This is a post-peer-review, pre-copyedit version of an article published in Urban Ecosystem. The final authenticated version is available online at: http://dx.doi.org/10.1007/s11252-017-0655-4

Correlation between the geometrical characteristics of streets and morphological features of trees for the formation of tree lines in the urban design of the city of Orestiada, Greece

Eleni C. Rantzoudi[1] · Julia N. Georgi[2]

Abstract This paper classifies the streets of the city of Orestiada, Greece, and examines the correlation between the geometric characteristics of streets and the appropriate height of trees that form the street tree lines so that the microclimate in each street may be improved. The rows of trees improve the aesthetic quality of the urban spaces, and also strengthen the sense of enclosure through tree planting, especially in monot-onous urban landscapes. Our main aim is to augment the veg-etation in urban areas to achieve the greatest shading of streets in order to contribute to the improvement of the urban environ-ment in terms of bioclimatic conditions. The methodology used in this paper aims to promote the use of trees in urban design, and to evaluate the effects of shading at the city scale with regard to microclimate and energy saving, and to develop tree selection and design guidelines for recommended planting pro-grams. It is expected that the results of the study will be useful to Urban Planners, Urban Arboriculturists, Urban Foresters and Landscape Architects that are engaged in the design and con-struction of streetscapes in Mediterranean region.

Keywords Street trees · Bioclimatic conditions · Microclimate · Urban design · Street orientation

Introduction

Urbanization tends to increase urban temperature, energy use, carbon dioxide emissions from fossil fuel power plants, mu-nicipal water demand, ozone levels, and human discomfort and disease (Dwyer et al. 1992). These harmful consequences are compounded by global climate change, which may double the rate of urban warming (Akbari et al. 1990). Environmental improvement of urban street trees has the potential to improve existing bioclimatic conditions and create comfortable condi-tions both inside and outside of buildings (Streiling and Matzarakis 2003; Mayer and Matzarakis 2006; Ali-Toudert and Mayer 2007a; Bourbia and Boucherida 2010; Georgi and Dimitriou 2010; Orlandini et al. 2017).

According to Evangelinos et al. (2005) city surfaces are constructed with artificial, dark coloured, heavy-weight mate-rials, which during the day absorb large sums of solar radia-tion and radiate heat, significantly raising the mean radiant temperature.

All the above drastically reduce the thermal com-fort of urban open spaces during hot days; people quickly cross these spaces and search for more shaded and fresh areas to sit and relax (Abreu-Harbich et al. 2014). Moughtin (2003) and Jacobs (1995) agree that a desirable urban condition is for a pedestrian to have a sense of the surroundings as a pleasant and protective space. This feeling can be achieved by the use of trees in city streets (Bourbia and Boucherida 2010; Georgi and Dimitriou 2010; Lowry et al. 2012; Moreno et al. 2015). "In particular, trees are defined as the most effective vegeta-tion element for reducing overheating in urban areas" (Orlandini et al. 2017) while street trees provide valuable en-vironmental, social, and economic benefits (Mullaney et al. 2015). Suggestions that involve planting trees along streets aim to create a landscape that is protected and shaded by the tree foliage. This will also succeed in creating the sense of an enclosed room, according to Moughtin (2003), which will

✉ Eleni C. Rantzoudi
erantzou@fmenr.duth.gr

Julia N. Georgi
j.georgi@nup.ac.cy

1 Department of Forestry and Management of Environment and Natural Resources, Democritus University of Thrace, P.O. Box 68200, Orestiada, Greece

2 Neapolis University of Pafos, Paphos, Cyprus

improve the microclimate of open spaces and prolong residence times.

According to Ali-Toudert and Mayer (2006), Ali-Toudert and Mayer 2007b) the need for comfort is strongly dependent on the use of the street. It is difficult to keep a whole street in optimal comfort situation because of other design imperatives. Fortunately, this is also not indispensable, and it is important to keep the space of the street at least partly comfortable. Studies based on social surveys have shown that the frequentation of urban spaces is favoured when a choice is given to people to adjust to a climatic situation by moving to shaded sub-spaces. The last example shows that a judicious combination of geometric aspects (aspect ratio, gallery, overhangs) and the orientation can lead to a substantial amelioration of the microclimate at street level even with keeping a minimum of solar access in winter for indoors and outdoors.

Street trees can improve the microclimate by reducing the temperature around 3 °C and the relative humidity around 10–20% and therefore by improving the thermal comfort (Dimoudi and Nikolopoulou 2003; Rantzoudi 2004; Georgi and Sarikou 2006; Georgi and Zafiriadis 2006; Ali-Toudert and Mayer 2007a; Zoulia et al. 2009; Georgi and Dimitriou 2010). The ideal arrangement of lines of trees in urban spaces depends on the width of streets, sidewalks, the height of nearby buildings, street orientation (Dafis 2001; Georgi 2000), and of course the morphological features of the chosen trees. More specifically, based on the sun's movement, there is an area of the street that is exposed to the sun every day during the summer. This specific area can be shaded by a line of broadleaf trees to protect the sides of buildings that face the street from increased solar heating that occurs during summer. Simple characterization of shading effects is complicated by the many possible permutations of building type, building surface orientation, tree location with respect to each building surface, tree size, canopy density, solar angle (time of day), season and microclimate (Simpson 2002; Shashua-Bar et al. 2010a, b).

The aim of this paper is to categorize the streets of Orestiada, Greece, and compare their geometrical characteristics with the size of suitable trees for the urban environment. It thereby considers the possibilities for regulating the contrasting conditions that exist in urban streets and in general to improve the environmental conditions in terms of bioclimatic criteria. Furthermore, the paper focuses on the effects that trees have on streets and buildings in the urban environment and the energy used in cooling and heating (Randrup et al. 2001). Given the difficulties associated to the measurements that include all of these factors, simulation models have been a necessary and practical alternative for evaluating these effects. The study took place in the city of Orestiada during the summer months, when temperatures are high and the need for shade is imperative. This is the forefront of this research. It examines a simple function of trees (the shadow), during the summer (where the discomfort is obvious in Mediterranean countries) that make a strong contribution in cooling and is part of bioclimatic design.

Methodology

Site description

The project applies to the urban part of Orestiada - study area (Fig. 1), which is a modern city that is situated at northeasternmost and northernmost of Greece with population around 20,000. Orestiada is only 2 km west of the Evros River, a natural border between Greece and Turkey. The street plan of Orestiada was designed in 1922 according to the Hippodamean grid pattern (Fig. 1), runs almost parallel from east to west and north to south. At this type of city plan, the streets can be grouped according to their geometrical characteristics. The streets of Orestiada's urban center are categorized in terms of the relationship between street orientation, width and the morphological features of trees to be planted along the streets.

During its early decades of development Orestiada boasted for the two-lane main avenue that ended to a forested and spacious square with a statue. The city grew along its central avenue which was planted with four-wide rows of trees along the median strip, which gave pedestrians a sense of space enclosure. However, this is no longer the situation in the modern city. Although surrounded by a rural landscape, the city bears the obvious results of urbanization that developed during recent decades without adequate planning. The best tree placement on a given street depends on the street orientation and width, height of the buildings that face both sides of the road, and types of trees that are chosen. So, in the ground plan of the streets we place lines of trees according to the geometrical characteristics of the street and orientation to find the best design solution (Figs. 5, 6, 7, 8, 9, 10, 11, 12).

The area of Orestiada is among the most fertile and productive areas of Greece. The soil of the broader area includes sand, gravel and shingles or compact rocks that the waterproof is owed to them in primary porosity. In the alluvia depositions of Evros River there is the existence of grainy or small waterproof shaping materials with high water wagon horizon. Inside the city of Orestiada, the soil where the trees rows are planted is brought in to the site.

