NATURAL DEVICES IN THE URBAN SPACES TO IMPROVE INDOOR AIR CLIMATE AND AIR QUALITY OF EXISTING BUILDINGS

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ABSTRACT

The role of outdoor spaces' design, as well as the mutual correspondence among urban microclimate, indoor air climate and air quality, have been specifically investigated for the case study of the Central Athens Area. A comprehensive urban design proposal including bio-climatic techniques to modify the outdoor environment in one of the hottest cities in Europe have been carried out within the framework of POLIS Research Project.
Urban (re-) planning of outdoor areas by using natural elements has been regarded as the first step to improve microclimatic conditions in the thickly - built urban Athens areas.
To perform accurately the physical phenomena in the urban environment different software research tools have been selected. More specifically, to assess climatic outdoor improvements of the proposed architectural-natural measures, research software modelling works developed in POLIS have been used. To extend the research and to investigate the influence of shading and green spaces on the indoor building's thermal behaviour a series of simulations have been performed using TRNSYS simulation programme.
Relative mutual comparison of results clearly indicate that outer surfaces' alternative design, even if limited to the buildings' envelope, acts as prior microclimate modifier and deeply improves both outdoor and indoor air climate and quality.

INTRODUCTION

The radical transformation of vegetated landscapes by the replacement with constructed cityscapes, accelerated by increased industrialisation and urbanisation of the recent years, has dramatically affected the urban environment and its atmosphere. As a result of the evolution of urban areas, cities are getting progressively hotter than the surrounding areas. Impermeable surfaces, massive buildings and air pollutants, help to increase well known urban phenomena such as the heat island effect with higher summer temperatures in urban areas than in the rural surroundings.
In this context the Athens central region has to be considered a very special pilot study. Recent measurements developed by the Group Building Environmental Studies of Athens in the framework of POLIStudies - a Multimedia Educational Structure on The Energy Efficiency of Buildings in Urban Areas - have shown dramatic higher temperatures in the Central Athens Area than in the suburban areas by 10-15 C [1].
It is well known that natural ventilation plays an important role in providing good indoor air quality and thermal comfort of occupants. However natural ventilation simply provided by

windows is not feasible in many urban environments, because of outdoor air condition and acoustics are not acceptable. In these conditions natural ventilation is unsuitable without using special design tools such as ducts and filter devices.
The increase of building's envelope insulation level by reducing infiltration and sealing up the building envelope cannot be a solution to achieve good indoor air quality and thermal comfort. Results coming from such a kind of solutions developed after the oil crisis in 1973 showed the growth of well-known phenomena such as the Sick Building Syndrome [2]. Furthermore it has been found that the increasing number of disorders due to humidity condensation, poor indoor air quality for low air change rates seriously impacts the health of building occupants.
The first step to avoiding problems of poor air quality is therefore to reduce pollution at source by improving efficiency and extracting pollutants. The following step is to ensure that unavoidable pollutants are dispersed safely. For example, where open spaces and buildings are naturally ventilated, we should assure that ventilation air is drawn from a source clear and green.
A planning strategy to minimise pollution impact should provide spatial separation of environmentally incompatible activities. An appropriate urban energy concept can exploit the potential of selected (natural) passive techniques in relation to the building envelope and its surrounding surfaces thus trying to achieve good air quality and thermal condition both in the open spaces and into the buildings.

Even if the reported research investigations address and simulate specifically microclimatic conditions, interactions among the climatic effects and current negative urban conditions such noise and pollution should be pointed out. It has been found, for example, that increased urban temperatures affect the concentration and distribution of urban pollution because heat accelerates the chemical reactions in the atmosphere leading to high ozone concentrations[1]. Moreover if pollutants land in sheltered areas like street canyons they may reside longer than they would in a windy environment. The roughness of buildings and urban structures may therefore increase pollutant's concentration ($S0_2$, $N0_2$).
In this framework we should also point out the key role of plants and vegetation in CO_2 absorption. High levels of CO_2 absorption by plants in relation to the rate of woody growth have been showed by Steemers [3]. Data referring to the rate of absorption per square metre of planted area could be used to determine the approximate amount and type (see Table 1.) of planting required to absorb CO_2 quantified concentrations, in an aim to ensure sustainability of the development.

