 

# PASSIVE COOLING - STATE OF THE ART

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ABSTRACT. This paper summarizes the results of an horizontal study on Passive and Hybrid Cooling for buildings, carried out by the authors, on behalf of the EEC Research Program "Building 2000" /1/. The state of the art of the strategies for the prevention of thermal gain is presented. Also the existing situation on the design tools and the computational methods regarding the Passive and Hybrid cooling techniques and components is analysed. Finally the data of several designed and constructed buildings in Europe using Passive and Hybrid cooling techniques and components are given and analysed.

## 1. INTRODUCTION

The major objective of the cooling strategy in a building is to provide comfortable internal conditions at a minimum cost. The overal strategy is based on the prevention of overheating as well as on the promotion of heat losses. The approach is illustrated in figure 1.
Equally, as with passive solar heating and passive solar design the study and application of passive cooling is a multilayered and multidisciplinary process. It is especially important to treat the subject in conjuction with other aspects of architectural design strategy. From such viewpoint passive cooling processes should be considered not as isolated phenomena but in close relationship to building types, occupancy patterns and the sources of heat gain to buildings in the climatic conditions of Europe.
Therefore the main objective of this paper is the critical reconsideration of the purposes and functions of the known cooling strategies in the light of present knowledge of building physics and environmental design, and not the presentation of novel techniques.

## 2. THE CLIMATIC ZONES

The Mediterranean climatic conditions are characterized by moderate high and low temperatures during the annual cycle. The design dry bulb temperatures for nine Mediterranean cities are given in figure 2 /2/. These climatic conditions require a proper balance of the design strategies on passive heating natural cooling and daylighting in buildings. Therefore passive strategies in the Mediterranean should not be approached singly, but in the context of an overall environmental design strategy.

## 3. PREVENTION AND MODULATION OF HEAT GAINS

The prevention and modulation of the heat gains involves consideration of the following design measures :
- Thermal insulation
- Storage mass
- Solar control and shading of building surface
- Landscaping and the use of outdoor and semi-outdoor spaces
- Building form, layout and external finishings.

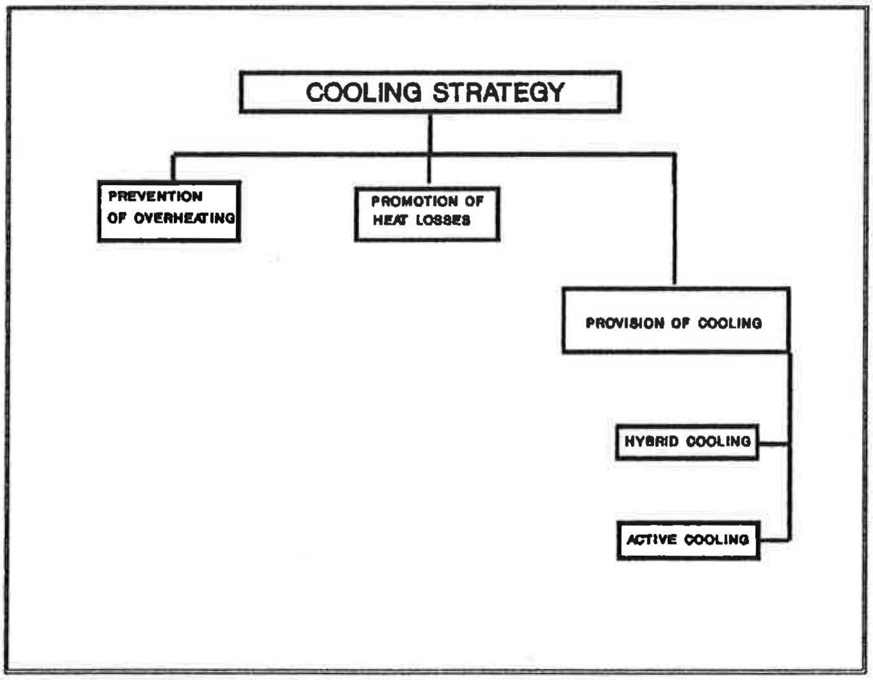


Figure 1 : The Cooling strategy in buildings.

