BRITA in PuBs

Reduction of overheating – Passive strategies

EU 6 framework programme

eco buildings

Guidelines

2007

1 Introduction

In the last two decades there is a tendency for **summer overheating** to be recognized as a major problem for non-domestic buildings in Europe. In fact, in spite of a broad consensus on the significane of energy-conscious principles in architecture during this period, and their contribution to the design and construction of buildings with low energy profile and reduced environmental impact, summer performance of buildings seems to escape such considerations.

The widespread use of **light envelope** construction for non-domestic buildings, combined with the **excessive use of glass** and the **absence of shading** has led to a dramatic increase in air-conditioning systems, even for countries in temperate or cold climates. Furthermore such systems are often required even during the winter, as high internal gains from occupants, their activities and equipment if combined with solar radiation and insufficient ventilation at certain hours of the day, can lead to overheating of major spaces.

Since **existing buildings** form a large majority of the building stock, it is obvious that the inclusion of sustainability issues in building renovation can have a considerable influence on human eco-systems. This is not easy to implement, however, since building renovation as a process has many limitations, related to small budgets, building and site drawbacks, service and use particularities and, last but not least, lack of energy conservation experience from the part of the decision-makers.
The aim of this handbook is to help remedy this situation in the case of **retrofitting of public buildings.**

1.1. Why use this technology

Due to their function, **public buildings** usually display a rather high occupant density as well as increased concentration of equipment and lights often resulting in increased heat gains. They generally have lower surface to volume ratios than domestic buildings, associated with lower fabric losses, and are normally occupied during the day when air temperature and solar gains are high. All these factors may create uncomfortable internal conditions for users even in temperate climatic zones.

Reduction of overheating in public buildings through **passive stategies** is a very efficient way to limit excessive energy consumption for cooling and create comfortable internal conditions for occupants and public (Fig. 1).

Passive strategies are based on the **“trias energetica”** concept for low energy retrofitting of existing buildings. This involves setting priorities in the retrofitting process according to the following order:
1) Application of energy efficiency measures
2) Integration of renewable energy sources, and finally
3) Minimisation of conventional energy sources to be used only as auxiliary systems and selected for their low environmental impact.
A discussion of the “trias energetica” concept can be found in the chapter on “Passive solar heating”.

Figure 1: Reduction of overheating by passive strategies Retrofitting, University of Ioannina, Greece [11-13]

1.2. Requirements in regulations

Following the 1970’s oil crisis most thermal building regulations in Europe focused on the **reduction of energy consumption** for heating and had a decisive influence on increasing thermal insulation and air-tightening of the building envelope, as well as reducing infiltration levels. As a result, serious problems followed related to air quality and the presence of mould, pointing to the need of sufficient ventilation. At the same time summer overheating became a general problem, resulting in a fast increase of air-conditioned buildings even in cold and temperate climates.

It is only recently, however, that European building regulations have been concerned by **summer comfort requirements in buildings,** and this to a rather limited extent. In fact, as reported in a recent EC-supported survey [1], only a limited number of European countries have specific requirements related to solar protection and thermal inertia of buildings, while several require specific calculation procedures for summer energy performance of buildings in their building regulations.

In the new European Directive on Energy Performance of Buildings (EPBD) it is stated that “priority should be given to strategies that enhance thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings” (article 18) [2].
However, this is not sufficient in order to induce all European countries into including passive cooling requirements into their own methodology for EPBD implementation and a new legal instrument is needed [3].

2 Current practice

In traditional architecture most public buildings included spaces of limited width and high ceilings, which were daylit and naturally ventilated through ample openings. resulting in stable interior temperatures and a reduction of overheating. Modern public buildings, however, usually have deep plans and low ceilings and are constructed of lightweight materials Moreover thermal gains from artificial lighting, and equipment create overheated conditions for the occupants. Therefore mechanical cooling is often a necessity, leading to high energy consumption and low environmental comfort for users.