The climate of the wider area of Northern Evros is classified as a continental type of climate with cold winter and hot summer. The maximum sunshine occurs in July and August, when shown the highest average temperature of the year, 25.7 °C. The average minimum temperature of 0.6 °C occurs in January. The average relative humidity reaches its peak with 82% in December and the minimum of 55% in August. The average relative humidity of the year is 69%. The average

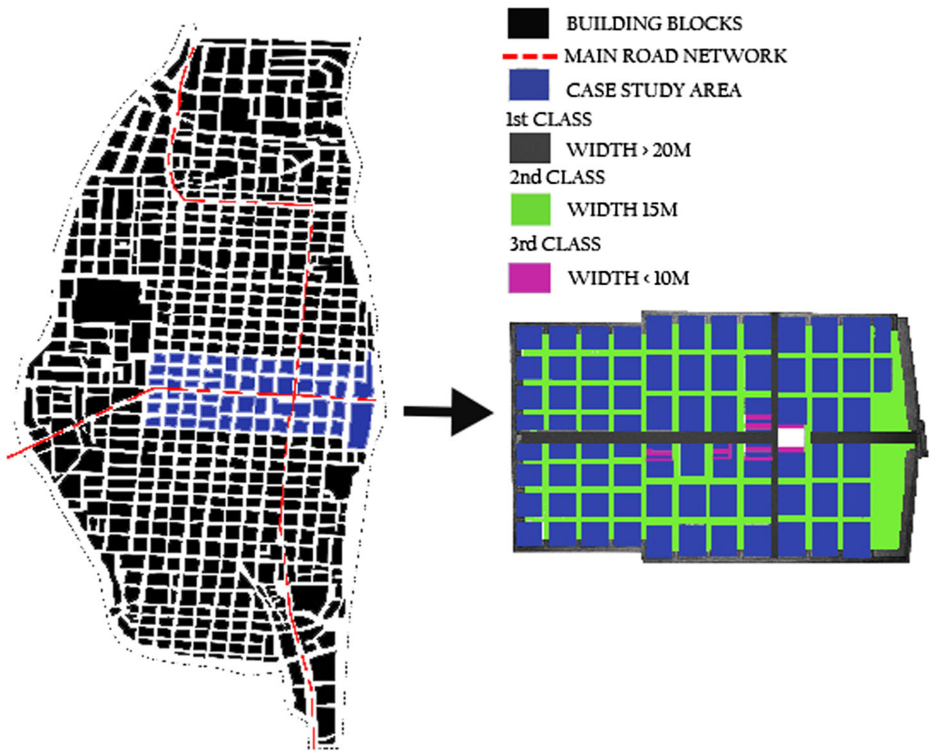


Fig. 1 Study area and street classification

annual rainfall exceeds 600 mm and the mean altitude of Orestiada is 29 m. The prevailing winds have northeast or northwest direction with an incidence of 39.2%, while the rate lull is only 4.2%. The maximum sunshine was recorded during the months of July–August and the minimum in the months December–February. Rainfall was recorded throughout the year with maximum intensity between November to May. Also, from winter to early spring snowfalls occur. The average number of snow days is 10.6, with a snow height in 10.12 cm (Matzarakis 2006).

As it is inferred from these data, the relative humidity in Orestiada is high throughout the whole year and this is caused by the vicinity of the River Evros. But it is a favourable factor for plant growth in general and of trees in the urban ecosystem as the environment of the city is drier than the countryside (Oke 1987; Yilmaz et al. 2007), which is negative to achieve rich and healthy vegetation within it.

Categorizing streets according to width

The streets of the study area can be divided into 3 groups according to their geometrical characteristics. The 1st category includes avenues of widths greater than 20 m, the 2nd category includes streets with widths of 15 m and the 3rd with width less than 10 m (Fig. 1). The 1st category includes two broad avenues of widths 30 m and 20 m that accommodates basic commercial activity and social services of the city. The second category streets accommodates mixed land uses, while the third category shows narrow streets are commercial streets to be used as pedestrian streets for developing retail activity in the city.

Categorizing streets according to orientation

All the categories mentioned above are examined according to orientation. As there are two orientations, from North to South and from East to West, in any category the study searched for the size of trees that can grow there (Fig. 4). According to the season and the position of sun, different parts of the street are shaded, but during the summer and specifically on the 21st of June when it is the summer solstice, sun heating reaches its peak. If this period it is managed to shade the street and the buildings in a satisfying range then we will have coincidently achieved thermal comfort conditions, saved a great amount of energy and improved bioclimatic and aesthetic conditions inside the city during the whole year.

Categorizing trees according to height

Simulation models that account for tree configuration. Effects of mature, deciduous trees have most often been modeled (Thayer and Maeda 1985; Huang et al. 1987; McPherson and Dougherty 1989; Simpson and McPherson 1996). The term tree type is used to aggregate species-related tree characteristics including mature size (crown width, growth rate and crown shape), foliation period (for deciduous trees) and shade coefficient for leaf-on period. With regard to tree height, the classification that Dafis (2001) proposed for street trees has been used. Therefore the trees have been categorized according height (Dafis 2001), as follows: The 1st class includes trees of height greater than 20 m (*δ3*>20 m), the 2nd class includes trees with height equal or less than 20 m (*δ2* ≤ 20 m) and the 3rd class with height equal or less than 10 m (*δ1* ≤ 10 m) (Fig. 2). The broad-leaf deciduous trees are the preferable trees for shade because they provide better shade conditions, during all the seasons of the year. In this way the suitable height of trees to improve bioclimatic conditions according the existing urban geometry is examined. According to this scheme, we sketch the groups of the trees to be used in the research for the most ideal planting position in the streets of the study area (Fig. 5, 6, 7, 8, 9, 10, 11, and 12), similar categorization has been used by Simpson (2002).

The choice of appropriate size of trees is made by taking three characteristics into account:

a) Appropriate morphological features (height) of the trees that improve the energy requirements of buildings that face the street and create comfortable thermal conditions in the streets (Fig. 2).
b) Maintain a minimum allowable tree height in an urban space so as not to prevent pedestrian movement, the transportation of merchandise and human activity in general, which is an important factor in a restricted urban space. Russ (2002) recommends a height of 2.4 m as the minimum acceptable. Consequently, in urban open spaces like sidewalks, an appropriate height is more than 5 m.
c) Maintaining a minimum distance from buildings according to Russ (2002), a tree should be planted at a distance equal to 1/4 or 1/3 of the height of the grown tree (Fig. 3). This distance is called ω and is considered to be the minimum allowed, equal to ¼ of the height of the tree. The symbol σ determines the height of the shade from the trees on adjacent building, whereas π represents the width of the street (Fig. 5, 6, 7, 8, 9, 10, 11, and 12). Searching for the best solution to minimize solar heating in both orientations (higher σ is better) involves making ground plans (adequate ω according to π) and sections for the summer solstice (21st June) and the specific midday hours of 12:00 and 15:00 according to Tzonos (1985) at the latitude of Orestiada. At the present study weather data and tree-shade represent typical or average conditions with no wind effect.

Results

The results from correlation are presented separately for each category of street classification, where the proposed size of