Such measures tend to be generally applicable under all types of climate and site conditions and are relevant to all building types.

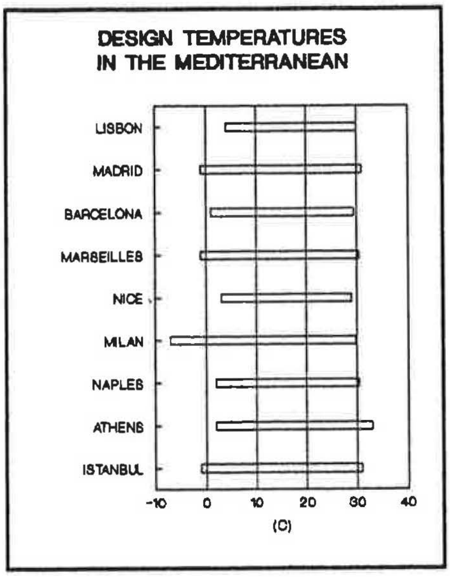


Figure 2: Design Summer and Winter Temperatures for Nine Mediterranean cities.

3.1. The role of the thermal mass

The capacity for heat storage in the building structure offers a "daily strategy" providing attenuation of peaks in cooling load and modulation of internal temperature with heat discharge at a later time.The larger the swings in outdoor temperature, the more important the effects of such storage capacity. However, when auxillary heating and cooling systems are used, an increase of the mass over a threshold value can increase the load. Therefore the determination of the optimum thermal mass taking into account the winter and summer performance of the building is necessary. The influence of the thermal mass on the energy performance, of the building during winter and summer in Israel is discussed in /3/.
The question if it is better to have the thermal mass as a part of the external walls or as an internal partition has many architectural, implications and influences highly the performance of the building. The results of such an investigation are given in /3/.
However it should be pointed out that there are not standarts on the optimum depth and the placement which take into account the Summer and Winter operation of the building.

3.2. The role of shading

Minimizing heat gains is the first design rule in any passive cooling application. Increase of the shading levels decrease directly the cooling load of the buildings but in the same time the lighting level is increased. Overshading reduces also the amount of solar energy penetrating through the window in winter increasing so the winter heating load. Therefore the problem of optimal window shading devices, taken into account heating, cooling and daylighting, arises in the Southern European Countries. An interesting method to define the optimum shading levels for a building in Israel, using intergral criteria, is proposed in /4/.
However, it should be pointed out that there is no criteria for optimal shading levels which take into account the heating and cooling performance of the building and the lighting requirements as well.

3.3. The role of the building form and shape

The architectural configuration of the building enclosure can be a major factor in preventing heat gains and encourages losses.
An important discussion on the building form, in order to achieve the best proportion for heat gains and heat losses is given in /5/.
However questions like :
- What is the best volume to surface ratio
- What is the optimum shape and
- What is the optimum spacing

are not systematically answered and further research on this topic is required.

4. THE PROMOTION OF HEAT LOSSES

The promotion for disposal of excess heat by natural means depend : a) On the availability of an appropriate environmental heat sink for the heat that is to be rejected and b) On the appropriate thermal coupling and sufficient temperature differences for the transfer of heat from indoor spaces to sink.The main processes of passive cooling are identified in the Table below.

| Process | Heat Sink | Heat Transfer node |
|---|---|---|
| Radiative Cooling | Sky | Radiation |
| Evaporative Cooling | Water | Evaporation |
| Convective Cooling | Air | Convection |
| Earth contact Cooling | Ground | Conduction |

The use of the environmental heat sinks for heat dissipation is possible over some climatic threshold conditions while in some cases the heat transfer to sink may be assisted by mechanical devices on a mean of overcoming low temperature differences or other limitations.