2.1. Sources of overheating in public buildings

The gains mostly responsible for overheating in public buildings are the following (Fig. 2):

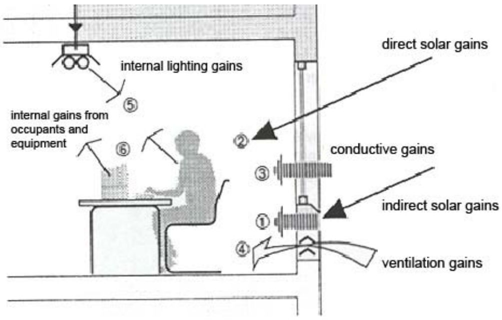

Figure 2: Sources of overheating in public buildings [4]

1. **Indirect solar gains:** heat from solar radiation on the external surfaces of a building.
2. **Direct solar gains:** solar radiation through windows.
3. **Conductive gains:** heat flowing from the hot air outside to the cooler interior through the building envelope.
4. **Ventilation gains:** heat carried into the building by warm fresh air indtroduced to replace stale but cooler air.
5. **Internal gains** from artificial lighting.
6. **Internal gains** from occupants and equipment.

3 Innovative solutions

3.1. Passive strategies for the reduction of overheating in public buildings

As mentioned above **passive strategies** can contribute to energy conservation even for large scale non domestic buildings, such as public buildings. As far as the **reduction of overheating** is concerned, passive solar strategies involve first **the reduction of heating loads**, including the minimisation of both external and internal heat gains, second the optimal use of passive **natural ventilation**, **daylighting** and **natural cooling** methods and finally the inclusion of mixed ventilation or air-conditioned zones only when necessary.
The third strategy is referred to as **mixed-mode** and may contribute to a low energy solution for large and deep plan buildings, provided that the interaction between passive and air-conditioned zones is well planned, so that it does not lead to energy waste. It should be noted here that architectural design is a very important part of an integrated approach to environmental design, and this is also true for retrofitting.

3.2. Reduction of direct solar gains

During warm periods of the year, the most efficient way of protecting a building from overheating is to shade its openings from direct sunlight. The type of shade necessary depends on the position of the sun with respect to the part of the building to be shaded. Permanent, movable or seasonal shades can be used, such as overhangs shutters, blinds, awnings and screens (Fig. 3).

Figure 3: Shading for atrium spaces
a) Berlin, Germany, b) Ioannina, Greece.

3.2.1. Fixed shading

Fixed shading devices can differ with the **orientation of the apertures** to be shaded.
South facing windows are best protected by **horizontal overhangs** (Fig.4). The depth of the overhang depends on both its distance above the window and the window height. Besides summer requirements, fixed overhangs should allow maximum benefit from winter solar radiation and this should be taken into account in their design.

Figure 4: Fixed horizontal shading, Fréjus, France [10]

East and west facing windows can best benefit from **lateral shading** (Fig. 19). Fixed screen dimensions depend on the width and height window and the distance of the screen from it. **Sun path diagrams** are useful to estimate the efficiency of each solution.

3.2.2. Adjustable shading

Since **climatic seasons do not correspond to solar seasons,** adjustable shading devices, such as shutters, blinds, venetian blinds, awnings and curtains are more effective for regions with prolongated warm periods (Fig. 18). Shading effectiveness is expressed by the **shading coefficient,** defined as the ratio of solar energy passing through a protected opening to the energy passing through the same opening if unprotected.

A movable shading system, should be designed so as to minimize unwanted solar gains but not darken living space, and force occupants to use artificial lighting. In general, **shading is preferable on the exterior of a building,** so that most sunlight can be reflected before it reaches the glazing. Internal screens do not stop solar rays until after they have passed through the window, so that both the screen and the air between it and the window heat up. Shades can be placed between two layers of glass in a double glazed unit, thus avoiding maintenance problems. The colour and texture of shades as well as their reflection and absorption properties regulate the amount of solar radiation reaching a building, interior.