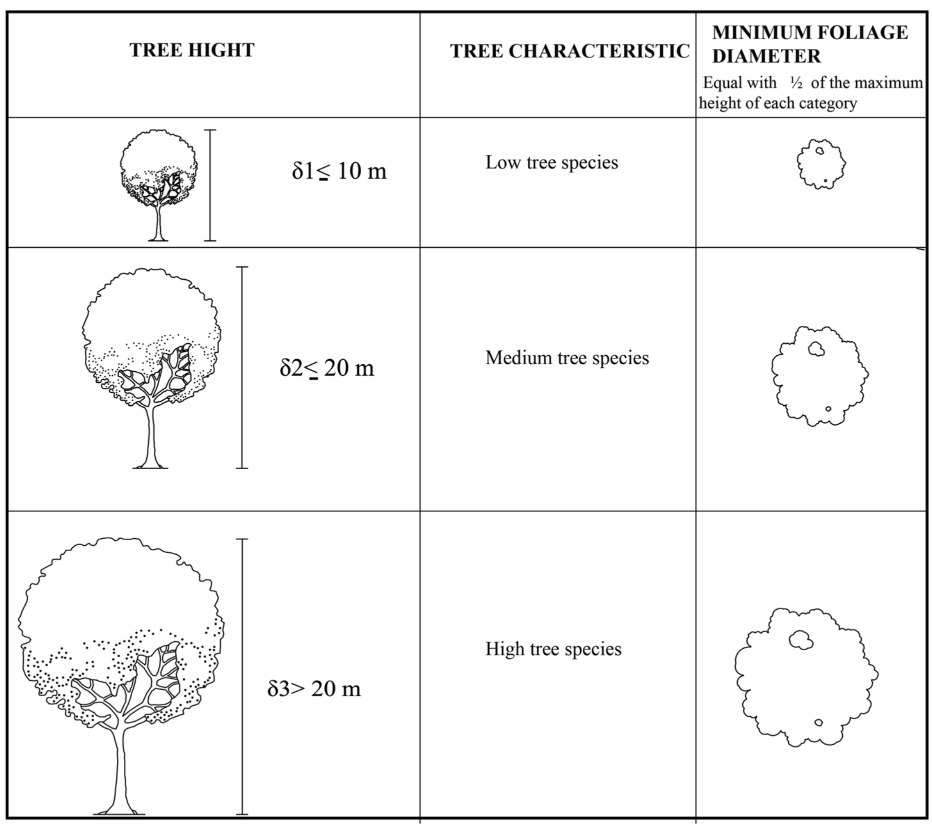
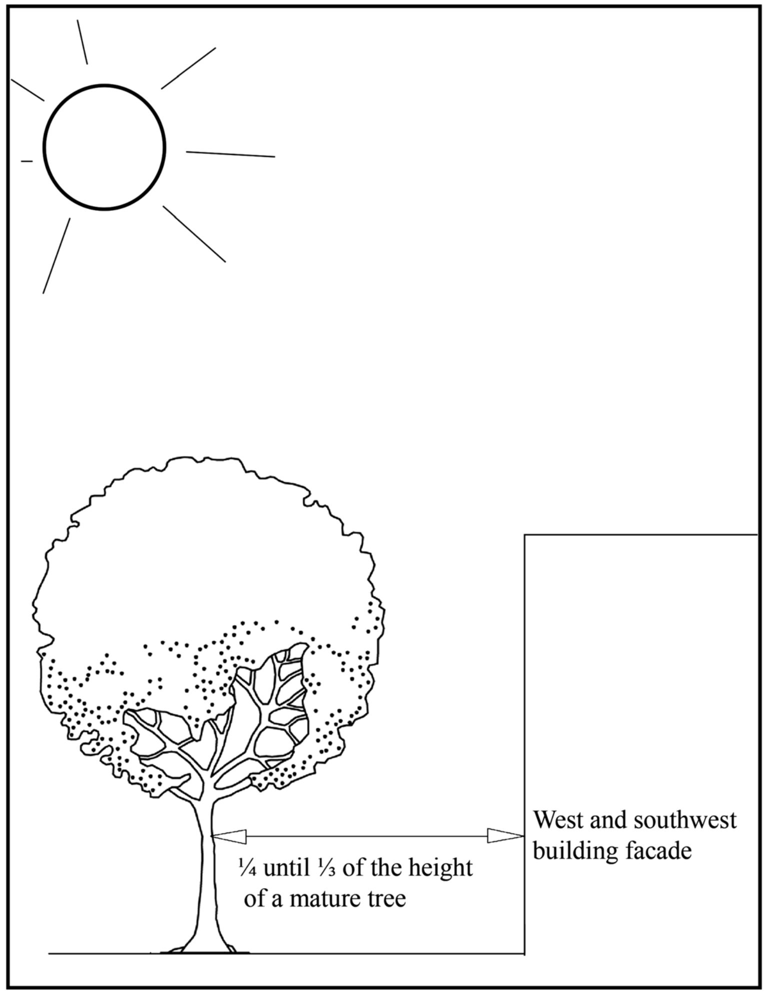


Fig. 2 Distinction of street trees according to height and diameter of the crown according to Dafis (2001)

Fig. 3 Proposed planting position of a street tree (after Russ 2002)



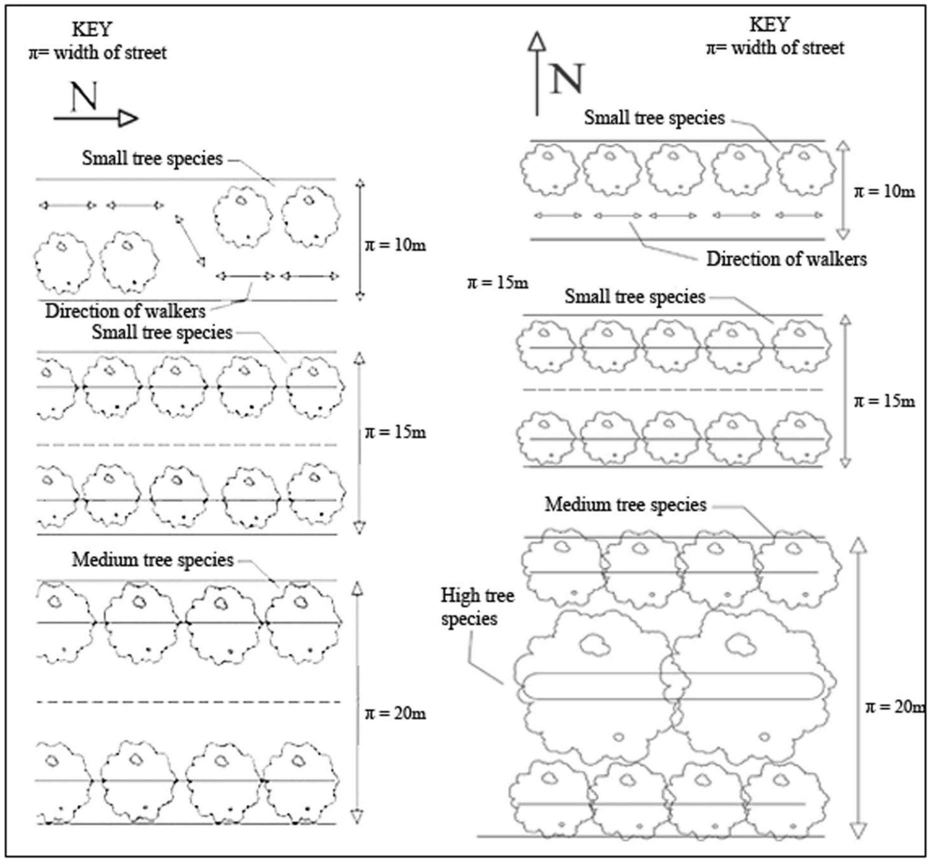
trees depends on the size and the orientation in each category of the street (Fig.4). The distance ω will be the closest position to building facades and is an example of the correct placement of a tree line. In every section, we explore the better position of trees at left, right or in the middle along streets for both orientations that are found for the city of Orestiada - northern and southern or eastern and western orientation. Our intention is to find the best position for the formation of tree lines in order to improve the microclimatic and aesthetic conditions of the urban open space.

Streets of the 3rd category (6-10 m)

Streets in this group include small downtown streets with buildings less than 11 m in height. A representative section in a pedestrianized street of 10 m width with east-west orientation and building heights of 9 m on the south side and 11 m on the north is selected (Fig. 5). The present study aims to find the best position of trees to create better bioclimatic and aesthetic conditions. The results for all 6 sections (Figs. 5) show that buildings with south-facing orientations need to be shaded. More specifically, from the previous sections, low trees according to classification at Fig. 2 that reaches no more than 10 m in mature age will provide necessary height and foliage to shade building frontages. In this way, solar radiation will not heat building facades during the hot days of the year and also the cold wintry winds will be efficiently reduced by the trees. Additionally, the tree lines will aesthetically enhance the road.

