms commonly encountered in educational buildings can be grouped into four generic types, Fig. 6:

- **Deep Plan**: a compact form with classrooms arranged around a central space
- **Courtyard Form**: spaces arranged around an open or semi-enclosed court
- **Linear Form**: a shallow plan with teaching spaces laid along a circulation path
- **Composite Forms**: combinations of linear and deep plan or courtyard elements.

The environmental attributes and design implications of these forms are discussed below.

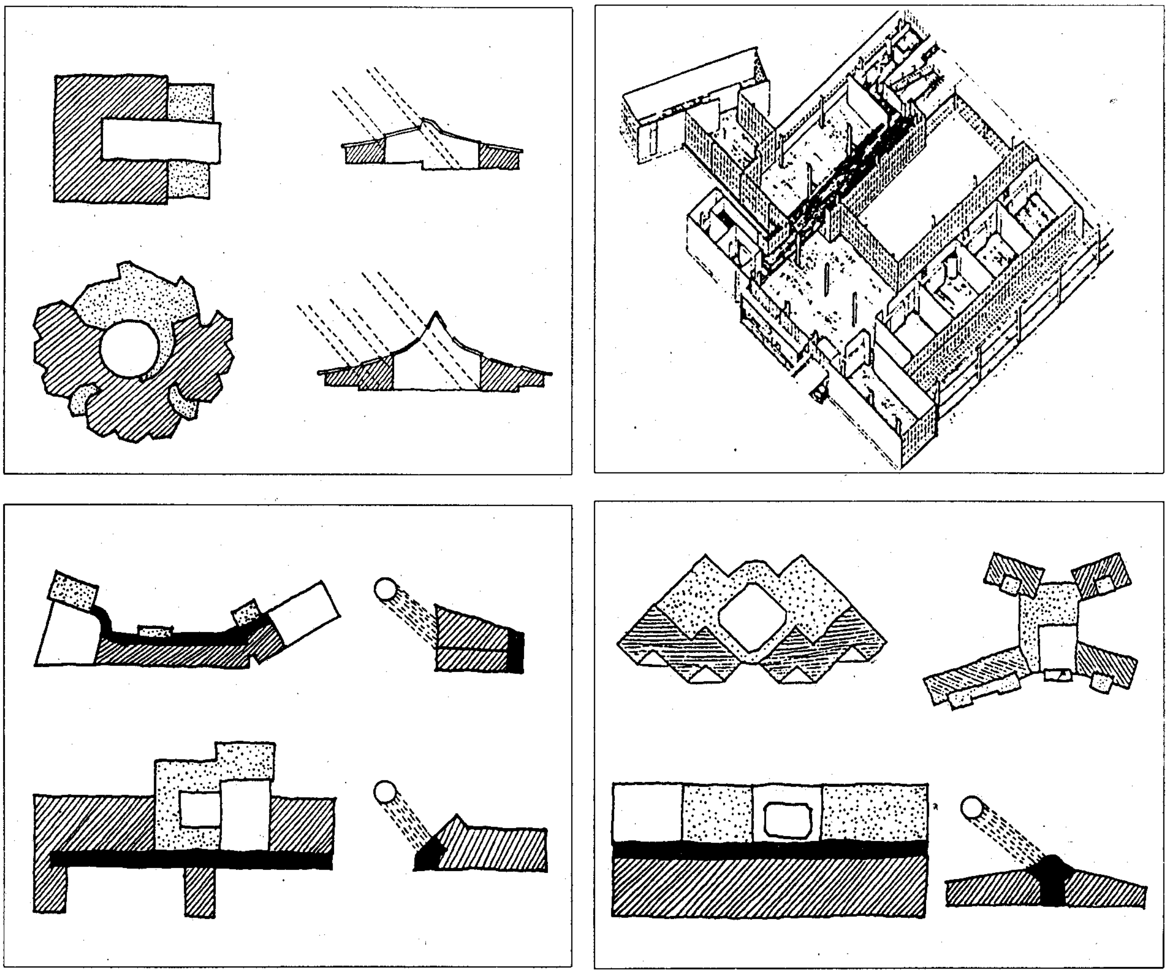


Fig. 6 Generic plan forms

Deep Plan

The main characteristic of this form is its *compactness*. The plan is focused toward a central space, traditionally the *hall*, with classrooms on two, three or all four sides. Compared to other plan forms such layout has a lower exposed envelope area, less circulation space, and provides easier access to the various spaces in the building.

- **plan / section**: spaces can be layered and zoned, but the depth of the plan inhibits ventilation and daylight penetration at the centre of the building; on low rise buildings careful development of the section can alleviate this problem.
- **grouping of spaces and relationship with outside**: the spaces at the centre of the plan have no other contact with the outside than through the **roof**, which becomes the critical element for this plan form.
- **orientation**: openings are required on all four orientations for daylight and ventilation; each elevation needs to be treated differently according to orientation and the use of internal spaces.
- **exposure**: overall, lower exposed envelope-to-volume ratio than other forms; however, higher exposure through the *roof*.

The deep plan form can become unworkable environmentally if the requirements for daylight and fresh air cannot be met successfully. The examples below illustrate the importance of the roof and of the section of the building as means of promoting daylight and ventilation to the core of the building.

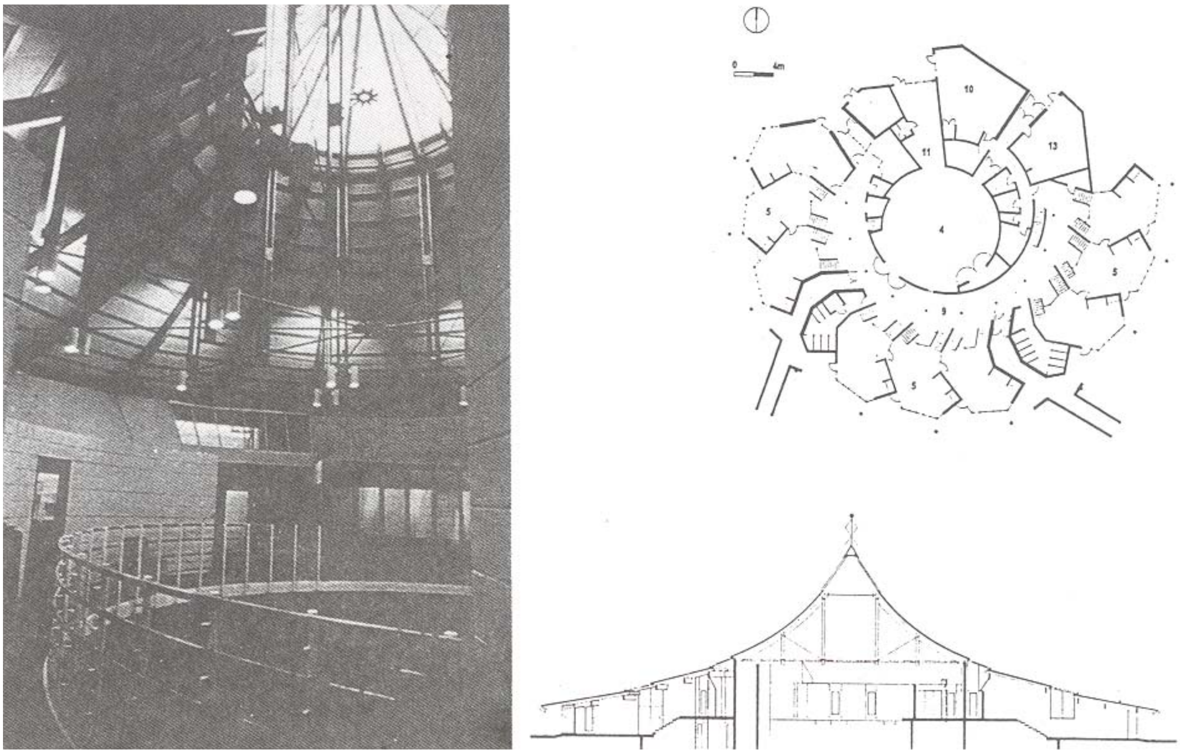


Fig. 7 Stoke Park Primary School

Stoke Park, Hampshire, UK (*Architects: Hampshire County Architect's Department*) : the roof was clearly recognised as a key element in the design of this primary school building. The conical rooflight at the apex is the main source of daylight for the central hall, and strips of rooflights supplement the daylight to classrooms, Fig. 7.