3.2.3. Environmental shading

In the design of individual buildings and their surrounding spaces, it is possible to use existing **neighbouring constructions** to stop unwanted solar radiation. This is observed in hot, dry climates where whole towns are built in a very compact form, so that most buildings can be shaded without hindering natural ventilation.

The **topography** of a place, can also contribute to shading and this should be taken into account in assessing the environmental performance of an existing building. Shading by topography, depends on the sun path, orientation and slope of the land.

Vegetation is very important for the reduction of overheating in an around buildings and if combined with the use of water and local breezes can create a cooling effect due to the **microclimatic treatment** of the surrounding landscape (Fig. 5). Deciduous planting should be preferred, since progressively increasing by growing foliage shade is created from spring onwards stop only bare tree blocks out some 20-40% of the sun’s rays.

Figure 5: Environmental cooling through microclimatic treatment F.L. Wright, Falling Water, Bear Run, USA [14]

3.3. Reduction of external heat gains

In the summer, the building envelope is heated by the sun and the warm outside air, resulting in overheating. This can be improved by the use of passive strategies, including insulation, reduced window size, thermal mass, reflection, and compact site layout.

3.3.1. Transmission gains

Reducing heat flow through a building envelope by increasing the **insulation level** can be used to prevent summer overheating by conduction.

Besides, insulation, transmission gains can be reduced by appropriate use of the **thermal mass** of the building envelope, **light colouring** of the building exterior or use of a reflecting material as a **barrier** to reflect radiation away from the building. As discussed above, the surface area of the building envelope is also reduced by means of a **compact urban layout**, often found in hot and dry climates (Fig. 6).

Figure 6: Reduction of external heat gains in the Mediterranean climate

3.3.2. Thermal mass

The exterior surface of the building envelope absorbs part of the incoming radiation radiation and converts it to heat. Part of this heat is conducted through the envelope at a rate which depends on the thermal mass of the material. This creates a **time delay** in the flow of heat through the building envelope, which can be exploited in a heavyweight building for **cooling purposes**. This is particularly helpful in hot, dry climates where daily variations in external temperature are significant. At night air temperature inside the building is higher than the temperature outside. The heat flow to the outside eventually decreases the temperature of the building envelope thus eventually cooling the interior (Fig. 7).

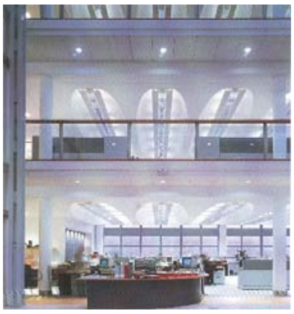

Figure 7: Thermal mass in a public building, PowerGen, UK [8]

The thermal mass of a building influences its thermal behaviour depending on its **distribution** in a given space,

and its position w.r.t. incoming solar radiation. All materials contribute to the thermal mass of a building, including furnishings, due to their large thermal coupling with the building space. In a building with direct gains, the **position of thermal mass** is important for its effectiveness. We can distinguish three types of thermal mass in relation to the absorption of energy from the sun: primary or direct, secondary or indirect and tertiary or remote thermal mass.
The relative effectiveness of these three classes is shown on Fig. 8. It is clear from this picture that recent practice in lightweight floor and suspended ceiling construction for office buildings results in minimising both primary and secondary thermal mass.