In the tests, it is found that in the 1st sections both at 12:00 and 15:00 at Fig. 5 the trees at the minimum allowed distance from nearby buildings ($\omega = 2.5$ m) offer better shading conditions when they are planted in the southern facades. Also, small size ($\delta 1$) trees are suitable enough in order for the sought bioclimatic aim to be achieved. Additionally, a second representative street is selected of 6 m width, north-south orientation and buildings of 11 m height on both sides of the street (Fig. 6). The tests show that for a north-south orientation, due to the fact that the street is especially narrow (6 m) a low tree should be used and placed to the minimum distance $\omega = 2.5$ m from adjacent buildings. It is obvious form the 3rd sections (Fig. 6) that at 15:00 the shade of one building on another is so

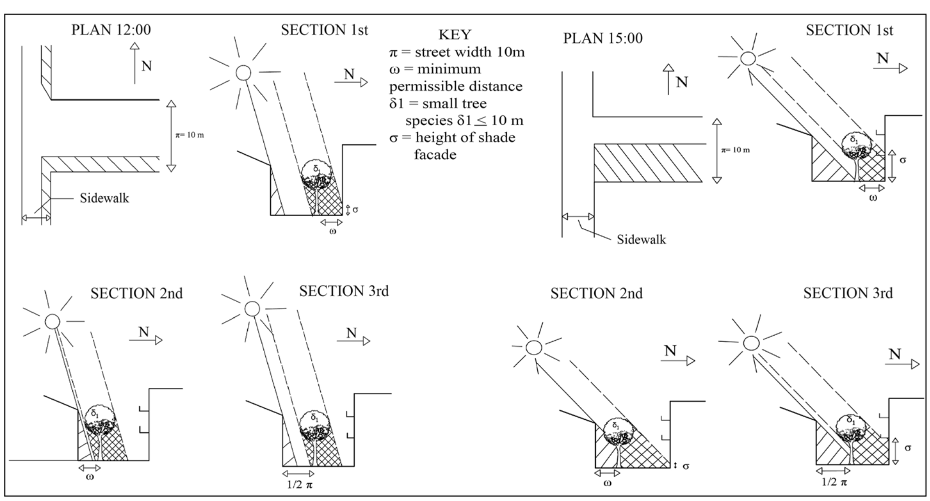
Fig. 4 Proposed placement of rows of street trees in north-south and east-west direction



complete that tree position doesn't directly influence shade conditions. However, at 12:00 the placement of trees affects west-facing buildings and is therefore important in terms of reaching our bioclimatic and aesthetic aims.

To conclude, in streets with a width less or equal to 10 m (3rd category), we suggest trees of 3rd class with a height lower than 10 m. In this way, we have the best effect on the microclimate of the streets using trees of a height of 10 m which is appropriate in a minimum distance of 2.5 m from nearby buildings. Concretely, regarding streets with orientation from east to west we select to shade the facades of buildings that are turned into the south and in distance $\omega = 3$ m (Fig. 3 and 5), whereas regarding streets with orientation from north to south we achieve the desirable result with the placement of low trees in the middle of the distance between the two facades of street (Fig. 3 and 6). Of course, any choice of

Fig. 5 Streets of the 3rd category (width = 10 m) under sun and shade in an east-west direction. At this figure we explore the best placement of trees for 21st June at 12:00 and 15:00 in order to improve microclimatic conditions of the road. Particularly, we place a low tree (*δ1*) in three different positions left, right or in the middle of the road. It's obvious that the shade is better at the 1st section, during the hottest day of the year



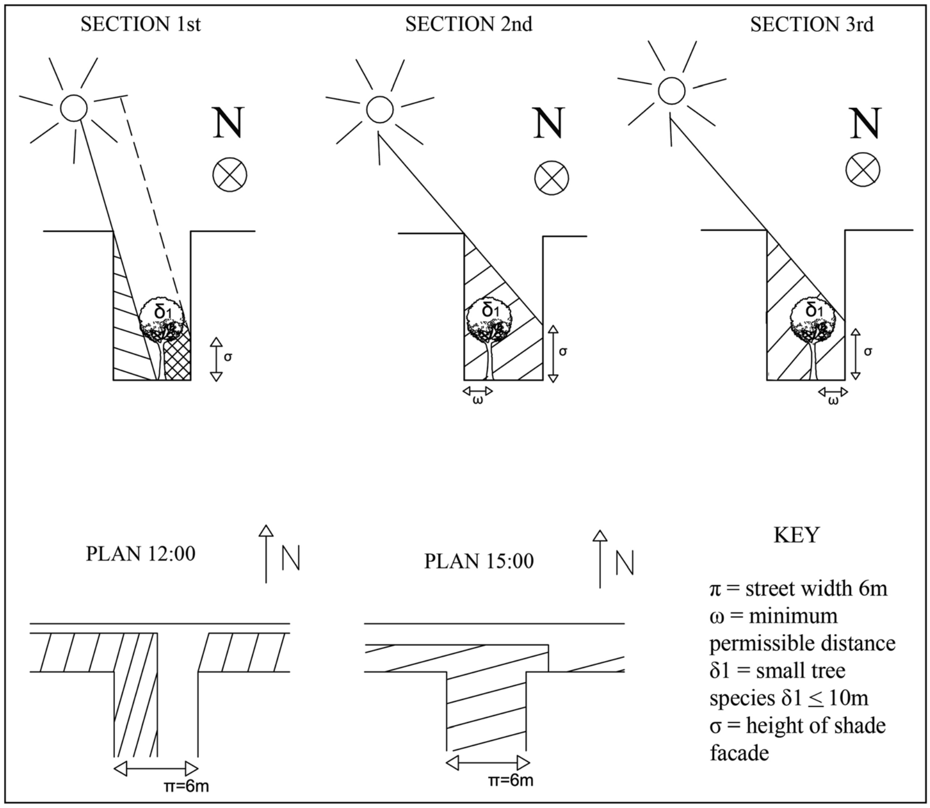


Fig. 6 North-south street of 3rd category (width 6 m) under sun and shade for 21st June at 12:00 and 15:00. This figure explores the best placements of trees in order to improve microclimatic conditions of the road. Firstly, we place a low tree (*δ1*) in the middle of the street (Section 1st) and we have satisfactory shade at 12:00. The other two sections depict the shade at 15:00. It's obvious that the position of the tree doesn't affect the shade condition.

arrangement of trees depends on the use of these small streets as footpaths for the movement of pedestrians or one way roads for the movement of vehicles.

Streets of the 2nd category (15 m)

At this case, streets whose width reach 15m and are included in our study area, are considered. These are usually residential streets with mixed uses where the buildings can be up to 16 m or five floors in height. A representative section was chosen where the heights of buildings on each side of the road are 16 m and 13 m respectively for an east-west road and 16 m height on both facades for a north-south road.

The sections of the streets were designed for the chosen midday hours when the sun is high. It was found that the south facing orientation needs to be shaded, the desirable height of trees to be up to 20m, which means trees of middle height to provide full shade to those building facades oriented toward the sun (Fig. 7, 8, and 9). It is obvious from the 1st and 3rd section shown at Fig. 7 that we cannot achieve efficient shade of the buildings with trees of the 3rd class whereas the situation is improved in the 2nd section of the same figure. These results are also confined by the section at Fig. 8 where at 15:00 the sun is closer to the horizon but a low tree of 3rd class cannot shade more than σ = 1/2 of the height of the building.

Consequently, the most appropriate choice, according to the geometry of the street where buildings can reach 19 m in height, is trees of medium height of 20 m (2nd class). However, it was obvious that this is a good proposal in specific streets with sidewalks of only 3.5m width. This width is satisfactory for pedestrian movement according to Lynch and Hack (2002) and Russ (2002), as it was previously mentioned. In this case, and due to the fact that the 15 m street in the center of the city of Orestiada is one-way road for vehicles with 2 lanes for parking space, the sidewalks are proposed to broaden to 5.6m in the 4rd section at the Fig. 7. This will consume room from the parking lanes so as to plant medium-height trees at such intervals that will enable parking between them. This proposal will create the sense of an enclosed-protected space, and the correct placement of the tree row will aesthetically improve the urban scene and will fulfill the bioclimatic purpose without disturbing traffic flow within the city (Fig. 7). These types of streets, especially in the suburbs where the use of land is residential, can be converted into woonerfs.