4.1. Passive Ventilation

Ventilation provides cooling by using moving air to carry out away from the building or/and from the human body itself. Air movement created by natural forces is due either to wind or to stack effect. Nightime ventilation may offer also a high potential for building cooling because of the lower outside temperature. Experiments using night time ventilation described in /6/, show an important decrease of the daytime indoor temperature.
In designing window system for passive ventilation cooling, four essential steps should be followed /7/. First it is important to have a clear picture of the directional range of the wind on the site involved through both diurnal and annual cycles. Second an assessment on the ventilative cooling needs for thermal comfort should be done. Third the shielding or "wind shadow" effects of the neighboring structures and of the topography should be evaluated. Also it is vital to choose a window type and size which corresponds to both the ventilation and the solar heating, cooling and daylighting requirements of the building.
However, regarding the four above steps, it should be pointed out that winds are extremely variable and weather data, are not available at most sites. Also the answer on the question : "what is the optimum size of the building openings", is that there is no standarts which take into account the balance of heating, cooling and daylighting performance of the building, together with the ventilation requirements.

4.2. Radiative, Evaporative and Ground Cooling

The use of the sky, water and ground as a heat sink for dissipation of the buildings excess heat has gained an increasing importance during the last years. An overview of the theoretical background and a description of possible uses is given in /8/. However the use of these type of cooling is associated with various problems like :

- The definition of the threshold values allowing the application of the sink.
- The definition of the selection and sizing procedure.
- The calculation of the overal building efficiency and
- The luck of information on construction details.

Unfortunately there is an important lack on appropriate climatological data while there is no available design tools for designers as well as information material, handbooks, etc.

## 5. THE DESIGN TOOLS ON COOLING

In order to identify the design tools available for cooling purposes, an extensive survey of the existing design tools for passive solar applications has been performed.
The results of the survey are given in figure 3. Hundred twenty eight programs having capabilities to calculate the cooling load of a building have been found. From them 107 programs come from U.S. However between these programs only 54 can calculate the cooling load and the variation of the space temperature as well. Also it is found that 67 programs can simulate the effects of mass, while 65 programs take into account and simulate the effects of shading devices. However there is only 49 programs which can estimate shading and mass effects together.

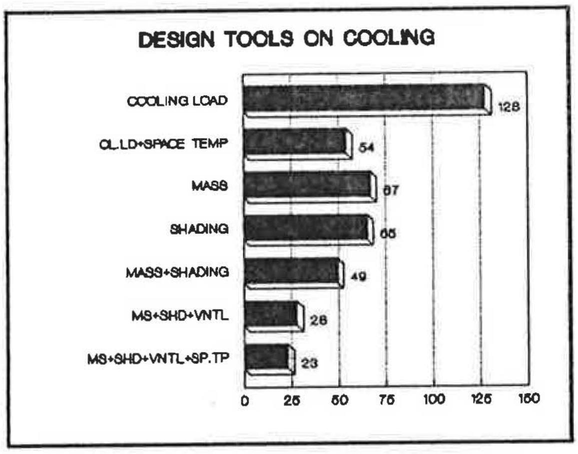


Figure 3: Design Tools on cooling Classification regarding the calculation capabilities.