Crookham Junior School, Hampshire, UK (*Architects: E. Cullinan;* rehabilitation) : this is a rehabilitation scheme which addressed the problems of an overglazed and uninsulated 1960's building. The window area was reduced, and roof openings were formed to supplement daylight and ventilation at the centre of the building. Overhangs were added as weathershields and for solar control on the elevations, Fig. 8.

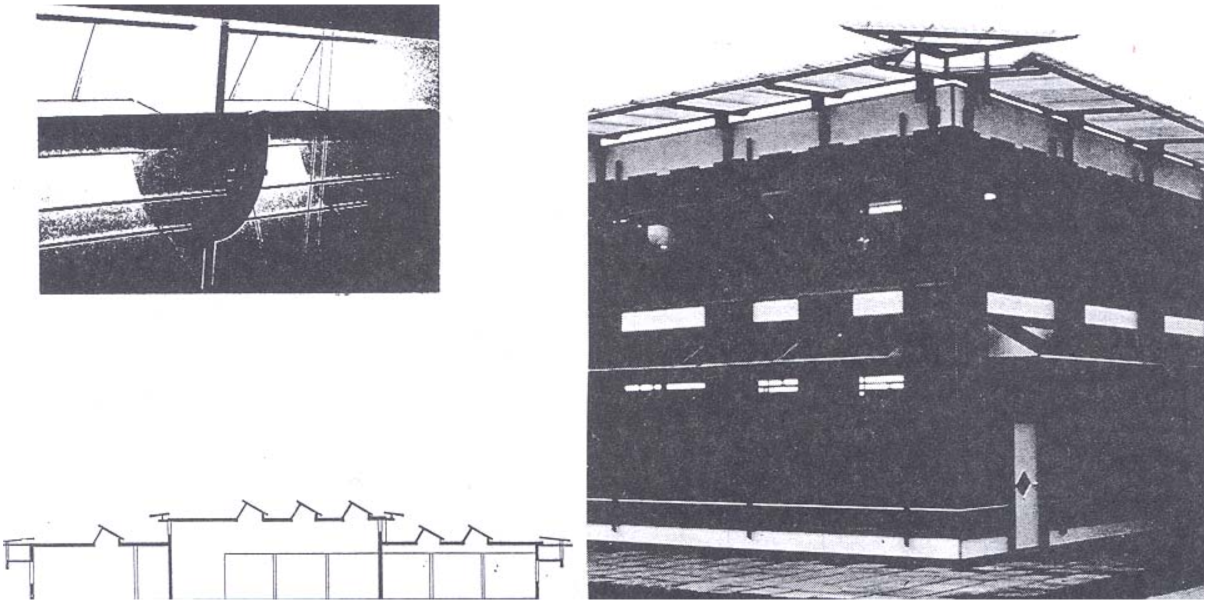


Fig. 8 Crookham Primary School

Courtyard Form

The open courtyard is a traditional solution to the ventilation and daylighting problems of the deep plan. The courtyard form has a long history and many variants. An open courtyard admits daylight and provides a means for cross-ventilation in what would be otherwise a deep plan building. The courtyard space itself is a more controllable and private space than the outdoor.

- **plan and section**: the courtyard form admits daylight in spaces from one or two sides; the proportions of the courtyard(s) and surrounding building need to be studied carefully on the section.
- **grouping and relationship with outside**: spaces are laid around the courtyard(s) with openings toward the courtyard and/or to the exterior perimeter of the building.
- **orientation**: an additional orientation is available for each space through the courtyard; each elevation needs to be treated differently as a function of orientation.
- **exposure**: the courtyard form has a higher exposure to the outside than a deep plan building; this may be partly modulated by the design of the courtyard.

ATAM Centre, Mairena del Aljarafe, Seville, Spain (*Architects: Pilar Alberich Sotomayor and Seminario Arquitectura Bioclimatica, Seville*) : The two symmetrical courtyards are designed according to local tradition with fountains, loggias and movable canvas awnings. In addition to their function as private semi-outdoor spaces they play an important role in the ventilation strategy of the building, Fig. 9.

