The contribution of urban green spaces to the improvement of environment in cities: Case study of Chania, Greece

Julia N. Georgi , Dimos Dimitriou

Show more

Add to Mendeley Share Cite

https://doi.org/10.1016/j.buildenv.2009.12.003

Abstract

This paper investigates how vegetation, mainly through evapotranspiration, affects the improvement of microclimatic conditions in urban areas and, more specifically, it examines the case for the city of Chania in Crete. The objectives of this study are to examine the bioclimatic role of green areas in urban sites as they affect the thermal comfort of residents, and to study the cross-correlation of factors that participate in this process.

To achieve these objectives, we have examined the parameters that contribute to the microclimate of a space and consider how it is influenced by vegetation. In addition, we have analyzed the effect of vegetation with respect to evapotranspiration, and have recorded the existing vegetation of Chania city and the relationship with the geomorphologic and urban characteristics of the city. This has involved calculating the evapotranspiration of various plant species, and collecting measurements at various places in Chania. These studies are designed to determine the cause of the changes of

thermal comfort in different parts of the city, and to examine the differentiation of thermal comfort that is observed between different plant species with respect to the evapotranspiration measure that has been calculated for each of them. The intention of this work is to aid efforts to improve the environment of Chania through better planning and the appropriate choice of the species used for planting open spaces. Finally, it is hoped that the results of this work will be of use in planning the environments of spaces in other cities that have similar characteristics.

Introduction

The development of large, densely populated cities has occurred in the twentieth century in many parts of the planet. The increased urbanization has affected the urban microclimate and continuous to do so today. According to [1] Gianna (2001), the factors that have particular importance in the configuration of an urban microclimate are the topographic configuration of space and the geometry of urban gorges; the distribution and the provision of green spaces and, more generally, all outdoor spaces; the sources of heat and the attributes of exterior surfaces; and the demographic and urban density as well as the layout of buildings. The absence of green spaces is characteristic of most contemporary cities globally, including those in Greece.

The urban outdoor spaces have exceptional environmental importance with regard to their contribution to the reduction of various types of pollution and to the improvement of microclimatic conditions. Furthermore, urban open spaces make positive contributions to human health and well being and they lead to an important contribution to human thermal comfort in exterior spaces.[2], [3]. According to Akbari and Taha [4] the factors that affect thermal comfort are(1) solar radiation; (2) temperature of exterior surfaces; (3) air temperature; (4) air humidity; and (5) wind speed. The undesirable attributes of these factors are moderated and counterbalanced by the presence of green spaces. Practical ways to cool urban areas include the use of reflective surfaces (rooftops and pavements) and planting of urban vegetation.

When considering the urban environment it is necessary to have an explicit and precise definition of the significance of thermal comfort. According to the physiological approach [1], [3], [4] thermal comfort is defined as a situation in which the brain expresses satisfaction with the thermal environment. Because 'satisfaction' tends to be of subjective nature, this definition reflects a wide range of individual levels of comfort. Nevertheless, the physiological factors are important, particularly in the outdoor environment.

The most useful way of expressing the degree of discomfort that prevails in a certain place, at a specific day or time is through the discomfort index [5]. This index is calculated from the air temperature and relative humidity, and it has been used in Greece with very satisfactory results [6], [7], [8].

According to data from the European Commission, Greek buildings are amongst the most energy consuming in Europe, using 35% of the energy budget to regulate the temperature indoors [9].

The trees and the open green spaces have multiple uses and their presence in the outdoors makes a major contribution to the saving of energy inside the buildings as well as to the improvement of the microclimate in the urban spaces adjacent to buildings and in urban subareas (Fig. 1). The amount of energy needed for heating and cooling is decreased considerably by the suitable placement of trees around buildings, so that there is much shading from the sun during the summer and as little as possible during the winter. "The improvement of urban microclimate is achieved through the effect that plants have on the balance of temperature and humidity, in the engagement of dust and gases of pollutants and in the regulation of air movement."[10].

Fig.1 shows that shading can be achieved with the presence of trees, and the resulting advantage of air cooling, without impeding the benevolent exposure to the sun during winter. Deciduous trees offer shade during the summer and the suitable selection of the right species can enhance cooling through 'evapotranspiration,' reducing the temperature by up to 3.1°C as mentioned before. During the winter, deciduous trees permit the sun to shine through the branches.