At Fig. 9 the solar heating of a 2nd category north-south street can be seen. The difference here is that the buildings on both sides are heated for a period during the day. It is concluded that a double tree line is also necessary here. Placing short trees does not cover the facade of the buildings; however, it is a satisfied solution for the current width of the sidewalks. A solution similar to this could be suggested in Fig. 9, as it

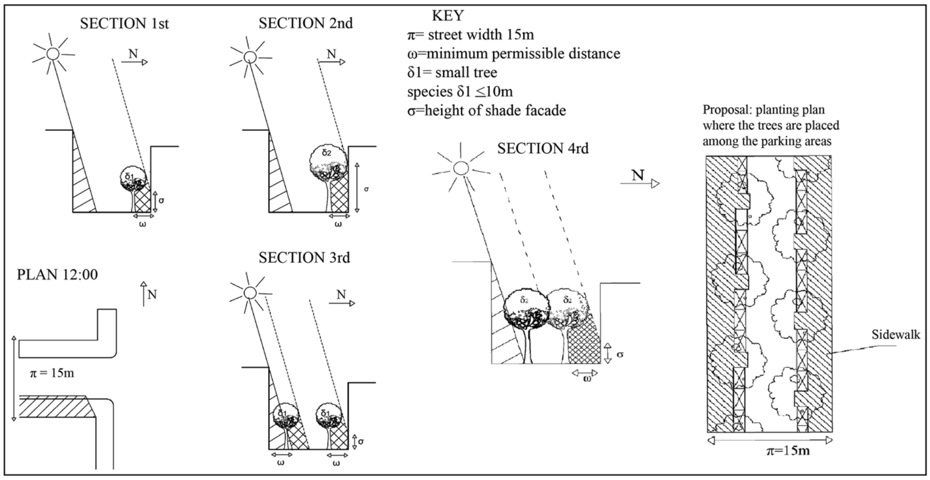


Fig. 7 Street of 2rd category (width 15 m) under sun and shade in an east-west direction. At this figure we explore the best placement of trees for 21st June at 12:00 in order to improve microclimatic conditions of the road. Also, we use two different size of tree in order to succeed better shading conditions. It's obvious from section 2nd that the tallest tree offers better bioclimatic conditions. Finally, there is a proposal planting plan at the same hour of the day, where the sidewalk is extended to enable middle height trees to be planted. So, this arrangement is a more desirable solution because it fulfils better the aim of bioclimatic and aesthetic purposes

proved ideal for placing medium height trees that are more appropriate for this size of street and height of the buildings.

To summarize, in the streets of the 2nd category we prefer trees with at least a height of 10 m according to the width of the sidewalks. Whereas, we could have better affect on the microclimate of the specific streets planting trees of medium height of 20m. Concretely, in both orientations, we achieve better results when we use two lines of trees of medium size that will shade the facades of the buildings which they should be planted in a distance, at least, of 2.5m away from the buildings.

Streets of the 1st category

Finally, the 1st category streets are considered an east-west avenue of 30m width with 3.5m sidewalks and a tree-covered median strip of 2.5m width; also a north-south street with a width of 20m. Both streets mainly serve commercial uses. A representative section was analyzed with buildings of 16 m height in both orientations (Figs. 10, 11, and 12).

In the 1st section (Fig. 10) of street we place trees of low height at the sidewalks and the median but the shade provided, is inadequate. In the 2nd section (Fig. 10) we achieve the same ineffective result, with medium height trees in the median and low height trees in the sidewalks because the street is broad and the facades of the adjacent buildings are not shaded. The choice for the medium height trees is suitable for the width of the existing sidewalks as its distance ω is the minimum acceptable from the facades of the buildings. The sections at 12:00 and 15:00 show that the best correlation for the specific road are trees of medium height on the sidewalks and tall trees in the median strip (section 3rd, Fig. 10 and section 1st, Fig. 11); this satisfies more our bioclimatic requirements.

In this 30m avenue there is a problem with the widths of the sidewalks, which are only 3.5m, as in the previous case with the 15m streets. Therefore, two solutions are suggested. The

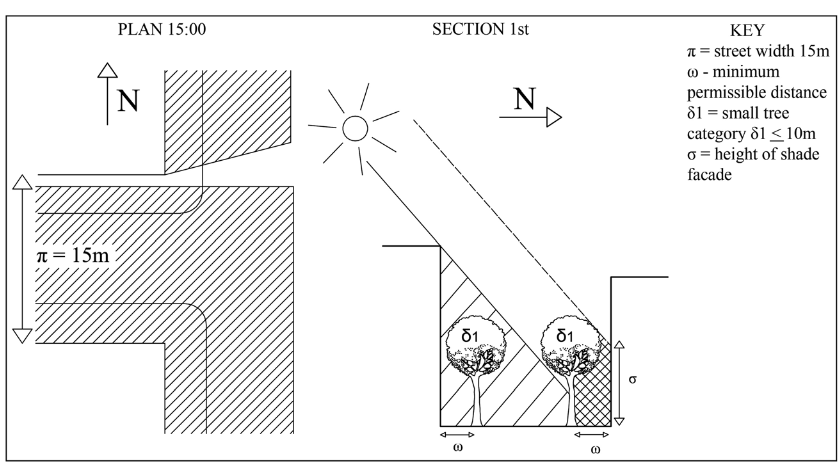
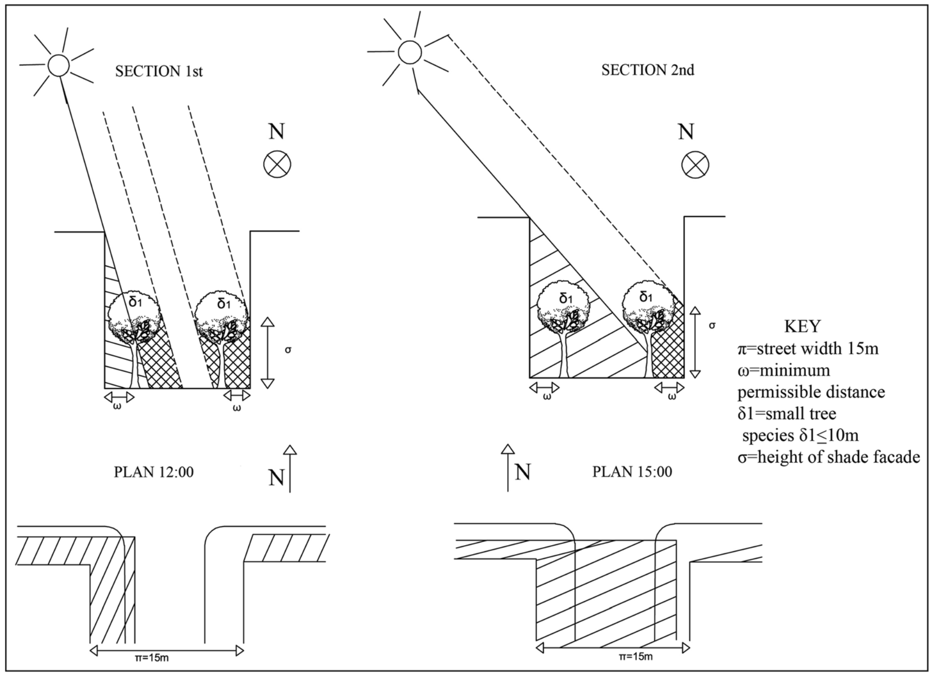


Fig. 8 Second category (width 15 m) east-west street under sun and shade. At this figure we see that the size of trees is inappropriate for 21st June at 15:00 in order to improve microclimatic and aesthetic conditions of the road