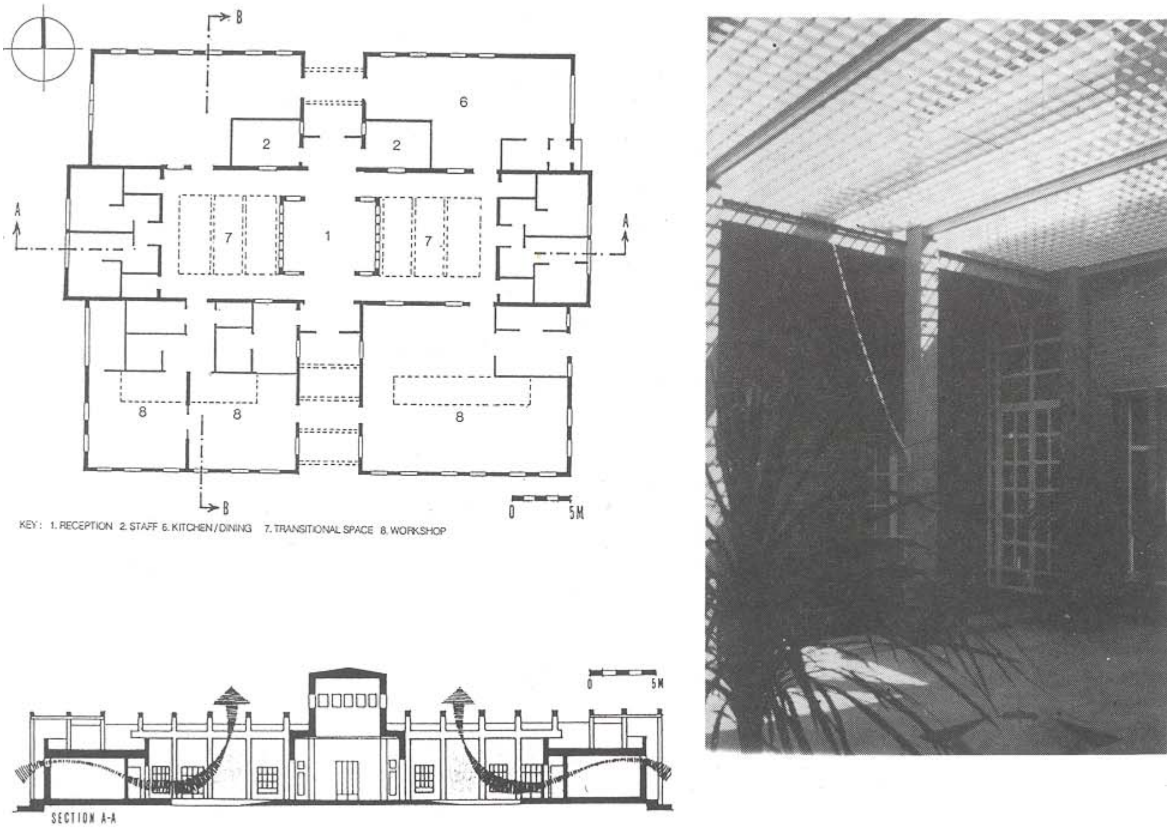


Fig. 9 ATAM Centre

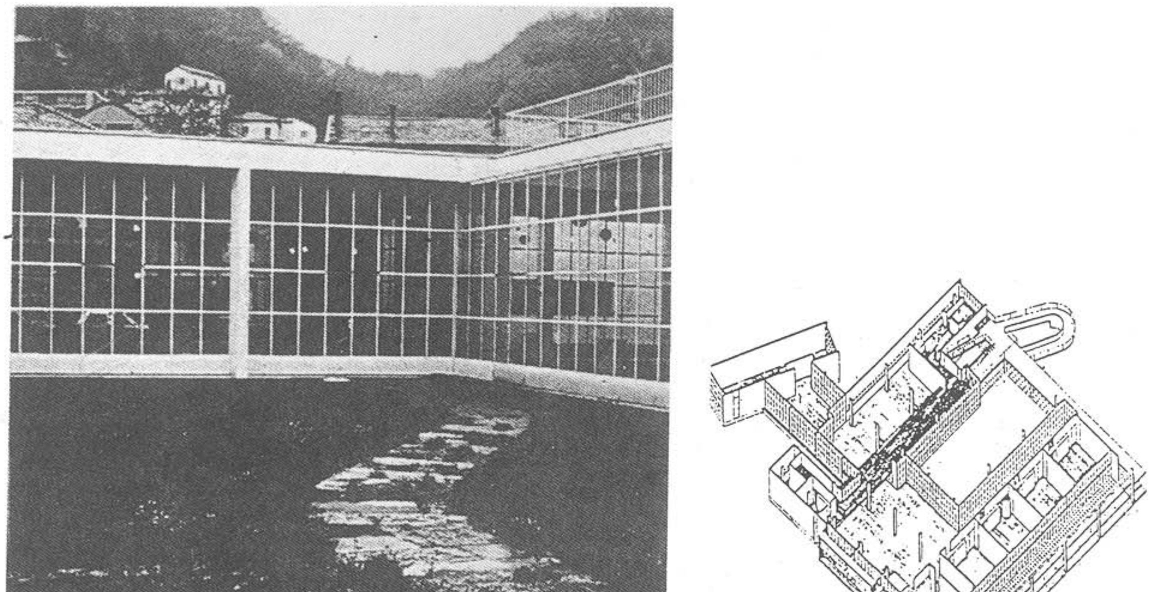


Fig. 10 Asilo Sant Elia

Asilo Sant Elia, Como, Italy (*Architects: G. Terragni*) : This school, built in the mid-war period, has been recently rehabilitated. The courtyard at the centre of the plan allows cross-ventilation and daylighting from two sides; the building is, however, excessively glazed, Fig. 10.

In cool climates a glazed roof over the courtyard can provide protection from rain and wind and higher temperatures, thus acting as a thermal buffer. Provisions for shading and for openable glazing are essential to prevent overheating in summer. Permanent glazing of a courtyard should be avoided in milder climates such as those of southern Europe.

Fig. 11 Daycare Centre, Berlin

Daycare Centre, Berlin, Germany (*Architects: Hartman & Lutkemeyer*) : The open courtyard of a 1930's building was glazed over as part of a rehabilitation scheme, providing some 225m^2 of protected playground area which can be used all-year round, Fig. 11. Internal roller blinds were fitted for solar control, and heat trapped in the airspace between the glazing and the blinds can be drawn to an underfloor thermal storage space or released to the outside through the ventilation flaps on the ridge of the conservatory.

Research Laboratory, Ulm, Germany (*Architects: LOG ID Group*) : a new building designed around a large glazed courtyard-conservatory, Fig. 12.

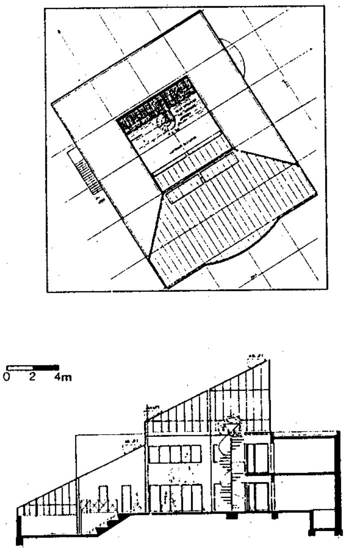


Fig. 12. Research Laboratory, Ulm

Linear Form

The linear form arises from the juxtaposition of teaching spaces along a circulation path. It provides a means of controlling the orientation and form of the plan thus addressing daylighting and ventilation issues.

- **plan and section**: a shallow plan form suits both daylighting and natural ventilation design objectives; however, the resulting long circulation path may lead to waste of space.
- **grouping / relationship with outside**: the circulation path acquires a prominent role and its position and orientation provide different possibilities for thermal and daylight control (see below).
- **orientation**: a linear form emphasises two particular directions of the compass; unfavourable choices of orientation will cancel some of the environmental advantages this form provides.
- **exposure**: the higher surface-to-volume ratio of this form leads to higher heat loss and air infiltration rates; this can be partly compensated for by building on two or three storeys, by judicious control of glazing area and solar heat gains, and/or by an increase in thermal insulation of opaque elements; **windows** and **walls** are the most critical elements for the linear form.

The linear form finds its environmental justification when the ***long axis*** of the building is pointing east-west. This provides a clear-cut choice between two options:

- ***Classrooms along the southern elevation with circulation path on the northern side***, Fig. 13a: in the northern hemisphere this configuration exposes classrooms to sunshine; solar control is an important consideration. The corridor space may act as thermal-buffer and, if required, provide supplementary daylighting and cross-ventilation through openings in the separating partitions.
- ***Classrooms along the northern elevation with circulation path on the south side***, Fig. 13b: in this configuration classrooms avoid direct sunshine; the corridor can be designed as a transitional, climate-modifying space (for example, as a conservatory in cool regions, or as semi-outdoor patio or verandah in milder climates).

A third option is where spaces are arranged linearly on either side of the circulation path, Fig. 13c. This configuration is discussed under ***Composite*** forms below.

