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THE INFLUENCE OF WATER, GREEN AND SELECTED PASSIVE TECHNIQUES ON THE REHABILITATION OF HISTORICAL INDUSTRIAL BUILDINGS IN URBAN AREAS

A. FERRANTE† and G. MIHALAKAKOU
University of Athens, Department of Physics, Division of Applied Physics, Laboratory of Meteorology, University Campus, Build. Phys-V, Athens GR157 84, Greece

Abstract—The present paper describes a new process for designing and applying selected passive heating and cooling techniques in a large urban area of Legnano, a city close to Milan. The planning restoration process is based on the integration of several natural and man-made factors with the bio-climatic criteria of individual buildings' design. The architectural rehabilitation of two historical industrial buildings, selected as representative in the overall urban renewal of the considered Cantoni urban area, has been considered as an integral part of the whole urban planning process. The buildings' design is further developed using solar passive heating/cooling techniques such as the insertion of an atrium between the buildings and the placement of green roofs on the building's bare coverings. The thermal behaviour of one of the above mentioned buildings equipped by passive heating and cooling techniques is calculated and analysed in the present paper using a transient building's performance simulation program.

1. INTRODUCTION

The need for concerted actions on the environmental question, as reflected in the issues of climate change and depletion of resources, has been officially recognised by the international community in events like the United Nations Conference on Environment and Development, held in Rio De Janeiro in 1992.

The spectrum of environmental dysfunction produced by the use of resources in urban areas ranges from effects at a local level, such as the heat island phenomenon and the air and water pollution, to regional and global effects, such as the global climatic change.

Cities have a disproportionately large impact on the environment, as they inevitably involve the consumption of energy for residential and commercial use. Complex problems in urban and regional planning are thus generated, among them the allocation of resources such as space, energy, water and landscape, the management of solid, liquid and gaseous waste and even the management of time in the increasingly problematic issue of mobility (OECD, 1990).

Air temperatures in densely populated and built areas are higher than those measured in the surrounding rural country. The phenomenon is known as 'heat island' and it is a reflection of the microclimatic changes brought about by man-made alterations of the urban surface (Landsberg, 1981; Oke, 1987). The intensity of the heat island is mainly determined by the thermal balance of the urban region while the temperature distribution at various locations in the urban area could differ by 15°C (Santamouris *et al*., 2001).

Discomfort and unhealthy living conditions caused by high temperatures, wind tunnel effects and undesirable climatic conditions due to wrongly designed high rise buildings are very common (Bitan, 1992).

Urban historical and geometrical constraints, specific legislation regulating urban spaces, as well as the complex nature of the surfaces of urban areas lead to both conceptual and practical difficulties (Nunez and Oke, 1977). Therefore, several factors influencing energy and buildings in urban environments, which impose specific restrictions and priorities not encountered in non-urban areas, have to be considered for improving energy efficiency in urban areas.

The restriction of possible solutions resulting from existing urban constraints is thus combined with the first priority of achieving thermal comfort by natural methods in urban spaces.

Even more than for passive cooling and solar heating in single or isolated buildings, the study and application of natural passive systems on the city environment is a multi-layered and multi-disciplinary process (Ferrante *et al.,* 1996; Santamouris *et al.,* 1996). It is especially important to treat the subject in conjunction with other aspects of physical parameters involving passive and

†Author to whom correspondence should be addressed.

active techniques in relation to architectural and engineering design. For these reasons, the rehabilitation of the urban area should be multidimensional in approach, encompassing enhancements to the physical and the built environment and to the social fabric. Priority should be given to the improvement of the quality of life for residents. Thus, the identity of an area should be enhanced, not destroyed, especially in terms of the cultural heritage and preservation of the positive aspects of existing built and natural environments.

To overcome conflicts between the holistic concept of considering the city as a whole integrated system and the simplified approaches of regarding buildings individually, comprehensive studies on the surface energy balances in urban areas as well as specific knowledge of urban building engineering and architecture applied on reference case studies are required.

The present study is designed primarily to investigate the city as an integrated natural and man-made network and secondly to apply bioclimatic techniques aimed at improving the microclimate in urban open spaces as well as the energy efficiency conditions in the whole urban area.

2. THE EFFECT OF NATURAL ELEMENTS IN THE URBAN RENEWAL OF THE AREA 'CANTONI'

A climatic conscious design of outdoor spaces and the appropriate use of natural components are key elements to reduce the outcome of unsound evolution of urban areas where impermeable surfaces and denuded landscapes determine undesirable climatic effects and unhealthy life conditions.