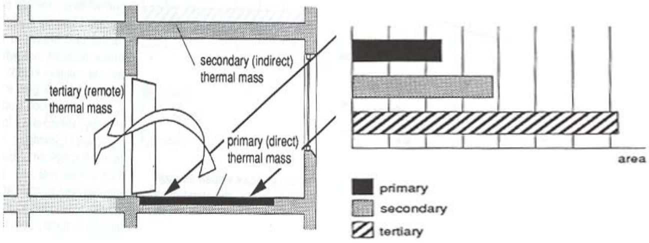

Figure 8: a. Classification of thermal mass,
b. Relative areas of exposed thermal mass surface for equivalent effect [4]

3.4. Natural ventilation

If in spite of the reduction of external gains, the air inside the building is warmer that the ambient air, **natural ventilation** is required to introduce cooler fresh air into the building. To do this it is possible to use the **stack or chimney effect** by providing openings as the top and bottom of the building. The warm air will rise naturally and escape from the top outlet while cooled fresh air will enter through the openings at the base. This can also be achieved by the use of a **sunspace or atrium**, or the provision of **cross ventilation** to help dissipate warm air and replace it by cooler air.
Wind pressure effect can also increase the dissipation of heat from a building due to the pressure difference between its exposed and sheltered sides. Finally, the **Venturi effect** can induce air circulation through a building, forcing it to flow through a narrow opening. This can be used to create **wind channels** in towns by the appropriate positioning of buildings or other obstacles (fences, walls or plantations) to guide wind flow to certain directions, thus affecting microclimate.

3.4.1. Night ventilation cooling

Night ventilation is useful in hot weather, in **massive buildings** with **high internal gains**. The building structure, should be massive enough to store the cooling effect of night ventilation until the building is occupied during the next day. **The users should also be in contact with the cooled mass** as much as possible**.** This may conflict with acoustic or other considerations in modern open plan office layout.
In favorable circumstances, night-time ventilation can be driven by natural forces. Wind pressure would require a reliable night-time breeze whereas thermal buoyancy or ”stack effect” would require generous temperature differences, considerable stack heights and large areas of opening to get significant volumes of air through the building (Fig. 8).

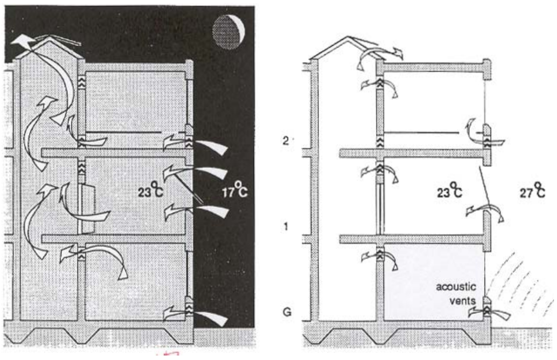

Figure 9: Options for air-flow paths for night and daytime ventilation [4]

Where neither of the above natural conditions prevail, mechanical ventilation must be used. If the daytime mechanical ventilation equipment can be used at night this may still prove to be an economical solution. However, the energy cost of the fan power must be considered in relation to the cooling achieved (Fig. 10).

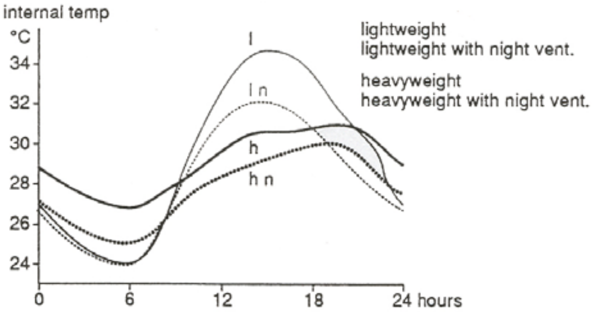

Figure 10: Response of building to night ventilation from computer simulations. Source: Szokolay.

3.5. Natural cooling

The use of natural cooling techniques such as **evaporative cooling, ground cooling** and **radiative cooling** can enhance comfort in warm periods of the year, while their combination with selected environmental or user-related parameters can lead to an improvement in the occupants perceived level of cooling either by natural or by mechanical means.