The simulation of the various natural ventilation strategies is performed by a very small number of tools. It is found that there are 28 programs which simulates the natural ventilation strategies and in the same time, take into account the shading and mass effects.
Finally there are 23 programs which can considered as "complete programs", which calculate the cooling load and the space temperature variation,while take into account the mass and shading effects and the natural ventilation systems as well.
From the above 23 "complete programs", 8 between them are designed for mainframe computers and are used especially for research purposes. Four of these programs come from the US, two from Switzerland and one from Italy and UK. Also two of the "complete programs" are designed for programable calculators, which come from the US.
Finally nine programs are designed for PC's. Seven of these programs come from the US and two from Greece. Also there are four more programs from the US designed for various type of microcomputers.All the collected information are placed in a data base. An extract of the data base offering important information on the identified design tools is given in figures 3-5.
As it can be seen from these figures there are 113 programs suitable for architects, 123 programs for engineers, 55 programs for techniciens, 28 programs for researchers and 42 programs for builders. The majority of the programs are written for micro's and PC's except the research programs which are mainly written for mainframes.
Also the most of the programs can be used for residential and small commercial buildings. Fifty five of these programs are suitable for the predesign phase, also fifty five for the schematic design phase, fifty two for the design development, 21 for Post design services and 16 tools can be used for research purposes. For the large commercial buildings there are 26 programs suitable for the predesign phase, 39 for the schematic design phase, 47 for the design development, 16 for post design services and 11 for research purposes. Regarding the design tools available to simulate the use of environmental, sinks, three tools managing the evaporative cooling techniques, have been identified. Also there are 42 programs capable to simulate convective cooling techniques, 2 for radiative cooling and 19 for ground cooling.

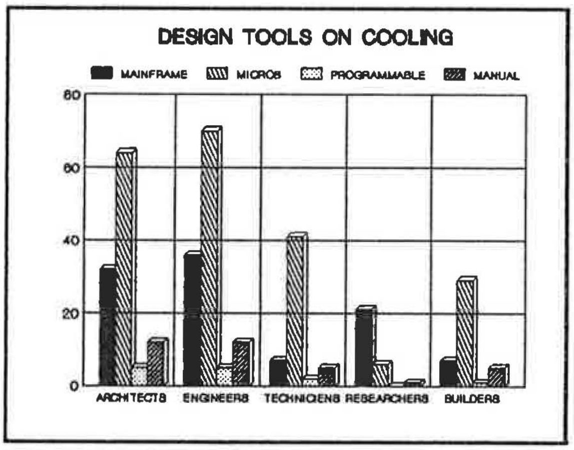


Figure 4: Design Tools on Cooling Classification regarding the computer type and the users.

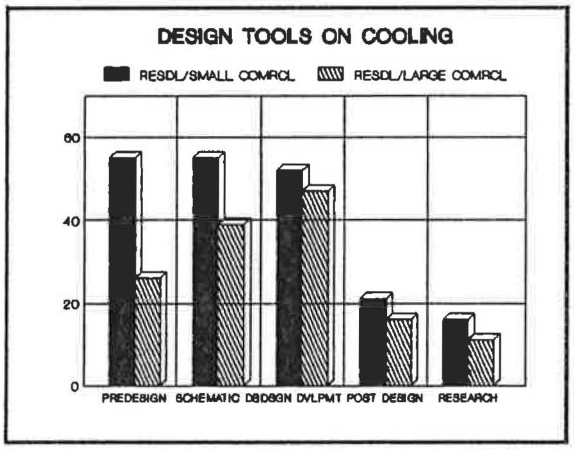


Figure 5: Design Tools on Cooling Classification regarding the design phase and the building's type.

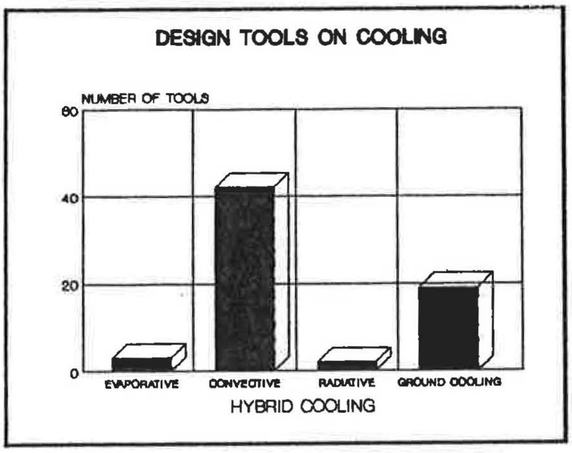


Figure 6: Design Tools on Cooling Classification regarding the heat sink.