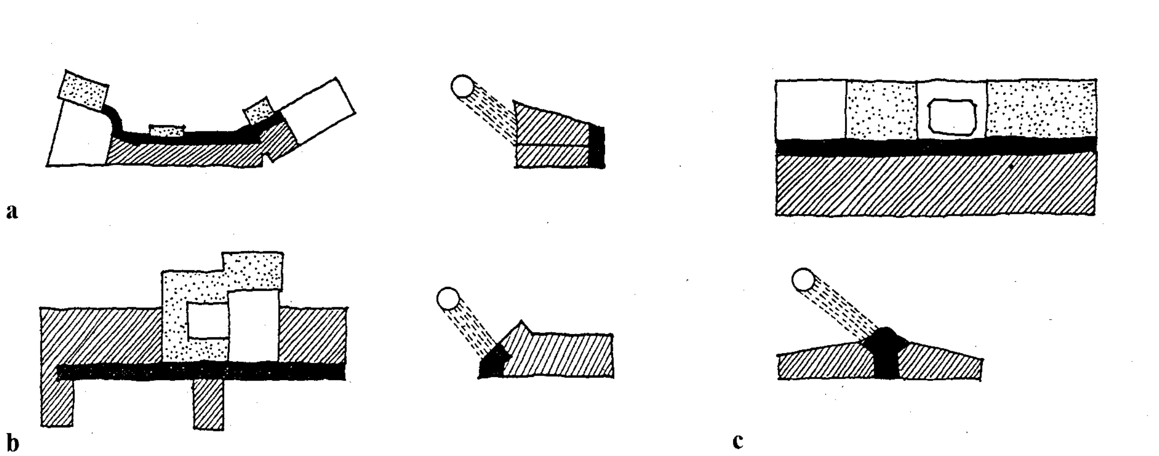
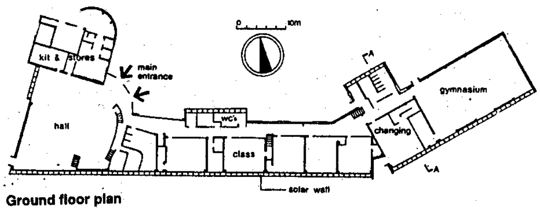


Fig. 13 Variants of Linear and Composite forms



Ground floor plan

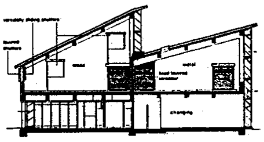


Fig. 14 St Mary's Secondary School

St Mary's RC School, Wallasey, UK (Architects: Wallasey Borough Architect's Dept.): Completed in the early 1960's, this building has met its space heating requirements solely from solar and internal heat gains despite the harsh winter in the region, Fig. 14. It is of heavyweight construction with a heavily insulated external envelope, minimum exposure on its north side and fully glazed to the south.

Netley Abbey Infants School, Hampshire, UK (*Architects: Hampshire County Architect's Dept.*) : The building has classrooms on the north side and a corridor-conservatory along the southern elevation, Fig. 15. In the cool period pre-heated air from the conservatory is drawn into the school's warm-air heating system. In the warm period, the higher temperature in the conservatory promotes stack-effect ventilation drawing in cooler outdoor air through louvres on the north side, and exhausting the warm air via the conservatory's ridge ventilator.

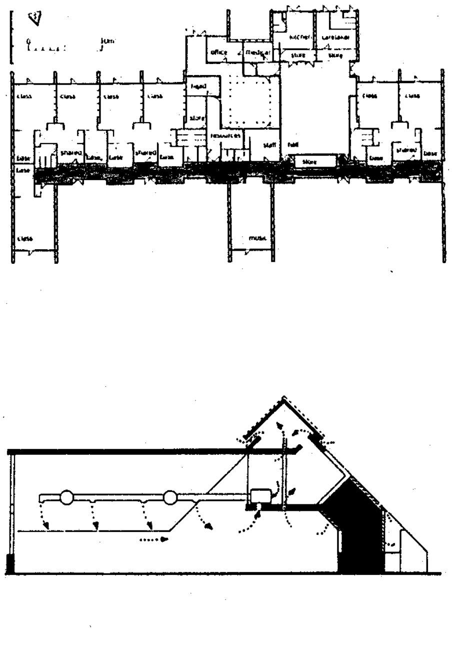


Fig. 15 Netley Abbey Primary School

Composite Forms

Most large educational buildings are of a composite form combining the characteristics of the linear and the deep plan or courtyard forms. The principles, environmental attributes, problems and likely solutions are similar to those described above.

- **plan and section**: in many cases the plan is essentially linear but with spaces laid out on both sides of a central circulation path or "*internal street*"; the latter becomes an important environmental and architectural feature.
- **orientation** : commonly two orientations will prevail; *north and south should be preferred.*
- **exposure**: usually more compact than the linear form; **roof, windows** and **walls** require attention.
- **grouping and relationship with outside**: in some cases the internal street may be a semi-outdoor space, and in cooler climates take the form of a glazed street or atrium.

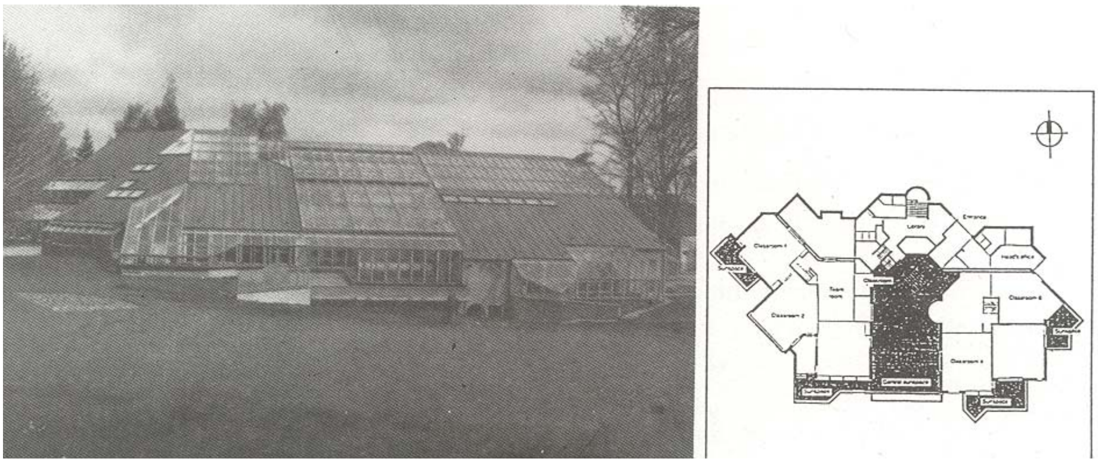
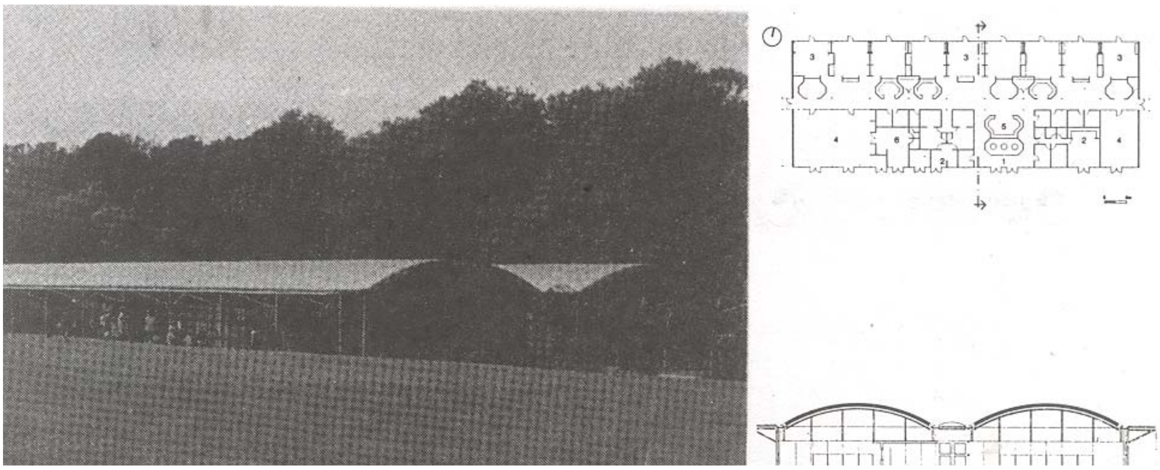


Fig. 16 Tournai Primary School

Tournai Primary School, Tournai, Belgium (*Architects: J. Wilfart*) : The considerable depth of the building is moderated by the insertion of a large central conservatory, Fig. 16. Attached conservatories on the southerly elevations extend the classroom areas.