4. Advantages and disadvantages

Passive solar strategies of overheating reduction have considerable advantages of low cost, durability in use and sensitivity to outdoor conditions if properly designed. They can also substantially contribute not only to lower energy costs but also to achieve a comfortable and healthy indoor envrionment, provided the user can be in charge of directly or indirectly controlling their operation according to his needs and wishes.

5. Costs

Although cost can vary depending on the solution and material selected, especially as far as shading components are concerned, it usually ranges within an average of 10-15% of the total building cost.

6. Maintenance and service

Both thermal mass and fixed external shading need little maintenance if used in average circumstances. In case of operable external and internal shading, a greater attention to correct handling and maintenance is required. Maintenance service is normally assured by installers for the initial period of operation.

7. Best practice examples

Some examples of non-domestic buildings where low-energy strategies combining thermal mass, solar control and natural ventilation are used in order to improve energy performance of buildings by reduction of overheating as well as internal air quality and comfort are briefly discussed below both for new and existing public buildings [9-11].

The projects discussed below use a **holistic approach**, resulting in a positive interaction between the architectural features and the environmental retrofitting strategies used, in order to achieve solutions of low environmental impact, well adapted to users' needs and presenting high levels of air quality and comfort.

The spatial distribution of a building and its dimensions and orientation are crucial for the choice of the **natural ventilation strategies** to be used. As noted in [12] natural ventilation strategies can be based on morphological characteristics of a building according to its spatial configuration, so that different types of space-related ventilation systems can be distinguished, such as: a) transition spaces, b) stack devices, c) ventilation shafts and d) façade-ventilation, including "double-skin" façade.

7.1. Grove House at Thames Vallee of Grove House, U.K.

A new natural ventilation concept fully integrated to the architecture of the building was central to the energy retrofitting strategy of **Grove House at Thames Valley University, UK.** Renovation of the building included a change in use, from offices to classrooms and computer laboratories, while both the external appearance of the refurbishment and its energy retrofitting strategy were vital for project implementation: the first because the building lies in a conservation area, the second to help the University maintain its Energy Efficiency Accreditation (Fig. 11).

The building acts as a pilot for its integrated environmental retrofitting system. It includes a **passive stack** and **façade-ventilation** system, as well as **night cooling**, vacuum tube solar thermal panels, more efficient heating and lighting systems with BMS controls and waterless urinals.

The **mixed-mode ventilation** is well integrated to this **heavy-mass** building with no problems to its façade: windows have been replaced to include air inlet grilles and the suspended ceiling in each laboratory is altered so that an air plenum is formed between it and the existing building concrete slab, from where fresh air is supplied to the building. The air is then drawn across the rooms into the corridors through acoustically treated vents and finally to the stairwells used as passive stacks to draw stale air out via roof mounted terminals (Fig. 10).

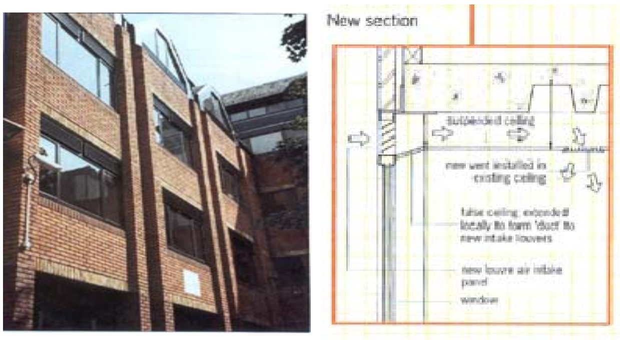

Figure 11: a. South-façade after retrofitting
b. Detail of the new suspended ceiling [11]

Night cooling works in the reverse way to lower the temperature of the large ceiling concrete mass, while wall transfer grilles are placed throughout the building to allow the flow of air. The system is very successful both from the point of view of environmental impact and water conservation and has low maintenance and running costs, while it required no structural alterations to this very sensitive building. Due to this combination of heavy mass building and cross and stack ventilation there is improved air quality, internal temperatures are substantially reduced in the summer, while large ventilation openings create no drafts in cooler periods.