The first step to avoid these problems is to increase the amount of open spaces and permeable surfaces as much as possible. Thus the climatic efficiency is improved both in open public areas and inside the buildings.

In dense urban environments, characterised by the lack of open spaces among buildings as well as by the relative absence of natural elements, a design strategy to minimise pollution impact should provide spatial separation of environmentally incompatible activities. Therefore the next step consists of investigating and designing, on a smaller scale, the building envelope and the potential of selected passive techniques such as building materials, components and shading devices in order to minimise thermal discomfort both in the open spaces and in the buildings.

For this reason a twofold rehabilitation process is designed for facing the problem of specific restrictions encountered in the central Cantoni area.

- On a larger scale, where open space is available, landscape planning and passive natural techniques are developed for providing an alternative use of green areas, water systems and courtyards.
- On a smaller scale, in densely-built urban zones, passive techniques applied to the envelope of historical buildings are designed to improve the architectural quality and the pedestrian connection among public areas.

The whole urban area consists of a huge amount of historical industrial buildings overlapping green areas and water systems (the environmental channel substantially generated by the river systems Olona and Olonella), for a total length of about 4 km.

The area Cantoni (Fig. 1) is at the heart of the whole area. It is located at the crossing point between the above mentioned natural channel and the historical urban centre. Moreover, it can be regarded as a kind of barrier between the two old historical urban centres Legnano and Legnanello, where up to now Eugenio Cantoni street has remained the only central crossing route between the two parts of the city.

The landscape planning of the whole area is mainly characterised by the re-design of green and water circulation systems; these systems are selected as the most representative among the natural resources of the area in a large scale investigation. The planning process is based on both the natural purification systems, such as algal macrophitic water treatment, and on climatic and biological effects resulting from the rehabilitation process.

In the specific context of the ecological paths crossing the urban area of Legnano, in spite of the high load capacity of the main river Olona, a partial macrophitic treatment containing about 25% of the total water amount is designed. The influence of the above mentioned systems on the landscape and on the urban restoration is remarkable.

The influence of outdoor spaces on the architectural design procedure is described in detail in Bitan (1992) and Tombazis (1995). The approach of regarding the building's volume as the negative counterpart of the positive open spaces working from the outside inwards is applied in the planning and architectural design of the present case study. Therefore, on a smaller scale, the plan of outdoor spaces (even when reduced to the