Queens Inclosure Primary School, Hampshire, UK (*Architects: Hampshire County Architect's Dept.*) : The building's vaulted metal roofs are separated by a glazed vault over the central circulation spine, Fig. 17. Classrooms face to the north and have glazed partitions toward the internal street.

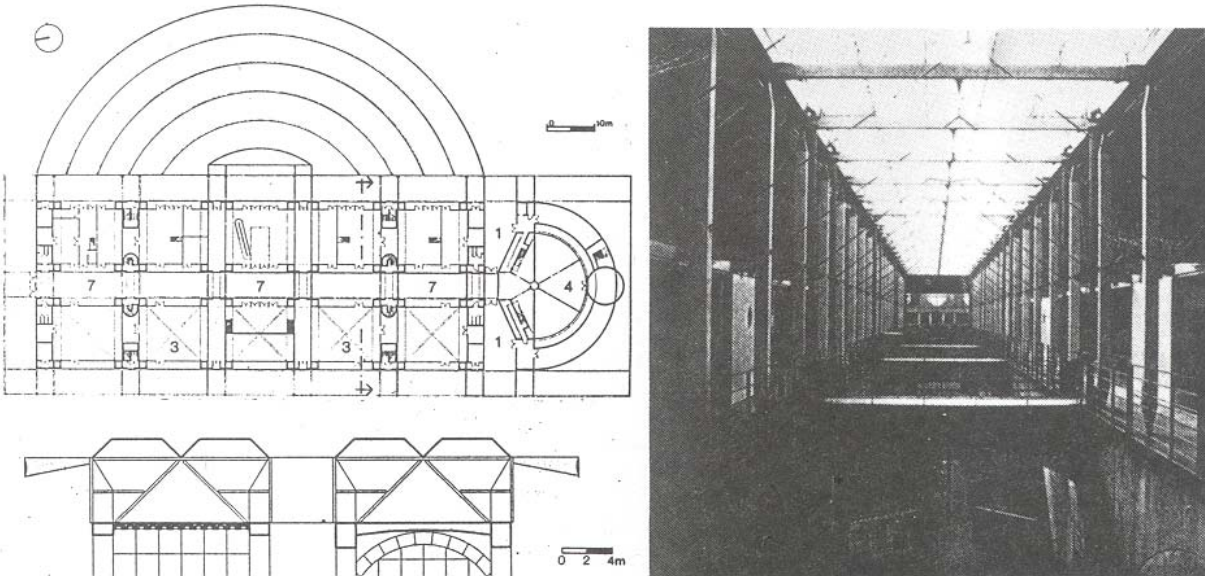


Fig. 18 Lyon School of Architecture

Lyon School of Architecture, Vaulx-en-Velin, France (*Architects: Jourda & Perraudin*): Lecture rooms (on the ground floor) and studios (upper floor) are arranged on either side of an internal street which is fully glazed at roof level, Fig. 18. Although the spatial arrangement is functional, the orientation of the building (heavily glazed upper levels exposed to east and west with insufficient solar control), and lack of means of solar control and heat dissipation in the internal street result in very high indoor temperatures in summer.

Almeria Primary School, Spain (*Architects: Pilar Alberich Sotomayor and Seminario Arquitectura Bioclimatica, Seville*) : The building is composed of two parallel volumes linked by a linear courtyard, Fig. 19. The pergola over the courtyard is made of thin concrete elements and designed to provide solar control in the warm period, while allowing sunshine penetration in winter. The classroom block is to the north with openings both to the north and south.

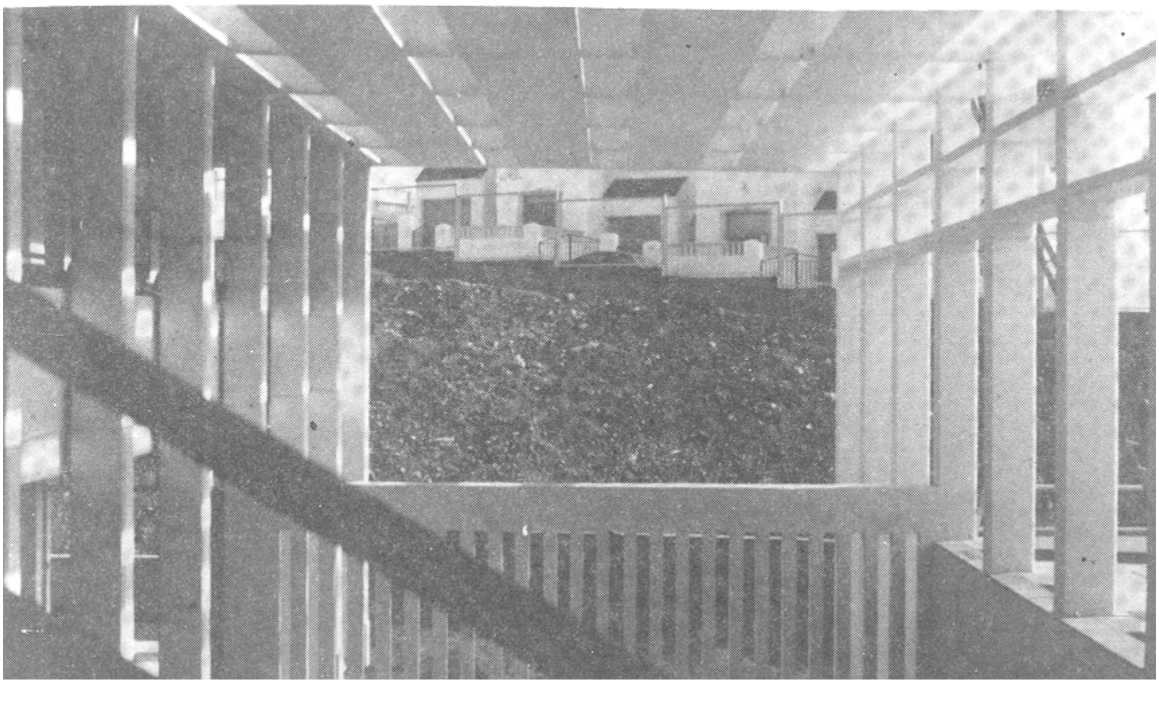


Fig. 19 Almeria Primary School

4 ELEMENT DESIGN

The exposure, detailing, and finishing of external building elements have considerable effect on a building's environmental performance. Careful specification of the properties of individual elements can also compensate for possible environmental weaknesses in siting, building form or internal planning. The following are the main design parameters:

- ***geometry*** (surface area, orientation, tilt);
- ***thermal properties*** (thermal resistance, emissivity, and inertia of both internal and external leaves of the element);
- ***solar-optical properties*** of internal and external surfaces;
- daily and seasonal adjustments to the above
- constructional *continuity*, and *detailing* at joints.