7.2. PowerGen Headquarters, Coventry, U.K.

The PowerGen Headquarters building belongs to a new generation of low energy, naturally ventilated office buildings using passive strategies to improve internal comfort. The building is arranged on three floors on both sides of a long **atrium**.

The exposed coffered concrete frame of the main structure is used to modify the building's internal climate through its **mass**. Three combined stair towers and business centres in the atrium help encourage social contact and improve internal communications (Fig. 12).

Figure 12: South façade and internal courtyard of the building
Bennets architects [10]

7.3. School of Philosophy, Ioannina, Greece

In the Ioannina School of Philosophy in Greece the centralized open courtyard was transformed into an atrium space serving as a winter garden and circulation space with occasional recreation uses (Fig. 1,3).

The retrofitting energy saving features are composed of:

a) a centrally located, **covered atrium**, formed by a solar roof specially designed to meet both heating and cooling needs of the building around it, and

b) a low temperature, long-term heat storage system, using earth as the storage medium and comprising an array of 27cm diameter PVC pipes placed at a depth of 1.5m under the atrium ground surface [13].

The covered atrium has a surface area of approximately 900m2 and an average height of 13m, while each underground heat storage pipe has a length of 40m.

This project has been partially financed by the EU as a THERMIE research project involving design, construction and monitoring of the innovative energy efficient systems involved (Fig. 13).

Figure 13: Ioannina School of Philosophy: View of the atrium roof from S.W. [13]

7.4. Inland Revenue Centre, Notingham (Great Britain)

The Inland Revenue Complex is a new office campus of courtyard and L-shaped buildings. Its many energy-saving features are based on the minimum application of air-conditioning systems. The design makes provision for effective **solar screening**, increased use of daylight by **light shelves** and independently-operated blinds. The building is mainly **naturally ventilated** through the perimeter walls. Stair towers act as stack-effect flues to assist in ventilation. The floors are exposed internally and provide **thermal storage** and a light-reflecting surface. The whole complex is heated by an existing district heating system fed from a refuse incineration plant. The overall energy target is 110kWh/m^2 per annum (Fig. 14).

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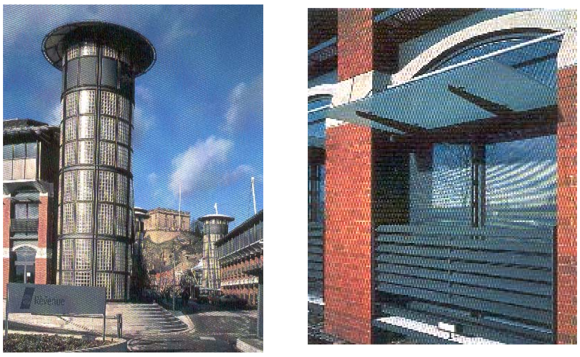

Figure 14: Vent towers and shading elements of the building

7.5. Egebjerg School, Ballerup, Denmark

The retrofitting of Egebjerg School in Ballerup, Denmark, combines modern heating and ventilation technologies to achieve a healthy indoor climate at a reasonable cost, using ecological materials and **natural ventilation** of spaces. The integrated design concept developed from a close cooperation between architects, engineers and consultants, and the resulting innovative ventilation system profits from the existing crawl space and double height common assembly room, to achieve pre-heating and cooling of ventilation intake and operation of a ventilation chimney for extract air. Another innovative feature is a natural lighting and ventilation collector, integrated to the roof of each classroom (Fig. 15).