Table 1. Examples of CO_2 absorption for various plants

PLANT TYPE	CO_2 ABSORPTION (Kg/m2/year)
Trees (average)	1.0
Hawthorn (Crataegus macrocarpa)	1.9
Blackthorn (Prunus spinosa)	1.4
Field Maple (Acer campestre)	1.2
Beech (Fagus sylvatica)	0.4

Thus, microclimatic enhancements in urban scale involving water systems, planting of trees and lightening of colours of urban surfaces may be able to decrease pollution loads and save huge

[1] In this context it should also be considered that higher urban temperatures increase the electricity demand and the consequent production of carbon dioxide and other pollutants.

amounts of energy[2], improving consequently both indoor and outdoor comfort conditions. Experimental researches in Athens and architectural implications of these researches have lead to a combination between architectural and natural devices in the main public spaces of the Athens Central Areas, aiming at modulating the harshness of the summer urban climate.

METHODS: THE REHABILITATION PROCEDURE IN THE CENTRAL ATHENS AREA.

The architectural rehabilitation design, by using passive cooling techniques like water, appropriate planting and vegetation, proposes alternative scenarios to improve thermal comfort conditions and restore natural elements as well as permeable surfaces in four urban canyons of the Central Athens area.
The present research work, initially planned to investigate and outline the energy potential of natural components in the public open spaces of urban sites, has been extended to show the consequent positive effects on the indoor building's thermal performance.

To approach the specific restrictions encountered in the Central Athens Region, a twofold rehabilitation procedure has been considered:

- Passive technological measures mainly related to the envelope of the buildings in existing dense thickly-built urban areas close to central high circulation streets;
- Passive technological measures related to an alternative use of outdoor spaces, courtyards and pedestrian streets as places able to improve microclimate, in existing urban areas where open free spaces were available.

The creation of gardens on the roofs of buildings has been considered an effective device for the environmental and climatic improvements in the main canyons of Central Athens area. In the alternative scenario design, an additional pergolas layer has been combined with the planted roof layer. The pergola and the roof garden under-planted with shade tolerant plants are both key elements to address the static problems of additional soil weight and essential tools to ensure shade on the roof garden thus increasing the cooling potential of air temperature simply provided by grass and soil.

Specific objectives in the urban rehabilitation procedure have been identified:

- Promotion of all forms of passive natural devices according to the potential effects on minimising the localised pollution problems and to enhance urban microclimate;
- Increase as much as possible the permeable surfaces in the outdoor spaces;
- Improvement of 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 oriented facades by using shading devices and "natural filters").
- Ensure CO_2 absorption by plants and urban pollutant dispersion by natural ventilation and night cooling.

Thus, specific proposals involving canyons with different geometrical features, orientation, types of buildings have been hypothesised. (See Fig. 1.)

[2] Research works have shown that evapotranspiration from a tree can save 1-2.4 MJ of electricity in Air Conditioning per year.

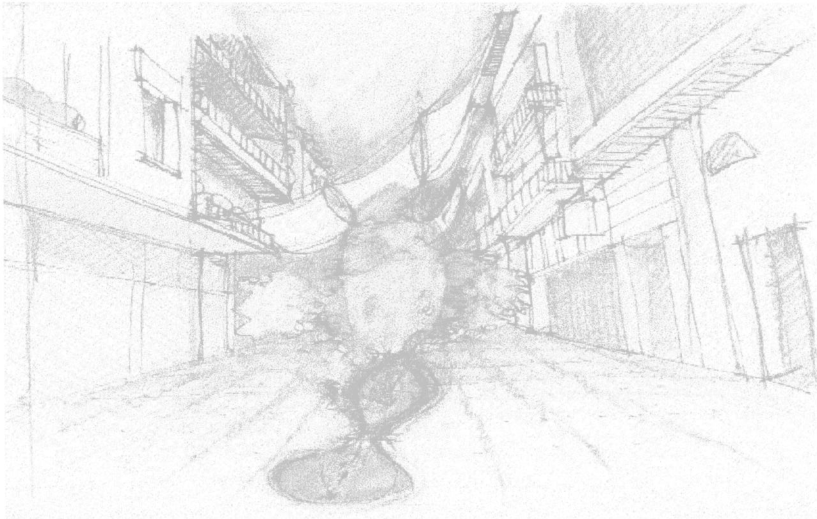

Fig. 1. A sketch of the view in Canyon Valaoritou. This pedestrian street, redesigned by trees, permeable pavements and watercourses, could provide evaporative cooling and better air quality and climate. Curtains and pergolas could also provide shadow for the buildings' facade (especially for the south - west oriented ones).