Roof

The roof has to sustain a heavy exposure to weather conditions and is often the element with the largest exposed area on school buildings. In addition to structural and general weathering considerations the following will have an important bearing on the environmental performance of the roof.

- **Roof shape and solar-thermal properties**: most school buildings are low-rise; the roof accounts for a considerable proportion of the exposed external envelope and a high level of thermal insulation is desirable in most climates, and a reflective external finish in warmer regions.
- **Roof openings**: the plan depth will often suggest the need for roof openings for daylight and ventilation, Fig. 20 (roof lights, skylights, light and air ducts).
- **Eaves and overhangs**: these can provide some of the shading that will be required on windows and external spaces adjacent to the building.
- **Roofspace solar collector**: glazing of part of a southern roof slope can provide a supplementary source of space heating in cool climates.

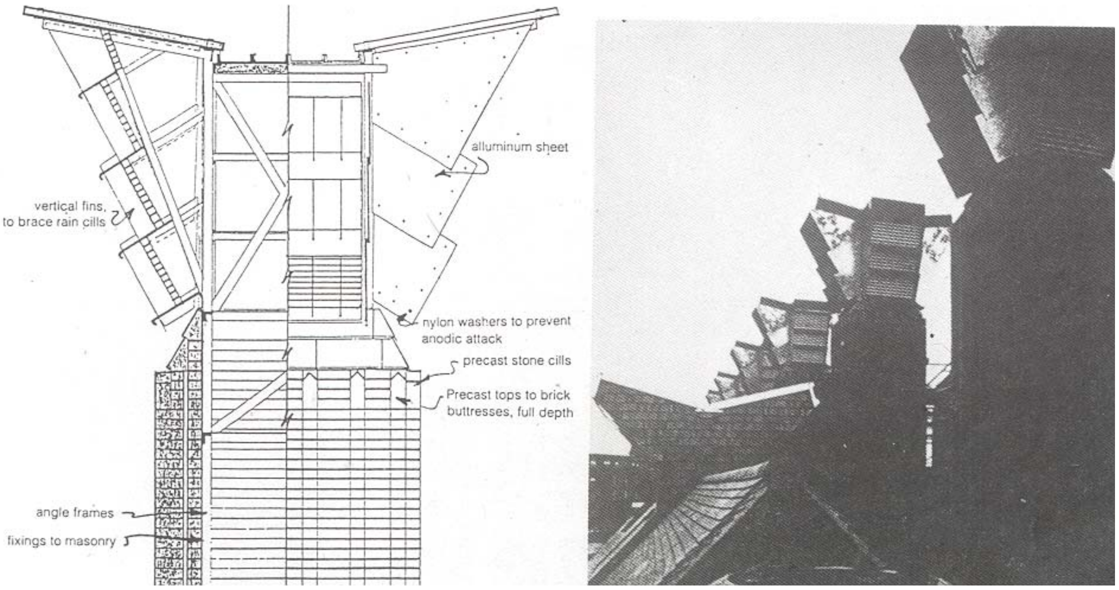


Fig. 20 Air duct, School of Engineering, Leicester, UK (Architects: Short Ford & Associates)

Windows and Walls

The relationship between glazed and opaque elements on the elevations is a critical design consideration for thermal and visual comfort. The thermal properties of an opaque wall can be controlled by application of thermal insulation, and by good detailing at joints. The capacity of the wall for heat storage can be equally controlled by the specification of appropriate type and thickness of material on its inner leaf, so that the cycle of heat storage and discharge is consistent with the function and occupation of the building. Window design is more complex; windows are more sensitive to environmental variables, as well as being required to perform several environmental functions. Transmission of solar radiation can reduce dependence on conventional heating and artificial lighting. However, windows incur heavy heat losses in the cool period, and heat gains in hot weather. Moreover, the various joints between window frame and structure, and between glazing and frame, are further sources of heat loss and gain due to thermal bridging and air leakage. Careful detailing is important. Blinds, shutters and other external and internal devices are essential window components for the control of heat losses and heat gains.

Special consideration needs to be given to the following environmental functions:

- ***Daylighting***: illumination levels and the quality of daylighting in rooms are determined by factors such as glazing type and size, orientation, window location, and the reflectances of room surfaces; as daylight penetration decreases with distance from the window, it is preferable to have windows on two sides, or to combine sidelighting with rooflights.
- ***Ventilation*** : in the cool period the supply of fresh air for ventilation should be achieved by controllable means (i.e. without having to open windows); however, openable window areas are required for the dissipation of excess heat during warm periods.
- ***Solar heat gain*** can compensate for the heat loss through windows, but can cause discomfort in mild climates and densely occupied spaces; thus orientation and access to sunshine need to be considered carefully as a function of location and building type.

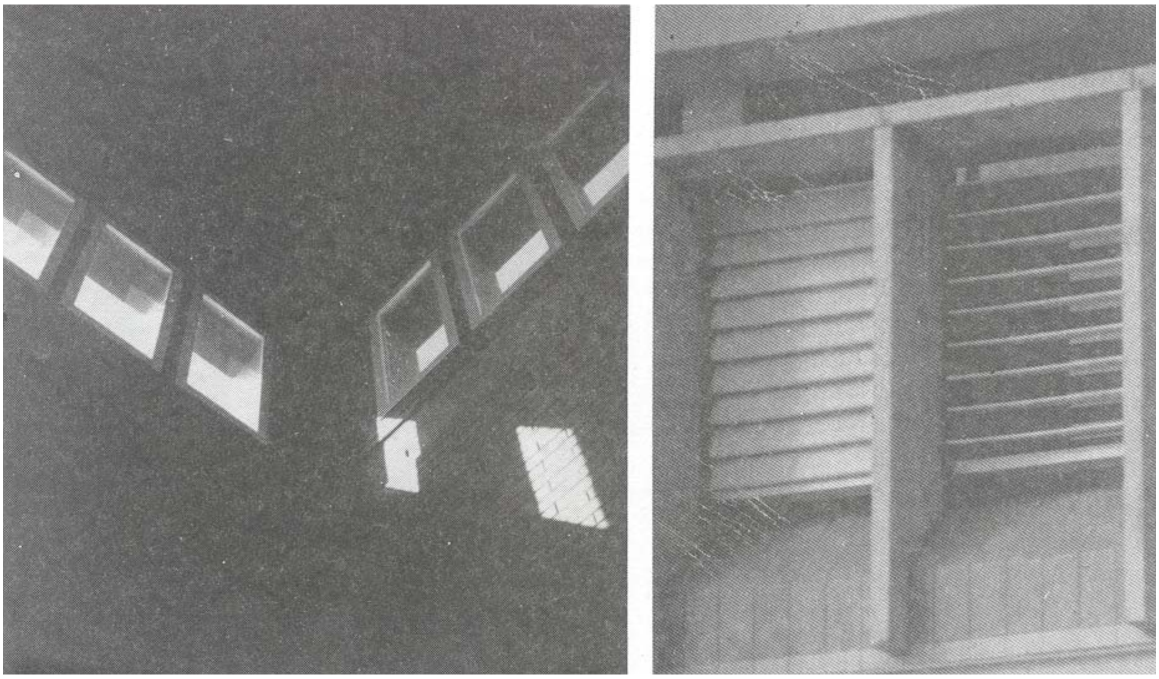


Fig. 21 Window design parameters and components

Transitional Spaces

Transitional spaces are partly or fully enclosed auxiliary spaces at the centre or perimeter of a building, which are not mechanically heated or cooled. Verandas and courtyards, and in cool climates, conservatories and glazed atria are examples of such spaces. The word transitional is used here to suggest both the function of these spaces, i.e. that their occupation is transient, and their environmental attributes, which arise from their position as intermediate spaces between the uncontrollable outdoor environment and the more carefully controlled indoor spaces.