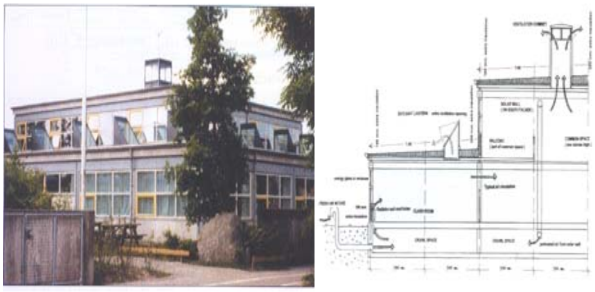

Figure 15: a) North view of Egebjerg School,
b) Section of the school showing ventilation principle [11]

7.6. Queen’s Building, De Montfort University, U.K.

The 10,000m^2 Queen’s Building accommodates a complete University School of Engineering and Manufacture, with some 2000 staff and students. The building is almost wholly naturally lit and naturally cross-, and stack-ventilated; narrow section elements, with free elevations on two or even three sides, so as to optimize daylighting and maximise matural ventilation and cooling (Fig. 16).

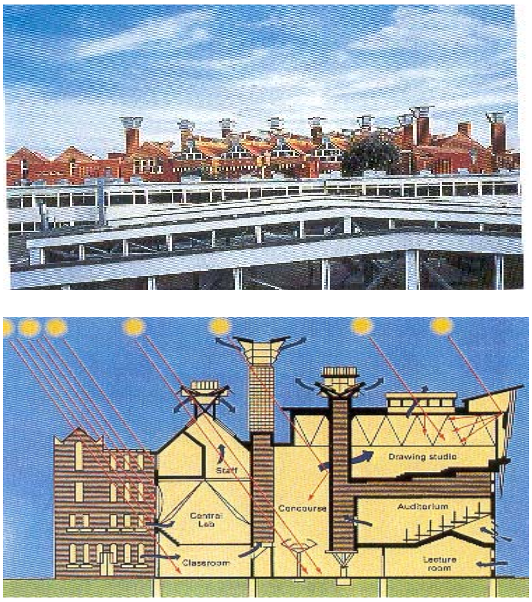

Figure 16: Overall view of the building and operation diagram of the system – Ford & Short, Architects [10]

7.7. The Ionica Building, Cambridge, U.K.

The new headquarters for the telecommunications company Ionica at Cambridge demonstrates the principle of environmental control by passive strategies, creating a low-energy, mixed-mode office building. It achieves occupant comfort by combining natural ventilation with a mechanical system.

The building operation depends on the use of wind and solar-driven ventilation, thermal mass with night-time cooling, ventilation machinery for peak-lopping in mid-summer and mid-winter, and a sophisticated computer control system.

The Ionica building won the 1995 RICS award for Energy Efficient Building of the Year (Fig. 17).

Figure 17: Main façade of the building - RH architects [9]

7.8. The Avax Office Building, Athens, Greece

The main aim in the thermal design of this building was to minimise the use of air-conditioning by use of a **passive ventilation strategy,** combining the following energy saving techniques:

- control of the building cooling loads by use of **external shading** and minimizing internal gains, especially from artificial lighting
- **“pre-cooling”** of the building with night **ventilation**
- use of manually controlled **ceiling fans**
- use of a central cooling system (air/water heat pump) if necessary, combined with a **cold storage system** (ice banks)

The system is controlled by a central dBuilding Management System which can limit the cooling load by operating solar shading and night ventilation. Occupants cooperate in the energy minimization strategy by opening windows and using the ceiling fans of air-conditioning units when required. (Fig. 18)

The Avax office building in Athens was part of the “Energy Comfort 2000” project of the THERMIE programme of the European Commission DG XVII.