## 6. EXAMPLES OF PROJECTS USING PASSIVE COOLING TECHNIQUES AND COMPONENTS

In the frame of the horizontal study on Passive and Hybrid cooling, data from European Buildings which use such cooling techniques and components have been identified. Seven of them are situated in Greece, two in Spain and three in Portugal. Three of the buildings are educational centers, five are hotels and the rest four are residential and commercial buildings.
Six of the reffered buildings are already constructed and six are under construction. All the studied buildings are designed taken into account all the basic principles of bioclimatic design for Summer protection. Therefore the buildings are firstly well insulated and are characterized by increased mass levels and very efficient shading systems.
For all the buildings, ventilation is the more important heat dissipation technique. Cross and stack effect ventilation techniques are used. Also the most of the buildings use cooling techniques based on the use of environmental heat sinks,like the sky, (radiative), the water, (evaporative),and the ground (earth contact).
A layout of the studied buildings as well as the used systems and the cover percentage of the cooling needs is given in figure 7. As it is shown from the above figure, the passive and hybrid cooling systems offer a very high percentage of the cooling needs, which varies from 20 per cent to 100 per cent.
However only two of the studied building are monitored systematically while for the rest of the buildings the cover percentage is the theoretical estimation. For each building a six page brochure has been created, where all the necessary information, like design strategies cooling techniques, energy efficiency, climatological data and cost can be found.

## 7. CONCLUSIONS - FUTURE RESEARCH ACTIONS

In the previous chapters the existing situation in the area of Passive and Hybrid cooling has been described. Various scientific gaps concerning different areas of knowledge have been identified since the new technologies require further theoretical and experimental investigation, while the more traditional ones often need better design tools and performance evaluation criteria. Moreover,several techniques lack practical guidelines to facilitate their use by architects.
Therefore three main areas where scientific research should be developed in order to improve the knowledge and possibility of application of Passive cooling technologies are so identified
a) Solar Control in mild climates
b) Passive heat removal techniques
c) Interaction between building and Environment

### 7.1. Solar Control in Mild climates

Several solar gain techniques have been developed in cold climates, but the application of these techniques in Southern regions requires lot of care, and still large uncertainties do exist in the theoretical and experimental knowledge necessary for the current applications. Among the solar gain techniques and products we consider of interest those that specially challenge the architects skill in southern climates :
- Thermochronic and electrochronic glasses
- Transparent insulation and
- Solar buffering

Therefore a research action in this field has to cover a wide range of aspects, spanning from component and material development to software application for control and design, performance evaluation both in laboratories and field conditions, detailed simulation and components and building behaviour.

### 7.2. Passive heat removal techniques

A considerable amount of research has been devoted so far to the passive heat removal techniques but still several dark areas remain in this area. The theoretical background is quite well known for eg.
- Passive ventilation (wind and stack induced)
- Radiative, Evaporative and buried pipes cooling.

The main obstacle to a larger use of these techniques is the absence of practical desing methods supported by well established experimental evidences. To fill this gap a research activity should gather the existing information, develop significant experiences, collect applications, run detailed simulations comparing results and experiments and finally supply design tools and guidelines.

### 7.3. Interaction between building and environment

The influence of the surrounding environment on the building thermal performance has long be studied. The aim of a research activity should be :
- To reduce the energy consumption and the thermal discomfort
- To improve amenity and to attenuate noise.

Specific studies to be considered are :
- Selection of suitable autochtonous vegetable species, capable of resisting local climatic conditions
- Study of single tree shapes in different periods of the year, identification of leave pront and fall time, evaluation of shading factors
- Study of wind screening effect of natural barriers (earth, banks, vegetation, screens)
- Evaluation of possible landscaping solutions
- Alternative uses of water
- Measurement campaign on existing landscaping applications
- Production of catalogues, handbook, performance indexes.