According to [1] Gianna (2001), the attributes of green urban spaces that affect the urban microclimate positively are:

(a) the high rate of absorption of solar radiation;

(b) the low heat capacity and thermal conductivity compared to the structural materials of buildings and urban open spaces;

(c) the reduction of air temperature *via* transpiration;

(d) the decreased infrared radiation;

(e) the reduction of wind speed around the soil;

(f) the detention of dust and pollutants from the air; and

(g) the sound protection that the presence of trees provides.

During the last twenty years, increasingly "City administrators are more aware of their urban climates and heat islands than they were decades ago, and urban planners and policy makers are now more willing to implement strategies that can modify the urban climate and save energy on the city scale"[4]

According to Dimoudi and Nikolopoulou [11] (2003), vegetation in the urban environment can greatly improve the urban microclimate, as well as mitigate the heat island effect, by reducing summer air temperatures. This effect is noticed not only within the boundaries of the green area, where measurements were taken, but extends beyond the park itself, particularly affecting the leeward side of it. Therefore increasing vegetation in the urban context can be an effective way of mitigating the heat island, and benefit urban centres.

Moreover trees offer their beauty, refresh the atmosphere with vapour-transpiration, they decrease pollution, they “absorb” storms and they prevent flooding, but even from an economical point of view, they increase the value of houses that are close to them considerably.

According to Dombrow etal. [13] (2000) and Mansfield etal. [12] (2002) many real estate professionals agree that houses with mature trees are preferred to comparable houses without mature trees. Simpson and McPherson [14] (1998) found that savings of 1.9%–2.5% on cooling costs have been estimated per residential tree, providing a strong financial incentive to choose housing locations with tree cover. According to Aurelia Bengochea Morancho [15] (2003) and the “hedonic technique”, the price of the housing relates inversely with the distance that separates it from an urban green space. These findings are in accordance with Bolitzer and Netusil (2000) [16] who concluded that proximity to an open space can have a statistically significant effect on home selling price. Tyrvainen and Miettinen (2000) [17] demonstrated that a 1 km increase in the distance from the nearest forested area leads to an average 5.9% decrease in the market price of the dwelling.

As far as environmental variables are concerned, only the distance from a green area is significant. According to the estimates obtained, every 100m further away from a green area means a drop of 1800€ approximately in the housing price. According to Zoulia etal. [18] (2008) the temperatures between two urban green areas and areas that are surrounded by buildings differ 7 °C or more during the summer. These results were generated by the measurements that were made by comparing measurements taken in the National Garden of Athens with measurements from selected urban streets with tall buildings along both sides. Therefore the effects of trees in urban spaces, as well as the microclimate that is created under the trees, have been the subject of extensive research.

Trees decrease high temperatures in two ways [19], [20], [21]:

(a) through shading, with solar radiation collected in the leaves of trees, from where it is absorbed or reflected; and

(b) *via* evaporation at the local level, by freezing the air because of the utilisation of energy for the transpiration and not for heating.

The most important mechanism through which trees contribute to the reduction of high urban temperatures is evapotranspiration (ET), which is the sum of evaporation and plant transpiration [21]. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through stomata in the leaves. Almost all the water taken in by a plant is lost *via* transpiration and only a very small fraction is used in the plant. Together, these processes are referred to as evapotranspiration. Evapotranspiration cools the air by using heat from the air to evaporate water [22], [23], [24].

Evapotranspiration plays an important role in the water cycle. Plants (Fig.2) take water from the ground through their roots and emit it through their leaves while water can also evaporate from tree surfaces, such as the stalk, or surrounding soil. Evapotranspiration creates pockets of lower temperature in an urban environment, known as the "phenomenon of oases". It is clear from the literature that evapotranspiration, alone or in combination with shading, can help reduce peak summer air temperatures and contributes to the creation of pleasant and comfortable conditions in a city [23], [24].

All mechanical air cooling systems "copy" the evapotranspiration operations and functions of trees. However, as it appears in Table 4, trees, in comparison with any other mechanical air cooling system, cost less and last longer.

For example, spraying fans copy the vapour-transpiration processes of trees and they increase the relative humidity of the space, resulting in the increase of thermal comfort. The presence of an awning or shelter is also required for shading in order to achieve thermal comfort. It is obvious that the cost of installation for the shading device should be added to the expenses, if we take into account the consumption of energy and water that is required as well as the cost for maintenance. The planting cost of a tree includes the cost of its purchase, installation, as well as the cost of its maintenance.