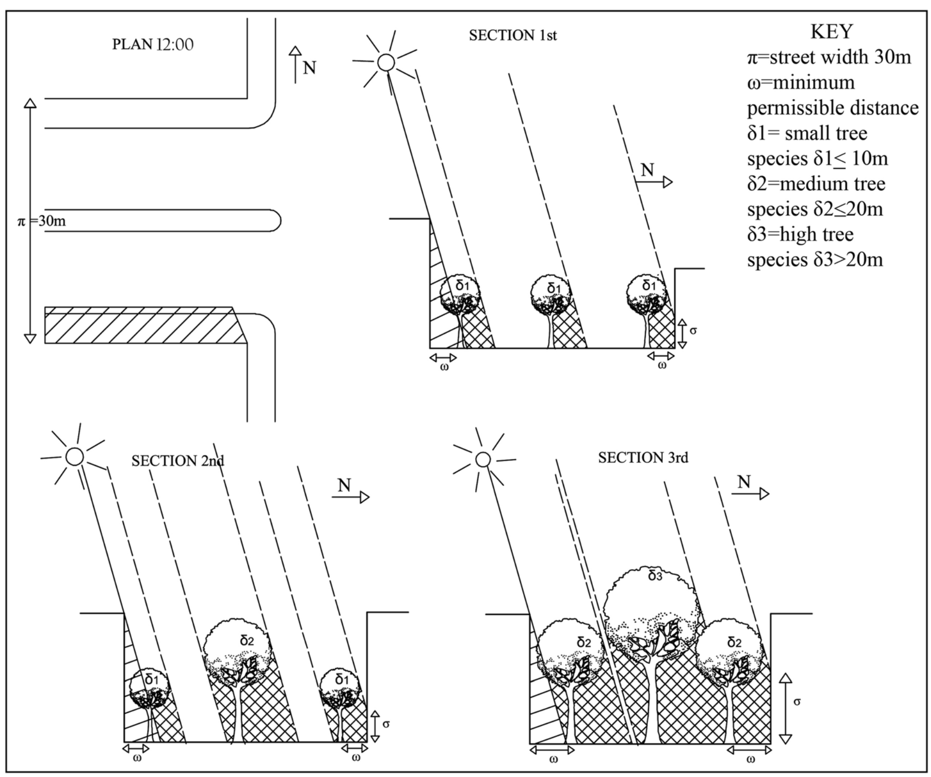
Fig. 9 North-south street of 2nd category (width 15 m) under sun and shade for 21st June at 12:00. At this figure we see that the size of trees is inappropriate for 21st June at 15:00 in order to improve microclimatic and aesthetic conditions of the road



first solution is presented in the section 3 of Fig. 10, it was mentioned earlier and the second solution proposes the widening of the sidewalks to 5.6 m and planting medium-height trees (section 3rd, Fig. 11). The tree arrangement proposed is relevant to The Ramplas Street (Jacobs 1995) in order an enclosed urban environment to be achieved (Rantzoudi 2004).

At Fig. 11, it is presented a 1st category north-south street during the solar heating of 21st June. In the 1st section of this street, as in all the other streets of this orientation, it is noted that at specific period of the day both sides of the street receive solar gain. Therefore, it is concluded that there is a need for a double line of trees. The use of low height trees does not shade

Fig. 10 East-west street of 1st category (width 30m) under sun and shade. In this figure we explore the best placement of trees for 21st June at 12:00 in order to improve microclimatic conditions of the road. Also, we use three different sizes of trees in order to succeed better shading conditions. It's obvious from section 3rd that the combination of the tallest trees offers better bioclimatic and aesthetic conditions, because they provide better shade and they enclose the urban environment



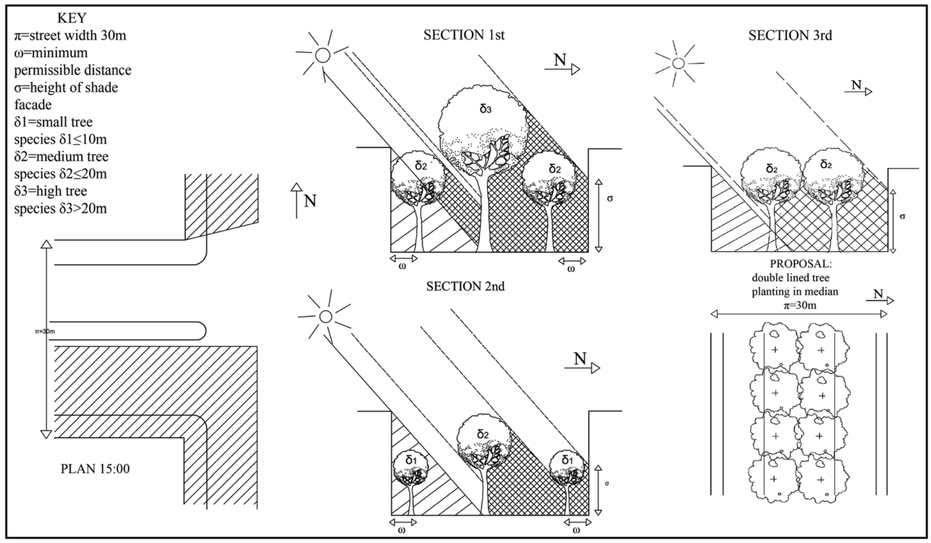


Fig. 11 East-west street of 1st category (width 30m) under sun and shade. At this figure we explore the best placement of trees for 21st June at 15:00 in order to improve microclimatic conditions of the road. The results are the same with the previous figure at 12:00. Also at this figure we explore the best placement of double line of trees in order to improve the microclimate of the road (relevant to The Ramplas Street)

all the facades of the buildings; nevertheless, it is an adequate solution to the width of existing sidewalks. Widening the sidewalks and planting taller trees is suggested; that is considered the ideal solution for the size of the street and height of adjacent buildings (as in the case of streets of 4rd category at Fig. 6). The idea comes from Saint Michel Boulevard (Jacobs 1995), that has similar geometrical characteristics and successful operation (Rantzoudi 2004). As a conclusion for streets wider than 20 m, we suggest trees with a height equal or more than 20 m (medium or high trees). The ideal solution would be to have trees the same height as the buildings and located in the middle of the street.

Discussion and conclusions

Consideration of all categories of streets provided the following acceptable results in terms of tree planting in the streets of the study area (Table 1); these results can also be applied in other cities with similar layout streets.

The results at the table show that short trees are suitable for streets of the 3rd category, whereas for streets of the 2nd category, medium height trees are more appropriate for tree rows. Also, for the 1st category, medium height trees are suitable for sidewalks and large size trees are suitable for the median strip (Fig. 4). Furthermore, from the figures (Figs 5, 6, 7, 8, 9, 10, 11, and 12) it's obvious that there is an immediate need of shading south-facing facades for east-west streets. Also, in north-south streets there is a need to shade west-facing facades. In any case, this effect differentiates as the size of the streets becomes bigger.

Trees contribute to the improvement of microclimate as well as the aesthetics of streets in the city. According to Ali-Toudert and Mayer (2007b) the use of a row of trees improves the thermal comfort situation within the urban street canyon, mostly because the direct solar radiation under the tree canopy

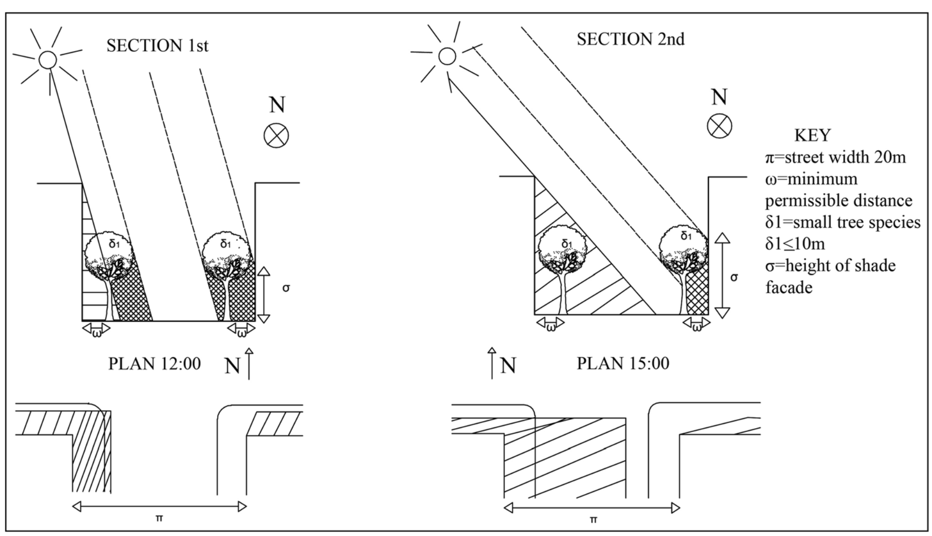


Fig. 12 North-south street of 1rd category (width 20m) under sun and shade for 21st June at 12:00 and 15:00. At this figure we explore the best placement of trees (according to the width of sidewalks) in order to improve bioclimatic and aesthetic conditions of the road. We notice that the size of trees is insufficient for 21st June at 15:00 in order to improve bioclimatic and aesthetic aims. It's obvious, that the combination of the tallest trees will offer better microclimate, because they provide more efficient shade conditions and enclose the urban environment