The **veranda**, Fig. 22, is essentially a shaded extension of indoor spaces at the perimeter of a building. A **conservatory** is a structure which is enclosed on all sides, mainly by glazed surfaces, and adjoins occupied spaces of a building from which it is separated by full height partitions. It is the equivalent of the veranda in a cool climate. The architectural functions of a conservatory in educational buildings are as a circulation space, entrance hall or as seasonal extension of the classroom space. The particular microclimate of a conservatory results from thermal exchanges with the outdoor, as well as with occupied adjacent spaces.

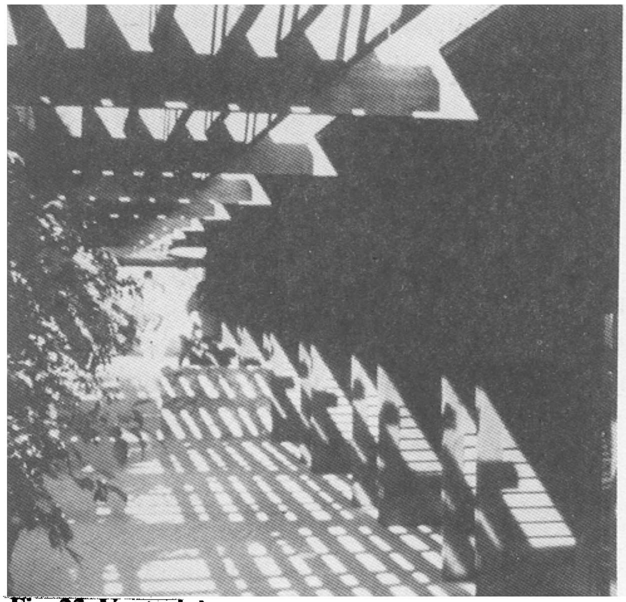


Fig. 22 Verandah

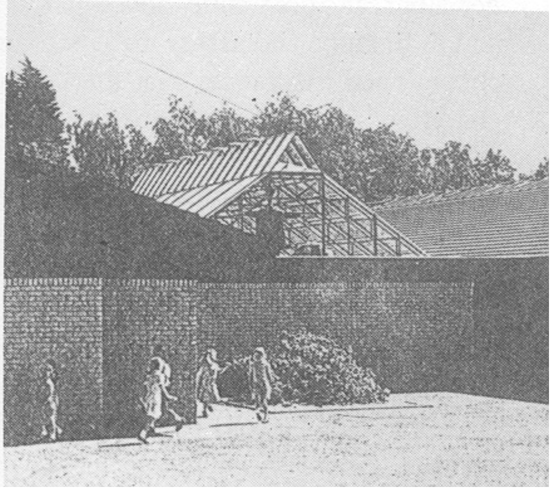


Fig. 23 Glazed Atrium

The environmental characteristics of a **courtyard** (or patio) as an opening in the centre of a building are:

- as a source of daylight, ventilation and solar heat gain for adjacent indoor spaces;
- a partly shaded and protected environment in both winter and summer, with the potential for exploiting the processes of convection, water evaporation and night-time radiation for cooling;
- a measure of privacy and acoustic insulation from other parts of the site and from the outdoor environment.

The **glazed atrium,** Fig. 23, resulting from the addition of roof glazing to a courtyard provides further protection, -from rain and wind-, and a moderate resistance to heat flow. The temperature in a glazed atrium is higher than that outdoors; this makes it act as a thermal buffer for adjacent spaces in winter.

5 ENVIRONMENTAL PERFORMANCE ASSESSMENT

The research and monitoring experience of the last fifteen years has yielded considerable evidence that the use of conventional energy in buildings can be greatly reduced, -or eliminated altogether in some cases-, and occupant thermal and visual comfort can be improved. Many recent schemes are aimed at near zero conventional energy for space heating and cooling, and a number of buildings are being designed to become producers of energy.

Climate is an important design consideration, but what we call climate-responsive design is not a response only to *outdoor* climate, but also a function of the *indoor* climate delineated by a building's function and occupation. In the case of educational buildings, the functional characteristics of the building type suggest the following design targets for new schemes:

- *daylighting* to provide the illumination required for most or all of the normal school day throughout the year.
- *control of thermal loads* and use of sources of *passive heating and cooling* to achieve thermal comfort targets without the need for mechanical equipment.
- provision of controllable means of *natural ventilation*, to safeguard fresh air supply and indoor air quality without undermining the thermal design strategies of the building.

In pursuing such objectives designers need empirical knowledge on which to base design decisions, and predictive tools which can allow them to test and compare alternative solutions, and to finetune and assess the environmental characteristics of their final designs. Similarly, clients need assurances that the completed buildings will meet the stated targets without compromising occupant comfort and indoor environmental quality. The empirical knowledge and predictive tools we have come from two sources: from schemes which have been built and monitored in different climates; and from recent advances in theoretical knowledge which have led to more detailed and encompassing predictive models. Clearly not all monitored buildings have achieved targets such as those listed above. Those which did provide the assurances that such targets can be met. Those which had set lesser targets, or failed to meet their design targets, have still provided valuable lessons on possible design improvements which can be applied to future schemes.

Thus on-site measurements and observations have become irreplaceable as the means by which we acquire information on how a building matches occupants' expectations and on the environmental conditions it achieves in the course of its operation. However, weather conditions vary from year to year; site microclimates are sensitive to natural or man-made changes in landscaping, topography and vegetation; a building's operational conditions also change over time, as well as being strongly driven by occupant behaviour. Thus in themselves, measurements taken over a short period in the life of a building are seldom generalisable, and can tell litle on how a building might have performed under different circumstances, or on what a different building design might have achieved under the same conditions. Nor can measurements tell directly whether a building's design has actually led to any energy saving or other environmental improvements compared to a different design or operation. To obtain such information it is necessary to have a comparative framework which alows the effect of individual design variables to be isolated and assessed. This is rarely provided by real buildings because operational variables can easily mask the effects of any building design variables and confuse the interpretation of side-by-side comparisons. Such comparative framework is, however, provided by the application of predictive tools and simulation models. The choice of tool, the availability and quality of input data, the way in which the building is modelled and studied, and the kind of interpretations and generalisations drawn from iterative use of predictive tools are important issues. What distinguishes a meaningful use of modelling and simulation from a meaningless and, potentially, misleading one, is not so much the sophistication or accuracy of the chosen tool, but the knowledge (both of building science and of architecture) and experience of those engaging in such activity.

With respect to the design process, predictive tools and simulation models provide the means for assessing the likely environmental implications of different design options as these are being considered by the designer. For example, common questions arising in the course of a design may include [1]: how does the varying patterns of sun angles over the day and year affect sunlight penetration in a room, and what is the effect of overhangs and other shading devices? how do window areas and orientations affect the use of space heating energy and electricity use for lighting, and what window sizes will provide adequate daylighting ? what type of glazing should be specified for windows ? should windows be fitted with insulated night shutters ? how much thermal insulation should be applied on opaque building elements ? how do the above parameters affect classroom temperatures, especially in the warmer part of the school year ? can increased air movement provide a source of cooling in hot weather (whether during occupation or at night), and what rates of air exchange can (or should) be achieved ? how are air flow patterns within a room influenced by the positions of openings ? finally, where one is operating across different climatic regions, how do different outdoor conditions modify the findings on any of the above ?