Reference evapotranspiration is defined as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m (4.72 in), a fixed surface resistance of 70 s m^{-1} (70 s 3.2ft^{-1}) and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground". In the reference evapotranspiration definition, the grass is specifically defined as the reference crop and this crop is assumed to be free of water stress and diseases. In the literature, the terms "reference evapotranspiration" and "reference crop evapotranspiration" have been used interchangeably and they both represent the same evapotranspiration rate from a short, green grass surface. [25], [38].

The reference surface is a grass surface with specific attributes. Crop Evapotranspiration under standard conditions (ETc), is evapotranspiration from disease-free, well-fertilized vegetation, under optimum soil water conditions, without restriction of the availability of water or nutrients under the given climatic conditions [26], [27], i.e. real evapotranspiration. *ETc* depends on the climate and the characteristics of the vegetation, and it can be calculated from climatic data and from parameters such as the thermal resistance, the albedo and the resistance of the atmosphere.

The experimental ratios of *ETc*/*ETo* are called crop/plant coefficients (*Kc*), and can be used in the correlation of *ETc* and *ETo* according to the equation *ETc*=*Kc* * *ETo*,where: $ETc = \text{Evapotranspiration crop}\left(\frac{mm}{d}\right), ETo = ET\ \text{reference}\left(\frac{mm}{d}\right)$ *Kc*=Crop coefficient

Differences in the anatomy of leaves, in the characteristics of the stomata, in the aerodynamic attributes and even in albedo cause differences between *ETc* and *ETo* under the same climatic conditions. Kc represents the difference of evapotranspiration of any vegetation type compared with that of the reference crop. In the present work, the values of Kc that are used are those given by FAO, and those given by Papazafiriou (1984) [28] specifically for southern Greece. The values of *Kc* for the tree species that were selected for our measurements are: (a) Indian laurel fig (*Ficus retusa ssp. nitida*), 1.10; (b) stone pine (*Pinus pinea*), 1.00; (c) Canary Island date palm (*Phoenix canariensis*), 0.95; (d) bitter orange (*Citrus aurantium*), 0.60; and (e) olive tree (*Olea europaea ssp. europaea*), 0.45.

Section snippets

Materials and methods

As it was stated earlier, the aim of this study is to examine the bioclimatic role of green areas in urban sites as they affect the thermal comfort of residents, and to study the cross-correlation of factors that participate in this process. The intention of this study is to aid efforts to improve the environment of Chania through better planning and the appropriate choice of the species used for planting open spaces.…

Materials and methods

As it was stated earlier, the aim of this study is to examine the bioclimatic role of green areas in urban sites as they affect the thermal comfort of residents, and to study the cross-correlation of factors that participate in this process. The intention of this study is to aid efforts to improve the environment of Chania through better planning and the appropriate choice of the species used for planting open spaces.…

Results

The values of temperature and *DI* measured in the shade of plants are lower in all cases than that of sunlit pavements, with a mean reduction of 3.1 °C. These measurements agree with those obtained by other researchers, e.g. Taha etal. (1988) [30] reported "measurements in the suburbs of Sacramento in regions where mature trees exist showed that the temperature of air under the trees foliage was 1.7–3.3 °C lower concerning regions where trees do not exist "; Parker (1989) [31] reported the…

Discussion

According to the measurements that were made, it was clear that evapotranspiration of plants influences their micro-environment by increasing the humidity of the dry summer atmosphere the conditions of planted regions are more pleasant and thermic comfortable, as well as the discomfort index decreases perceptibly.

This becomes comprehensible according to the measurements. Plants with a high level of evapotranspiration have the most thermal comfortable micro-environment as well as the lowest…

Conclusion and recommendations

Concerning the documentation of theoretical part, the case study that we investigated and the results that were exported and formulated above, we have led to the following observations:

- ✓ The existence of plants in the spaces of a town can improve in a satisfactory level the DI because of their functions of Shading and Evapotranspiration. For the plant selections should be taken into consideration the relative humidity of each species because *DI* is small for plants that produced high levels of…

…

Acknowledgments

The authors wish to thank associate professor Menelaos Triantafillou at University of Cincinnati, School of Planning for his pre-review and his corrections in grammar, English and structure of the paper and Achilleas Kampouris for his Technical Assistance for the present paper.…

References (38)

H. Akbari *et al.*

The impact of trees and white surfaces on residential heating and cooling energy use in four Canadian cities

Energy (1992)