Table 1 Codification in terms of the relationship between street widths and the height of street trees

Correlation between street width and tree height

Street category	Tree category	Min. Distance from the nearest building (m)	Tree height for the best energy behaviour
3rd	Small trees ($\delta 1$)	2,5	> or =10
2nd	Medium trees ($\delta 2$)	5	> or =20
1st	High trees ($\delta 3$)	5	< 20

is strongly decreased. All features of urban street canyons influence the human thermal comfort with a differentiated situation across the street between the centre and the edges. Hence, manifold possibilities by means of design are available to control the thermal environment of people. Trees create "great streets"; open spaces with social activity for its residents (Rantzoudi 2004).

Planting acts as a medium of unification, as a bulkhead, separating the paving zone from the vehicles zone and as a bollard against the illegal parking (Georgi and Sarikou 2006; Li et al. 2014). The choice of appropriate trees according to our categorization and the geometrical characteristics of the tree help to create a planting design that can be tailored to the needs of individual cities. Its application will improve urban design and bioclimatic conditions of open spaces and buildings; tree lines give identity to streets and encourage strolling under their foliage, which in the future will reduce the use of cars. So, the use of trees improves the urban environment (Haq 2011; Moreno et al. 2015).

The microclimate effect of urban green areas might be obtained by means of several strategies::

i) reducing solar heat gains on windows, walls and roof top through shading (Song and Park 2015).
ii) reducing the building long-wave exchange with the sky by lowering the building surface temperatures through shading, hence reducing heating and cooling costs in the surrounding constructions (McPherson et al. 2005).
iii) reducing the conductive convective heat gain by lowering dry-bulb temperatures through evapotranspiration throughout the hot period (Georgi and Dimitriou 2010).
iv) increasing of latent cooling by adding moisture to the air through evapotranspiration (Georgi and Dimitriou 2010; Dimoudi and Nikolopoulou 2003; Staley 2015).
v) improving the air-quality by enhancing the collection of pollutants on leaves of the urban trees (McPherson et al. 2005; Baldacchini et al. 2017).

Estimation of the decrease of air temperature below the urban canopy due to tree species is therefore a critical issue (Shashua-Bar et al. 2010a, b; Dimoudi and Nikolopoulou 2003; Orlandini et al. 2017).

A recent valuation of urban forests carried out by the City of London showed that the 8 million trees growing in the urban area produce annual benefits of about £132 million, mostly related to the removal of air pollution, and they have an amenity value estimated at £43 billion (Rogers et al. 2015). Trees and forests in and around cities provide a wide range of goods and ecosystem services, and they make major contributions to the livelihoods and quality of life of urban dwellers. Well-maintained, healthy urban forests are one of the few municipal capital investments that appreciate in value over time – because the economic benefits increase as trees grow and require less maintenance (Salbitano et al. 2016).

Generally trees can be used as tools in urban street design and in achieving desirable characteristics and scenery that provides a sense of enclosure, safety, and friendliness to the satisfaction of those who use it. Development of similar research to the present study can help to develop principles of landscape design, ecology, and city planning when planning plantings in the city and especially in streets within central urban areas.

Urban trees can alter the solar radiation rates in shaded areas. The variation of microclimate conditions in the shade of trees depends on the tree species (Georgi and Zafiriadis 2006; Georgi and Dimitriou 2010; Gómez-Muñoz et al. 2010; de Abreu-Harbich et al. 2015). Additional characteristics, like existence of trees and green areas, orientation of streets relatively to the wind direction, are influencing the local thermal conditions. These parameters, among others, may explain the low temperatures recorded at wider streets with lower H/W ratio (Zoulia et al. 2009).

Because of the weather data, tree model and buildings used represent typical or average conditions, results reflect the average long-term impacts for a residential area rather than impacts of extreme events on individual buildings. The methodology applied in this research provides a conceptual framework to use detailed, rigorously validated models to real-world problems, and thus to provide an improved accounting of the complex interactions between trees, sun, building shade and furthermore energy save in a simplified, practical approach (Georgi and Dimitriou 2010).

Moreover, results from Donovan and Butry (2009) show that trees on the west and south sides of a house reduce summertime electricity use, whereas trees on the north side of a house increase summertime electricity use and more precisely the current level of tree cover on the west and south sides of houses in their sample reduced summertime electricity use by 185 kWh (5.2%), whereas north-side trees increased electricity use by 55 kWh (1.5%).

Results from our study provide a useful method to scale up tree-shade effects to an urban area at a neighbour scale, appropriate for national appraisals. To conclude, the lookup sections arrangement (Fig. 5, 6, 7, 8, 9, 10, 11, and 12) lends itself to develop recommendations and guidelines designed to select and locate shade trees to improve microclimate and maximize energy benefits, important for evaluating proposed tree planting programs at a national level. The shade factor of urban trees is a significant issue for the bioclimatic improvement and energy savings at a similar northern Mediterranean city scale that should be taken into consideration by city planners, designers, landscape architects, and architects.

Further research could address other problems such as what are the best locations, climate, what type of buildings, and what type of trees should be used, or what is the best direction that trees can be shaded.

References

Abreu-Harbich LV, Labaki LC, Matzarakis A (2014) Thermal bioclimate as a factor in urban and architectural planning in tropical climates - the case of Campinas, Brazil. Urban Ecosyst 17:489–500

Akbari H, Rosenfeld A, Taha H (1990) Summer heat islands, urban trees, and white surfaces. ASHRAE Trans 96:1–8

Ali-Toudert F, Mayer H (2006) Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Build Environ 41:94–108

Ali-Toudert F, Mayer H (2007a) Thermal comfort in an east-west oriented street canyon in Freiburg (Germany) under hot summer conditions. Theor Appl Climatol 87(1):223–237

Ali-Toudert F, Mayer H (2007b) Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. Sol Energy 81(6):742–754

Baldacchini C, Castanheiro A, Maghakyan N, Sgrigna G, Verhelst J, Alonso R, Amorim JH, Bellan P, Bojović DD, Breuste J, Bühler O, Cântar IC, Cariñanos P, Carriero G, Churkina G, Dinca L, Esposito R, Gawroński SW, Kern M, Le Thiec D, Moretti M, Ningal T, Rantzoudi EC, Sinjur I, Stojanova B, Urošević MA, Velikova V, Živojinović I, Sahakyan L, Calfapietra C, Samson R (2017) How does the amount and composition of PM deposited on *Platanus acerifolia* leaves change across different cities in Europe? Environmental Science & Technology. doi: 10.1021/acs.est.6b04052

Bourbia F, Boucherida F (2010) Impact of street design on urban microclimate for semi arid climate (Constantine). Renew Energy 35(2): 343–347. doi:10.1016/j.renene.2009.07.017

Dafis S (2001) Urban forestry. Art of text, Thessaloniki, pp 113–114

de Abreu-Harbich LV, Labaki LC, Matzarakis A (2015) Effect of tree planting design and tree species on human thermal comfort in the tropics. Landsc Urban Plan. doi:10.1016/j.landurbplan.2015.02.008. 0169-2046