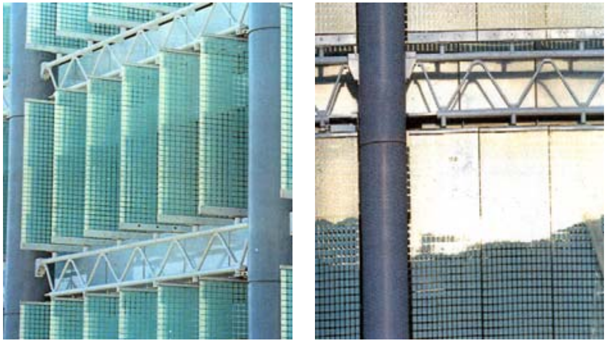

Figure 18: External shading system: a. Fins open, b. Fins closed. A. Tombazis, architects [15]

7.6. EDF Regional Headquarters, Bordeaux, France

This new regional headquarters in Bordeaux for the state electricity company is designed as a showpiece for the **innovative use of electricity**. Thanks to the ingenious application of **natural ventilation** and other **energy-saving devices** appropriate to the warm climate of southern France, the building is expected to have an energy consumption approximately 30 per cent less than buildings of a similar type in France.

The building envelope minimizes heat gain and loss and is fitted with bleached cedarwood louvres, which provide shade without obscuring views out. **Internal heat gain**s are reduced by restricting heat-producing office equipment to a central air-conditioned zone.

Natural ventilation is used where possible. The **thermal mass** of the exposed concrete ceiling soffits helps maintain comfortable interior temperatures during the day. At night the windows on the east and west sides open automatically, allowing air to cool the concrete.

The energy-efficient water-based heating and cooling system is run by an electric heat pump that works off a centralized exhaust stack. The water-cooled floor is kept at the ambient temperature of 20^{o}C in summer and 22^{o}C in winter. Natural lighting is employed as much as possible (Fig. 19).

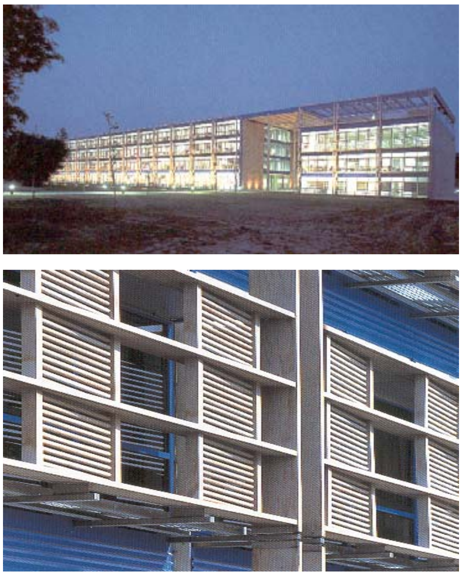

Figure 19: Main facade and permanent external shades N. Foster architects [9]

7.7. BRE Office of the Future Garston, Hertfordshire, UK

The Office of the Future is located at the Building Research Establishment (BRE) in the outskirts of London.

The offices are arranged on three storeys, with their main axis aligned close to east/west. The building envelope is well insulated, with low emissivity argon-filled double glazed openable windows making up about 50 per cent of the main facades. These have **external motorized glass** louvres on the south side to screen the office-space from the sun. Trickle ventilation is provided by BMS control of high-level windows, with manual trickle vents on the top floor (Fig. 20).

Figure 20: South facade and shading elements of the Building - F. Clegg architects [9]

The floor-to-floor height is 3.7 metres, while the undulating concrete floor slab incorporates raised access floor panels, large low resistance voids for air movement, and panels of under floor heating and cooling pipes. Outside air, controlled by BMS-operated windows can enter the rooms directly (at “high points” in the slab) or enter the voids in the structure (at the slab’s “low points”).

8. Calculation tools

TRNSYS software as well as other calculation tools, such as SUNCODE can be adapted to include passive cooling simulation for buildings. Simpler tools such as L-T or Method 5000 can be used by designers for an overall estimation of the cooling performance of a building at an early stage of the design procedure. It is expected, however, that the new CEN regulations for cooling, will be adopted by most countries as part of the EPBD so that a new standard will soon be available in this area.

9. References

9.1 Compilation

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10 Disclaimer