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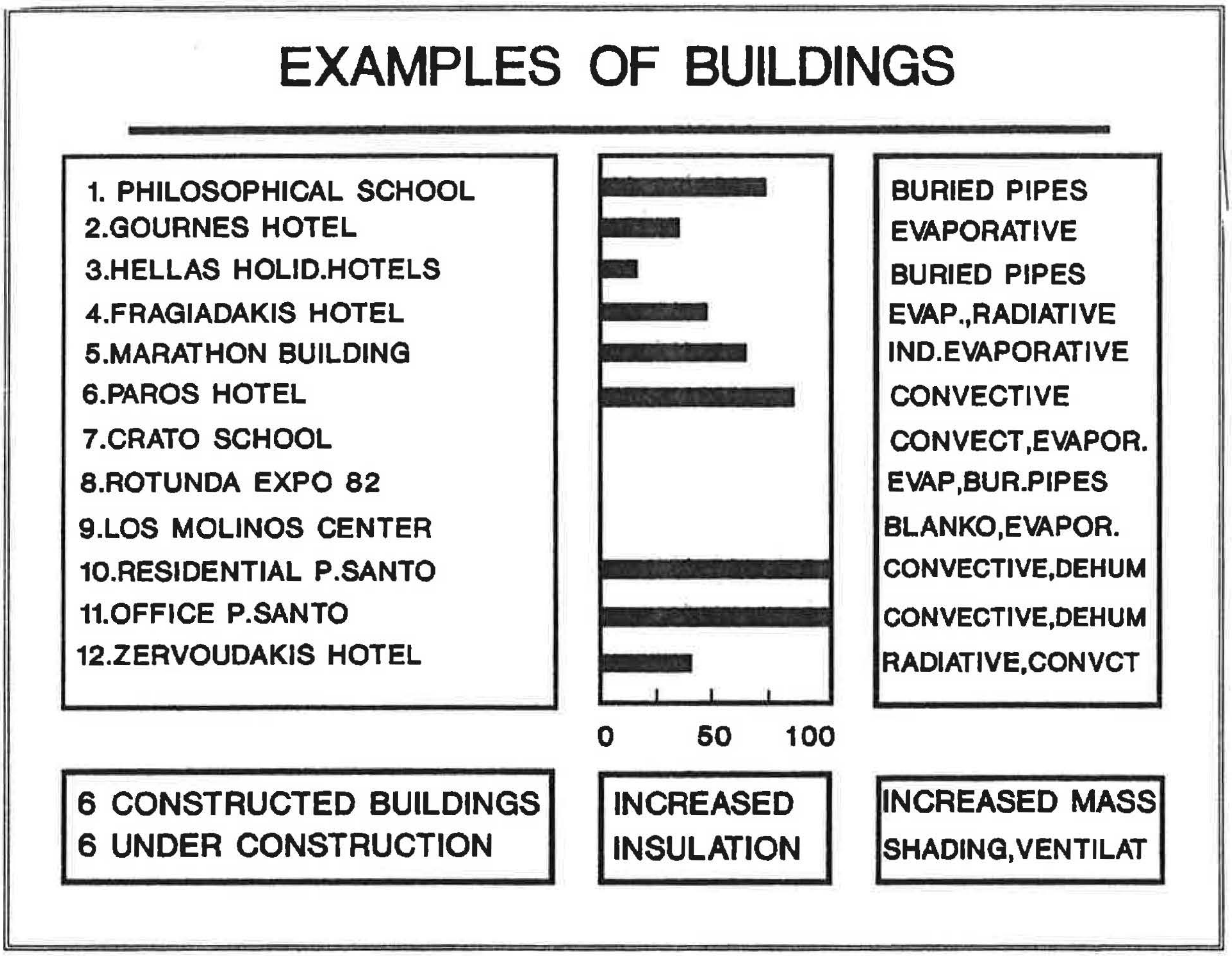


Figure 7: Data of the buildings using passive and hybrid cooling techniques and components.