Dimoudi A, Nikolopoulou M (2003) Vegetation in the urban environment: microclimatic analysis and benefits. Energy and Buildings 35(1):69–76

Donovan GH, Butry DT (2009) The value of shade: estimating the effects of urban trees on summertime electricity use. Energy and Buildings 41(6):662–668. doi:10.1016/j.enbuild.2009.01.002

Dwyer JF, McPherson EG, Schroeder HW, Rowntree RA (1992) Assessing the benefits and costs of the urban forest. Journal of Arboricultural 18(5):227–234

Evangelinos E, Bougiatioti F, Oikonomou A (2005) Schematic design proposals of the implementation of PDEC in the urban open spaces of Athens. In Santamouris M (Ed.) 1st International Conference Passive and Low Energy Cooling for the Built Environment, Palenc 2005, Santorini, Greece, Athens; Heliotopos Conferences Ltd, pp 791–796 (vol. II)

Georgi JN (2000) Aesthetic, functional and ecological behaviour of street and park trees of Thessaloniki. PhD thesis, Department of Forestry and Natural Environment, Aristotle University of Thessaloniki

Georgi JN, Dimitriou D (2010) The contribution of urban green spaces to the improvement of environment in cities: case study of Chania, Greece. Build Environ 45(6):1401–1414. doi:10.1016/j.buildenv.2009.12.003

Georgi JN, Sarikou S (2006) Unification and planning of urban public spaces with bioclimatic criteria. Case study Drama, Greece 46th Congress of the European Regional Science Association: Enlargement, Southern Europe and the Mediterranean. Department of Planning and Regional Development, University of Thessaly, Volos, August 30th - September 3rd. available at: https://ideas.repec.org/p/wiw/wiwrsa/ersa06p893.html

Georgi JN, Zafiriadis K (2006) The impact of park trees on microclimate in urban areas. Urban Ecosystems 9(3):195–209. doi: 10.1007/s11252-006-8590-9

Gómez-Muñoz VM, Porta-Gándara MA, Fernández JL (2010) Effect of tree shades in urban planning in hot-arid climatic regions. Landsc Urban Plan 94(3–4):149–157. doi:10.1016/j.landurbplan.2009.09.002

Haq SMA (2011) Urban green spaces and an integrative approach to sustainable environment. J Environ Prot 2(5):601–608. doi: 10.4236/jep.2011.25069

Huang YJ, Akbari H, Taha H, Rosenfeld AH (1987) The potential of vegetation in reducing summer cooling loads in residential buildings. J Appl Meteorol 26:1103–1116. doi:10.1175/1520-0450(1987)026<1103:TPOVIR>2.0.CO;2

Jacobs BA (1995) Great streets. MIT Press, Massachusetts, pp 56-60:93–96

Li Z, Luo D, Lin H, Liu Y (2014) Exploring the quality of public space and life in streets of Urban Village: evidence from the case of Shenzhen Baishizhou. Journal of Sustainable Development 7(5): 162–176. doi:10.5539/jsd.v7n5p162

Lowry JH, Baker ME, Ramsey RD (2012) Determinants of urban tree canopy in residential neighborhoods: household characteristics, urban form, and the geophysical landscape. Urban Ecosyst 15(1):247–266. doi:10.1007/s11252-011-0185-4

Lynch K, Hack G (2002) Site planning. MIT Press, Massachusetts, pp 208–209

Matzarakis A (2006) The climate of Evros. Freiburg. Available at: http://www.urbanclimate.net/matzarakis/papers/Climate_Evros.pdf

Mayer H, Matzarakis A (2006) Impact of street trees on thermal comfort of people in summer: A case study in Freiburg (Germany). Merchavim 6:285–300

McPherson EG, Dougherty E (1989) Selecting trees for shade in the southwest. J Arboric 15(2):35–43

McPherson G, Simpson JR, Peper PJ, Maco SE, Xiao Q (2005) Municipal forest benefits and costs in five US cities. J For 103(8): 411–416

Moreno A, Tangenberg J, Hilton BN, Hilton JK (2015) An environmental assessment of school shade tree canopy and implications for sun safety policies: the Los Angeles unified School District. International Journal of Geo-Information 4(2):607–625. doi:10.3390/ijgi4020607

Moughtin C (2003) Urban design – street and square. Elsevier, Oxford, pp 127–169

Mullaney J, Lucke T, Trueman SJ (2015) A review of benefits and challenges in growing street trees in paved urban environments. Landsc Urban Plan 134:157–166. doi:10.1016/j.landurbplan.2014.10.013

Oke TR (1987) Boundary layer climates. Methuen & Co, London, pp 297–298

Orlandini S, Vanos J, Matzarakis A, Massetti L, Petralli M (2017) Urban forestry and microclimate. In: Ferrini F, Fini A (eds) Konijnendijk van den Bosch CC. Routledge Handbook on Urban Forestry. Taylor & Francis, Oxford, pp 96–111

Randrup TB, Mc Pherson EG, Costello LR (2001) A review of tree root conflicts with sidewalks, curbs, and roads. Urban Ecosystems 5(3): 209–225. doi:10.1023/A:1024046004731

Rantzoudi EC (2004) The contribution of the vegetation across the roads at the improvement of the urban environment considering bioclimatic and aesthetic criteria (Case of Study the city of N. Orestiada). Master's thesis, School of Science and Technology, Hellenic Open University

Rogers K, Sacre K, Goodenough J, Doic K (2015) Valuing London's urban forest results of the London i-tree eco project. London Treeconomics. Available at: www.itreetools.org/resources/reports/Valuing_Londons_Urban_Forest.pdf

Russ T (2002) Site planning and design handbook. McGraw-Hill, New York, pp 95, 163–165, 183, 348

Salbitano F, Borelli S, Conigliaro M, Chen Y (2016) FAO.2016.Guidelines on urban and peri-urban forestry. FAO Forestry Paper No.178, Rome, Food and Agriculture Organization of the United Nations

Shashua-Bar L, Potchter O, Bitan A, Boltansky D, Yaakov Y (2010a) Microclimate modelling of street tree species effects within the varied urban morphology in the Mediterranean city of Tel Aviv, Israel. Int J Climatol 30(1):44–57. doi:10.1002/joc.1869

Shashua-Bar L, Tsiros IX, Hoffman ME (2010b) A modeling study for evaluating passive cooling scenarios in urban streets with trees. Case study: Athens. Greece Building and Environment 45(12):2798–2807. doi:10.1016/j.buildenv.2010.06.008

Simpson JR (2002) Improved estimates of tree-shade effects on residential energy use. Energy and Buildings 34(10):1067–1076. doi:10.1016/S0378-7788(02)00028-2

Simpson JR, McPherson EG (1996) Potential of tree-shade for reducing residential energy use in California. J Arboric 22(1):10–18

Song BG, Park KH (2015) Contribution of greening and high-albedo coatings to improvements in the thermal environment in complex urban areas. Adv Meteorol 2015:1–14. doi:10.1155/2015/792172

Staley DC (2015) Urban forests and solar power generation: partners in urban heat island mitigation. Int J Low-Carbon Technol 10(1):78–86

Streiling S, Matzarakis A (2003) Influence of singular trees and small clusters of trees on the bioclimate of a city : a case study. J Arboric 29(6):309–316

Thayer RL Jr, Maeda BT (1985) Measuring street tree impact on solar performance: a five-climate computer modeling study. J Arboric 11(1):1–12

Tzonos P (1985) Heliasmus. Paratiritis, Thessaloniki

Yilmaz S, Toy S, Irmak MA, Yilmaz H (2007) Determination of climatic differences in three different land uses in the city of Erzurum, Turkey. Build Environ 42(4):1604–1612. doi: 10.1016/j.buildenv.2006.01.017

Zoulia I, Santamouris M, Dimoudi A (2009) Monitoring the effect of urban green areas on the heat island in Athens. Environ Monit Assess 156:275–292. doi:10.1007/s10661-008-0483-3