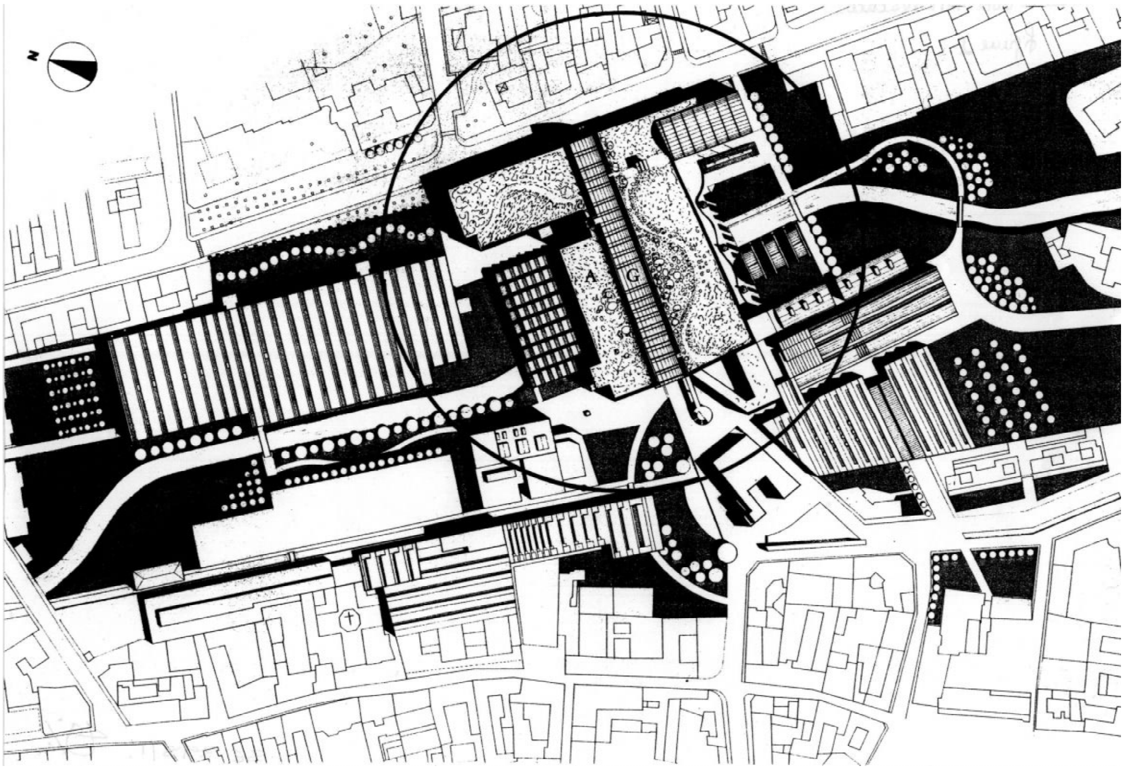

Fig. 1. Plan-volumetric view of the Cantoni area. Inside the circle: on the left, the building (A); in the middle, the atrium (G).

buildings' envelope within existing thickly-built urban areas) and the use of natural elements can be regarded as the main design tools to improve urban microclimate conditions in the urban areas.

The architectural rehabilitation design proposes an alternative scenario to improve thermal comfort conditions and restore natural elements as well as permeable surfaces in the Cantoni area. The open spaces of the investigated area act as the main factors for the identification of the building's external surfaces design. Thus, by re-designing the building's surfaces and elevation facades, the street layout and the plan-volumetric shapes of existing buildings, an alternative scenario is proposed.

The main objectives identified in the urban planning and architectural rehabilitation process of the central area can be summarised as follows.

- Promotion of all forms of passive natural devices according to the potential effects of minimising localised pollution problems and enhancing urban microclimate.
- Increase of permeable surfaces in the outdoor spaces.
- Improvement of solar heating and natural cooling, minimising solar heat gains both in the open spaces and on the building's facades (allowing protection for south-east and south-west facades using shading devices and 'natural filters').
- CO_2 absorption by plants and urban pollutant dispersion by natural ventilation and night cooling.

To meet the above objectives, in the areas where adequate open space is available, the following strategies are proposed.

- Ensure openings from internal green courtyards (where the air is fresher and cleaner) towards public open spaces and buildings' facades.
- Increase permeable surfaces on the pavements thus enhancing the water–green-climate interactions.
- Ensure shading and filtering for the buildings' facades (especially the south-west and south-east oriented ones during the warm period of the year) using vegetation, water ponds and water river extension in pools equipped with macrophitic treatment of waste water.

To provide solutions against the lack of open free spaces between buildings, the following strategies have been set.

- Provide spatial separation between polluted areas and open public spaces by designing a pedestrian walkway in place of the car circulation street crossing the area Cantoni.

- Ensure openings from the pedestrian areas towards the buildings' facades.
- Provide shading and filtering for the buildings' facades (especially on the south-east orientation in the warm summer season and north-west ones in the cold winter season) using selected passive techniques such as winter gardens, pergolas, deciduous trees and curtains.
- Design planted roof gardens on the exposed roofs of the buildings.

The urban area selected for a further definition of the restoration process (Fig. 1) is transformed and restored by developing the following articulate design proposals.

- Partial demolition of the industrial buildings suffering from degradation and unhealthy conditions.
- Re-balance of the environmental processes for the climatic improvement in the free open spaces, such as macrophitic algal treatment and urban green renovation.
- Urban rehabilitation of the main crossing central route between the two historical centres by transforming it as a pedestrian gallery crossing the commercial, social and public activities.
- Insertion of selected passive systems such as an atrium between the two buildings intimately connected to the urban rehabilitation of the above-mentioned gallery.
- Re-design of coverings using the technique of green roofs to improve the buildings' thermal inertia and to increase the system cooling potential during the warm period of the year.

A couple of buildings along the main route of Cantoni are selected for a further solar heating and cooling restoration. For this reason, two principle bioclimatic architectural techniques are used.

- The insertion of an atrium between the two buildings in relation to the urban and pedestrian restoration.
- The re-design of coverings and roofs using the idea of green spaces on the exposed roof of the buildings.

3. THE ATRIUM AS A PASSIVE HEATING/ COOLING SYSTEM

The transformation of an area with a lot of traffic like Cantoni into a pedestrian commercial gallery can be regarded as the main urban-scale input in the architectural rehabilitation of the selected buildings.

The atrium may contribute significantly to the energy balance of the buildings as well as to the thermal performance of the open public space itself (Goulding *et al*., 1986). The glass covering systems between the two buildings lead to a thermally compact building with reduced heat losses during the winter period (Fig. 2b), while the passive gained solar energy can be very useful.