The cooling potential of the proposed techniques has been investigated for the Canyon Valaoritou, by means of a theoretical software model developed in the MATLAB [4] program. The thermal energy balance for transient conditions at any surface of the considered canyon can be expressed by the following differential equation:

$$\rho C \delta T_{si}/\delta T = h_c(T_{si}-T_{oi}) + \lambda/\Delta x(T_{si}-T_{mi}) + \Sigma F_{ij}\sigma(T_{sj}^4-T_{si}^4) + a_s q_s + F_{i/sky}(\varepsilon_c \sigma T_c^4 - \varepsilon_i \sigma T_{si}^4);\ [5]$$

On this basic equation[3], to investigate the proposed alternative scenarios, a series of transformations have been considered.
Firstly, as far as it concerns the scenario equipped by shading devices, it has been assumed an additional energy balance between the proposed curtains and the ground, so to simulate the new thermal performance of a theoretical first scenario modified by the curtains in the canyon. Secondly, to assess the microclimate modifications brought about by the use of permeable surfaces and green (in place of existing stone slabs) in the pedestrian street, the equations representing the macroscopic or "mean" energy and vapour balance in a canopy[4], have been

[3] where: $h_c(T_{si}-T_{oi})$ is the heat rate transferred by *convection* between the surface at temperature T_{si} and the adjacent air layer; $\lambda/\Delta x(T_{si}-T_{mi})$ is the heat rate transferred by conduction into the wall or the ground. The temperature T_{mi} is defined as the temperature inside the wall at a distance Δx from the surface; λ is the conductivity constant and Δx has been set up by the operator; $\Sigma F_{ij}\sigma(T_{sj}^4-T_{si}^4)$ represents the rate heat exchange by long wave radiation between a surface i and the n surrounding surfaces (j=1:n); $a_s q_s$ represents the short wave solar irradiance absorbed by the surface element, a_s is the absorption coefficient, while q_s is made up of the direct solar radiation and the diffused irradiance from the sky and the surrounding surfaces. It has been calculated for each segment as a function of their partial shaded area (PSA). The total solar radiation (direct, diffuse and reflected) incident on each segment by the following equation: $I(t)=I_{dir}(t)(1-PSA(t))+I_{dif}(t)SVF+\Sigma I_{dir+dif}(t)_i(1-m_i)F_{iA}$.

[4] $(\rho c)_\rho\, d\, LAI\, dT_p/dt = \varphi_{rad.sol} + \varphi_{rad,TIR} + \varphi_{conv,\rho-a} + \varphi_{trans,\rho-a}$; $(\rho c)_a H\, dT_a/dt = \varphi_{conv,a-\rho} + \varphi_{conv,a-g} + \varphi_{conv,a-\infty}$; $\rho a\, H\, d\theta_a/dt = \varphi_{vap,a-\rho} + \varphi_{vap,a-g} + \varphi_{vap,a-\infty}$
where: T_p= Leaves temperature (average in control volume), (°C); T_a= Air temperature (average in control volume), (°C); θ_a= Air specific humidity (average in control volume), ($Kg.Kg^{-1}$); d= Average leaves thickness, (m); $(\rho c)_\rho$, $(\rho c)_a$= Leaves and Air -respectively- specific thermal capacity, ($J.m^{-3}.K^{-1}$); ρ_a=Air density ($Kg.\ m^{-3}$); H= Canopy layer thickness (m); $\varphi_{rad,sol}, \varphi_{rad,TIR}$ = Solar radiation absorbed by leaves and Net thermal radiation flux on leaves, respectively, ($W.m^{-2}$).

considered [6].
In addition the equations describing:

- the convection heat transfer between leaves and air ($\varphi_{conv,\rho\text{-}a}$),
- the heat and vapour transport between the air within the canopy and the outdoor air ($\varphi_{conv,a\text{-}\infty}$ and $\varphi_{vap,a\text{-}\infty}$),
- the transpiration flux, the energy flux consumed to let water evaporate in leaves ($\varphi_{trans,\rho\text{-}a}$),
- the heat and vapour flux between the ground surface and the air ($\varphi_{conv,a\text{-}g}$);

have been introduced in the software model developed in POLISTUDIES Multimedia Tool.