Within the geographic region of the European Union, climatic conditions vary considerably, though less so than across Latin America. In principle, for educational buildings, space heating is a requirement throughout Europe; however, the duration and intensity of the heating season vary widely both with climate and building design. Thus the need for installing and operating a mechanical heating system is also variable, depending closely on a building's ability for making good use of solar and internal heat gains. Figure 24 shows the relative differences in heating degree-days (to base 20°C) and sunshine hours on an average day in January for seven European locations. The differences between Seville (mildest winter, highest sunshine) and Munich (coolest winter temperatures) are quite substantial; London represents some sort of average in terms of temperature, but has lower than average sunshine and daylight. As can be seen from Fig. 25, -which shows simulated values of conventional heating for a single classroom for the same January day-, the differences in outdoor degree-days and sunshine can be bridged or intensified by building design measures. The graph covers six constructional variants of the same room which was assumed as 6m deep by 8m long, with identical

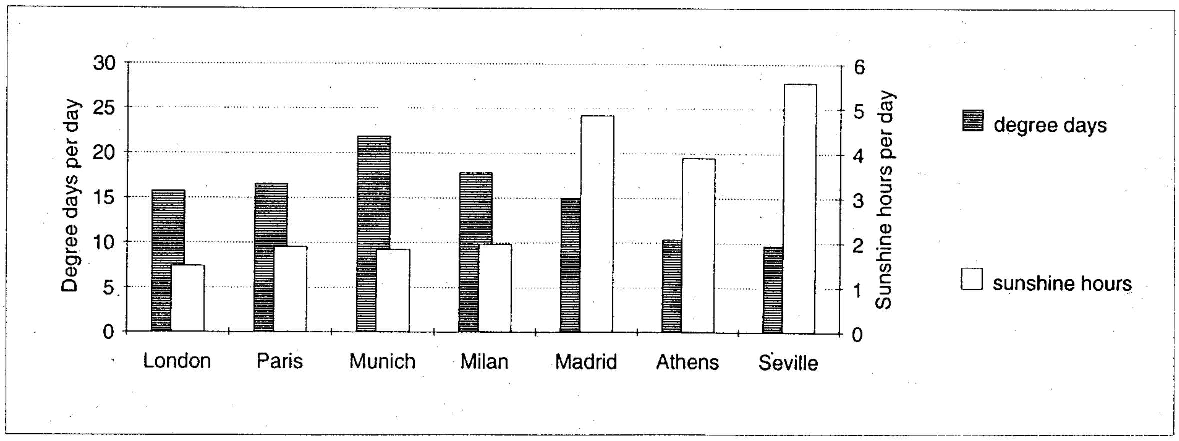


Fig. 24 Heating degree-days and sunshine hours for typical JAnuary day in different European locations

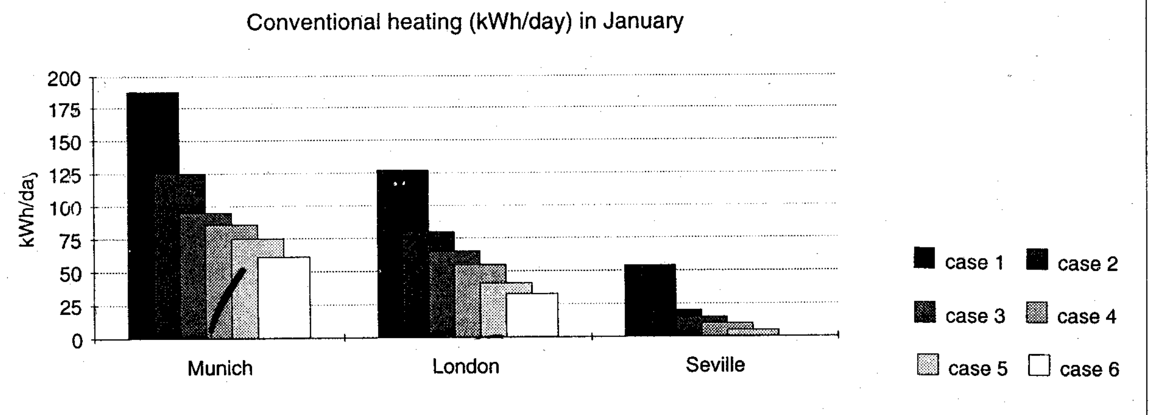


Fig. 25 Simulation results for different constructional variants of a classroom in European locations [1]

classrooms on either side, and having only one external wall and its ceiling exposed to the outside. Case 1 represents a worst case specification without any thermal insulation and single glazed windows; this represents a mean thermal transmittance value of 2.7 W/m^2 K for exposed building elements. Buildings of such poor insulation are of course no longer built in Europe. However, there still is a very large number of schools with these characteristics which were built before the 1970's and have not yet been improved. The next three variants were derived by incremental improvements in thermal insulation, including the use of double glazing, and for some of the variants (cases 4-6) insulated shutters on windows at night. Case 6 has the same constructional specification as case 5, but its classroom windows face north and the circulation space placed on the south is highly glazed to act as a free-running conservatory. It can be seen that both Munich and London critically depend on these improved specifications which when applied additively are predicted to reduce the use of conventional heating by 65-75% compared to Case 1. In the climatic conditions of Seville on the other hand, even the first improvement (case 2, which is assumed to have its external wall and roof insulated to give a thermal transmittance of 0.6 W/m^2 K) is quite sufficient to reduce the use of conventional heating to a very low level. The simulations suggest that further improvements can eliminate the use of conventional heating on all but the coldest winter days; this is also confirmed in practice by a number of recently completed school buildings in the area [2].

Northern Europe does not normally experience high temperatures in summer, and although solar radiation can be quite intense, both simulations and monitored buildings show that a well designed building provided with means of solar control and openable windows should be able to avoid overheating during the school year. In Central and Southern Europe, however, much higher outdoor temperatures make serious overheating a certainty for any building which lacks solar protection and heat storage, or is excessively glazed. The high internal heat gains in school classrooms tend to further aggravate the effect of the outdoor climate. Measurements and simulations reported in [1][2], and further measurements and simulations carried out in the context of the European Commission's Joule R&D Programme [3] have underlined the importance of these factors and provided guidelines for design.

CONCLUSION

School buildings have been notorious for poor environmental conditions and high energy consumption. Yet, as the brief review in this paper has shown, understanding of the functional and indoor climate requirements of the building type, and expression of such understanding through site layout, architectural form and building construction can allow designers to exploit natural sources of energy and produce buildings of high environmental quality with minimum dependence on non-renewable energy sources. As design targets become more ambitious, field measurements attesting to their attainment, and predictive tools capable of providing meaningful and reliable answers to design issues acquire an important role as means of environmental performance assessment.

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[3] Yannas, S. and E. Maldonado (Eds., forthcoming 1995). *Designing for Summer Comfort: Heat Gain Control and Passive Cooling in Buildings. Volume 1: Design Principles and Guidelines, Volume 2 : Examples.* European Commission Joule II R&D Programme, PASCOOL Project.

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