To achieve an improved thermal performance in the winter, that is to gain heat from solar radiation, the atrium is considered closed by two glazed entrances. However, to avoid undesirable overheating during the summer period of the year the following bioclimatic techniques are used.

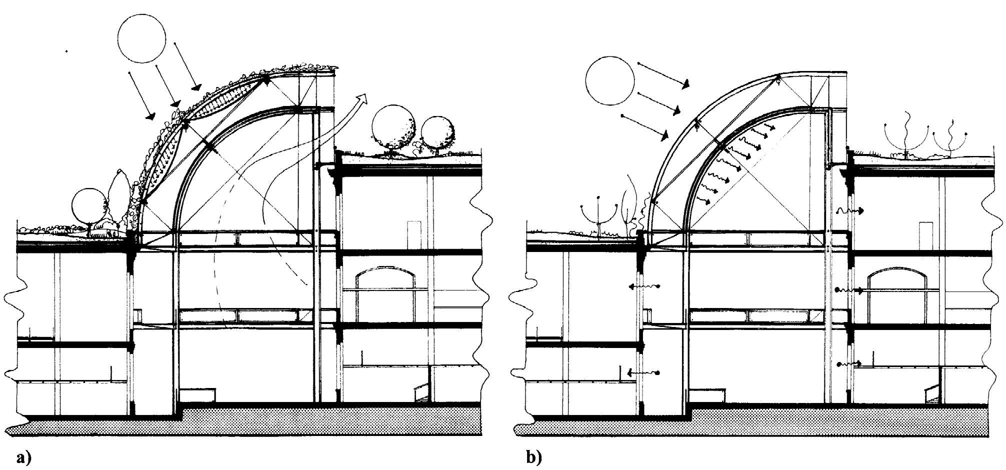

Fig. 2. (a) A cross section of the atrium showing the thermal performance of the compacted buildings during the warm summer period of the year. (b) A cross section of the atrium showing the thermal performance of the compacted buildings during the winter period.

- The openings of the above mentioned glazed entrances should facilitate ventilation techniques during the summer. Additionally, the openings at the top (Fig. 2a) are designed for hot air extraction. The outdoor air is allowed to enter inside the atrium and remove the stored heat which is trapped during the day. Also, the air movement should provide a considerable increase of heat dissipation from the building materials, and the warmer air is exhausted into the low temperature atmospheric heat sink (Evans, 1957; ASHRAE, 1976, 1991).
- Insertion of curtains as additional selected passive systems addressing the cooling need of the buildings and the atrium during summer. These shading devices could be useful for avoiding the overheating process, by reducing direct solar gain.
- Insertion of a secondary grid on the shell of the atrium, made up of steel and wood. This grid is designed to provide adequate structural support to the deciduous plants coming up from the green top of the lower building, in order to achieve a further improvement of thermal performance during summer.

4. THE PLANTED ROOF GARDENS

Plants have a strong effect on climate. Trees and green spaces can help cool our cities and save energy. Trees are able to provide solar protection to individual houses during the summer period while evapotranspiration from trees can reduce urban temperatures. Trees also help mitigate the greenhouse effect, filter pollutants, mask noise, prevent erosion and calm their human observers. Moreover, evapotranspiration from soil vegetation systems can remarkably reduce urban temperatures. Shading from trees is an effective way for reducing significantly the energy for cooling purposes.

Results of computer simulations aimed at studying the combined effect of shading and evapotranspiration of vegetation on the energy use of several typical one-storey buildings in US cities showed that by adding one tree per house, the cooling energy savings varied from 12 to 24%. Moreover, three trees per house can reduce the cooling load between 17 and 57% (Akbari *et al*., 1997). The direct effects of shading account for only 10 to 35% of the total cooling energy savings. The remaining savings result from temperatures lowered by evapotranspiration.

The evaporative and transpiration cooling effects of plants are used to pre-cool ventilation air, for buildings and open spaces. Furthermore, dense vegetation helps filter particles from air.

The technique of planting green gardens is used to re-design the roofs in the main buildings of the Cantoni area. Planted green roofs on the exposed roofs of the buildings represent an ecological solution contributing not simply to the reduction of the thermal loads of the building's envelope, but to the improvement of microclimate in densely built urban areas.