To extend the research and to investigate the influence of shading and green spaces on the buildings' thermal behaviour a reference building along canyon Valaoritou has been selected and a series of simulations have been performed using TRNSYS simulation programme. TRNSYS is a transient system simulation environment with a modular structure to facilitate the addition to the programme of mathematical models not included in the standard TRNSYS library. Simulations have been performed for a single zone building.
The selected building has been regarded as one thermal zone with the base floor on the ground and with three floors considered as internal partitions. Simulations have been performed for the summer period of the year 1997. Hourly values of the following climatic parameters, measured in Athens, were used for the calculations:

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

Figure 2 shows the ambient air temperature in two different scenarios -Ambient and Ambient (1)- for the representative day of the summer period (15th of July) as well as the indoor air temperature's variation inside the building -scenario1, scenario2 and scenario3.

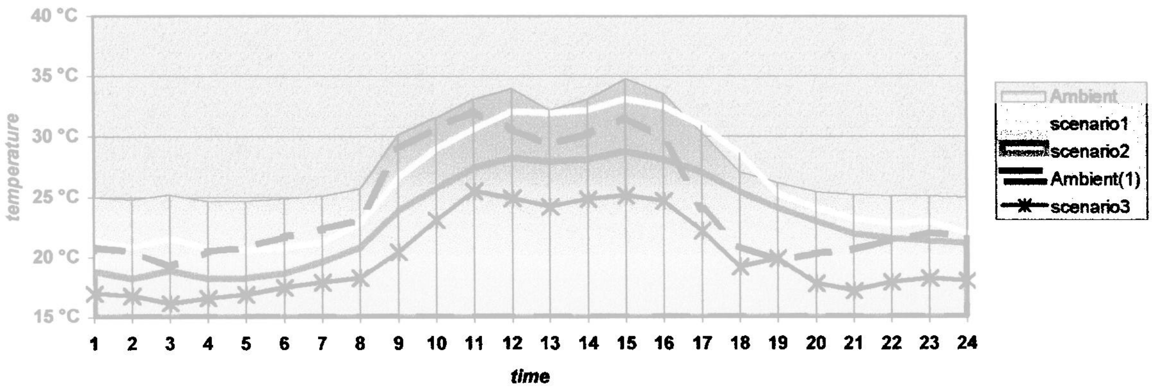

Fig. 2. Ambient air distribution in the urban canyon and inside the building.

Scenario1 represents the air temperature inside the reference building as it is in the real scenario (not shaded, nor equipped by green) and for existing ambient temperature (Ambient). Scenario2 is the air temperature inside the reference building equipped by both shading devices and under-planted roof gardens in existing ambient temperature (Ambient). Scenario3 represents the air temperature inside the reference building equipped by both shading devices and under-planted roof gardens, but using as ambient air climatic data the external air temperatures resulting from the software model developed in MATLAB simulating the urban canyon's alternative scenario -Ambient (1)-.

RESULTS

Relative mutual comparison of results clearly indicates that:

- The outdoor air temperature in the middle of the canyon -see Ambient (1) in Fig. 2- is strictly influenced, governed and improved by the presence of green and shading devices;
- The indoor temperature' reduction brought about the use of architectural and natural devices on the building's envelope -see scenario2 in Fig. 2- is very much increased considering the outdoor climatic conditions of the proposed alternative scenario in the urban canyon -see scenario3 in Fig. 2-;
- Outer surfaces' alternative design, even if limited to the buildings' envelope, acts as prior microclimate modifier and deeply improves both outdoor and indoor air climate and quality.

DISCUSSION

Qualitatively, a very good correspondence between the two different simulation tools has been found. Quantitatively, results show high temperature variations throughout all the different considered scenarios.

It can be concluded that the energy potential of the proposed architectural measures cannot be properly analysed separately from an overall comprehensive investigation addressing the combination of the building with the surrounding urban boundary conditions.

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