The heat transfer processes in a planted roof present significant differences in comparison with the normal processes in exposed roofs: the air temperature and the relative humidity are reduced as the air passes through the foliage covering the roof. The plants, because of the biological functions of photosynthesis, respiration, transpiration and evaporation, absorb a significant proportion of solar radiation, creating a protective layer and thus reducing the ambient air temperature during summer.

Therefore the gardens on the roofs of buildings can remarkably improve the thermal performance of the whole area and offer a public refreshing urban space overlooking the city centre. Fig. 3 shows a detailed section of a roof garden.

5. THERMAL PERFORMANCE CALCULATIONS

To assess and quantify the expected climatic improvements, the thermal behaviour of the atrium as well as of a representative industrial building of the Cantoni area is calculated using TRNSYS (1997). TRNSYS is a transient system simulation program with modular structure which facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. Building A (Fig. 1) is taken as the representative building selected for the calculations. The whole building is considered to be one thermal zone, $(20 \times 20 \times 3.2)$, with the floor on the ground and with internal partitions. Climatological sets of measurements of the city of Legnano, and various representative days, have been selected for the thermal performance calculations. Analytically, hourly values of the following climatic parameters were used in this research.

- Ambient air temperature (°C).
- Global solar radiation (W/m^2).
- Diffuse solar radiation (W/m^2).
- Relative humidity (%).

The ventilation rate was taken to be equal to

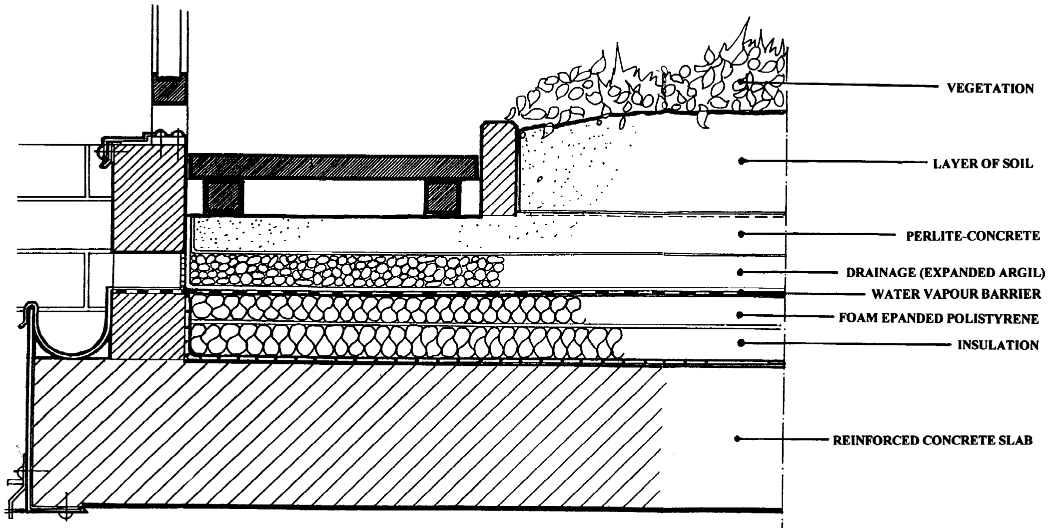

Fig. 3. A detailed section of a roof garden.

four air changes per hour for January and 12 air changes per hour for July.

The indoor air temperature values of the above building are calculated primarily without using any passive or conservative heating/cooling system. Furthermore, the calculations are extended taking into account separately the influence of the atrium and the influence of an insulated green roof on the building's thermal behaviour. Finally, the combined case-scenario of both atrium and insulated green roof is considered for the indoor air temperature calculations.

Figs. 4 and 5 show the indoor air temperature values of building A for two representative days in July and January 1995 (2nd of July and 14th of January, respectively). In these figures, the indoor temperatures calculated for the following four scenarios are shown.

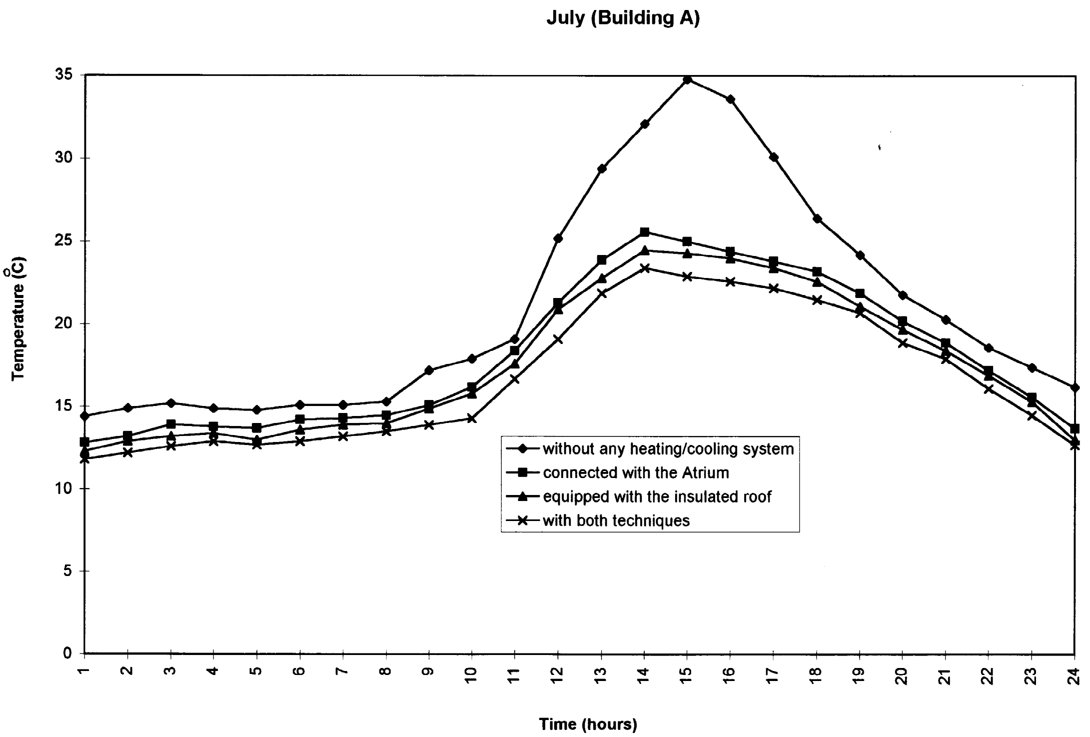

Fig. 4. Indoor air temperature values of building A for a representative day in July 1995 for the four considered scenarios.

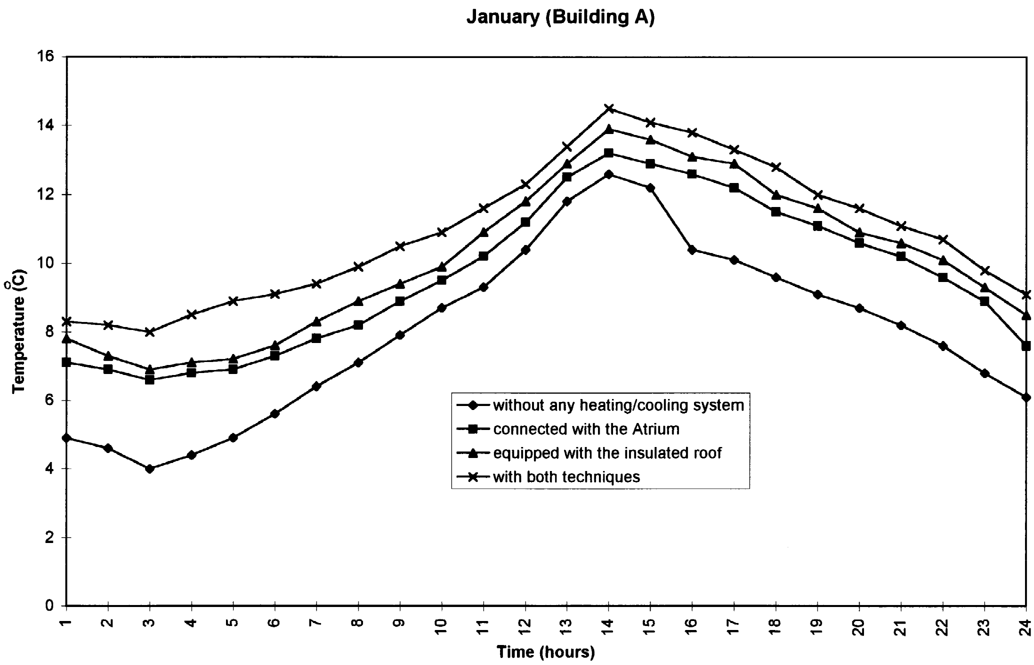

Fig. 5. Indoor air temperatures of building A for a representative day in January 1995 for the four considered scenarios.

- The building is not equipped with any heating/cooling system (initial scenario).
- The building is connected with the atrium.
- The building is equipped with a thermal insulated green roof.
- The building has the thermal insulated green roof and is connected with the atrium (combined scenario).

From these figures it can be seen that the indoor air temperature values for the representative day of July varied between 14.4 and 34.8°C for the initial scenario, between 6.6 and 13.2°C for case 2, 7.1 and 13.9°C for case 3 and between 8 and 14.5°C for the combined scenario. Similarly, for the representative day of January, the indoor temperatures fluctuated in the range of 4–12.6°C for the first case, in the range of 6.6–13.2°C for case 2, in the range of 7.1–13.9°C for the initial scenario and in the range of 8–14.5°C for the combined scenario. Thus, the more effective method for heating/cooling building A was shown to be the combination of the atrium with the insulated green roof, while the insulated roof was shown slightly more effective than the atrium. Figs. 6 and 7 show ambient air temperatures as well as the air temperature values inside the atrium for the same 2 representative days of July and January, respectively. As shown, the ambient air temperature varied between 13.8 and 35.6°C for July and between 3.6 and 10.6°C for January while the temperature inside the atrium fluctuated between 10.6 and 23.8°C for July and between 6.7 and 14.2°C for January.

6. CONCLUDING REMARKS

An integrated planning and design process for the environmental and climatic rehabilitation of urban areas is presented in this paper. The methodology is essentially based on a twofold rehabilitation procedure considering both landscape planning methods for the alternative use of natural resources and passive techniques for the improvement of the thermal performance of historical buildings.

The architectural approaches proposed in the present case study are based on several passive heating/cooling techniques and on fundamental natural resources such as green and water systems to improve microclimate in the urban areas. The thermal performance of the atrium and of one historical building is calculated for 2 representative days of summer and winter period.

From the obtained results it is found that:

- as expected, the air temperature inside the atrium is satisfyingly higher than the ambient temperature in winter and similarly lower during the summer. Thus it is shown that the commercial gallery is a comfortable public open space;

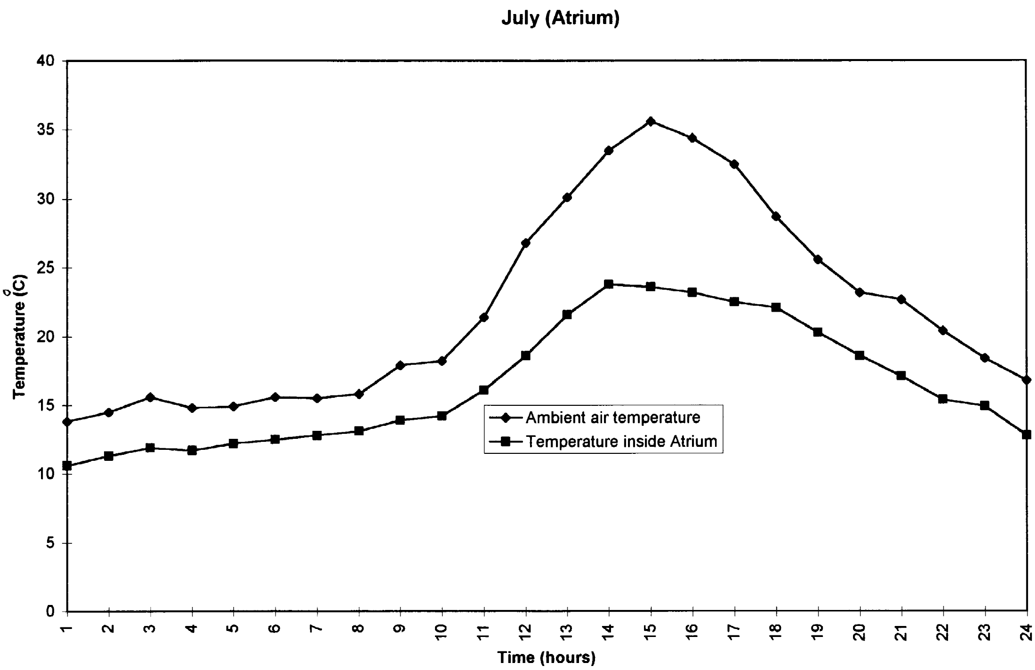

Fig. 6. Ambient air temperatures and air temperature values inside the atrium for a representative day in July.

- the thermal performance of the historical building is strictly influenced, governed and improved by the presence of its thermal insulated green roof (which acts as prior microclimate modifier). The most improved thermal performance of the building is achieved for the combined scenario of the atrium and the insulated green roof.

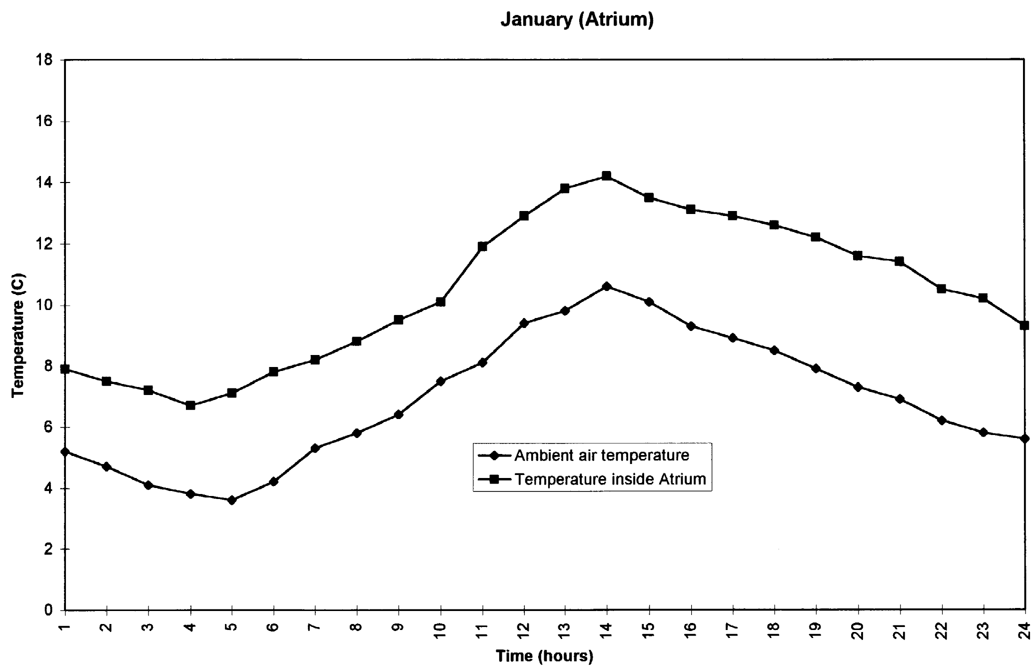

Fig. 7. Ambient air temperatures and air temperature values inside the atrium for a representative day in January.

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REFERENCES

Akbari H., Kurn D. M., Bretz S. E. and Hanford J. W. (1997) Peak power and cooling energy savings of shade trees. *Energy Build*. **25**, 139–148.

ASHRAE (1976). *Handbook of Fundamentals*, ASHRAE, Atlanta, GA.

ASHRAE (1991). *Handbook of Fundamentals*, ASHRAE, Atlanta, GA.

Bitan A. (1992) The high climatic quality of the city of future. *Atmos. Environ*. **26B**, 313–329.

Evans B. (1957) Natural air flow around buildings. In *Research Report No. 59*, Texas Engineering Experiment Station, Texas A&M College System.

Ferrante A., Mihalakakou G. and Odolini C. (1996) The rehabilitation of an historical urban area. *Renew. Energy* **10**, 577–584.

Goulding J., Lewis J. O. and Steemers T. C. (1986). *Energy in Architecture — The European Passive Solar Handbook*, E.U. Publication, Batsford, London.

Landsberg H. E. (1981). *The Urban Climate*, Academic Press.

Nunez M. and Oke T. R. (1977) The energy balance of an urban canyon. *J. Appl. Meteorol*. **16**, 11–19.

OECD (1990). In *Environmental Policies for Cities in the 1990s*, pp. 5–18, OECD.

Oke T. R. (1987). *Boundary Layer Climates*, Routledge.

Santamouris M., Mihalakakou G. and Asimakopoulos D. N. (1996) On the coupling of thermostatically controlled buildings with ground and night ventilation passive dissipation techniques. *Solar Energy* **60**, 191–197.

Santamouris M., Papanikolaou N., Livada I., Koronakis I., Georgakis C., Argiriou A. and Asimakopoulos D. (2001) On the impact of urban climate on the energy consumption of buildings. *Solar Energy* **70**, 201–216.

Tombazis A. N. (1995) The design of exterior spaces in relation to their effect on the indoor climate of buildings. In *Proceedings of the International Symposium Passive Cooling of Buildings, Athens, Greece*, pp. 83–88.

TRNSYS 14 (1997). In *A Transient System Simulation Programme*, Solar Energy Laboratory, University of Wisconsin, Madison, Transsolar, Stuttgart.