LOUAFI BELLARA Samira, ABDOU Saliha, REITER Sigrid, 2016. Thermal and visual comfort under different trees cover in urban spaces at Constantine city centre - hot and dry climate. In: La Roche P., Schiler M., Proceedings of the 32nd International Conference on Passive and Low Energy Architecture. PLEA 2016: "Cities, Buildings, People: Towards Regenerative Environments", Vol. II: 1037-1043. Los Angeles.

Thermal and Visual Comfort Under Different Trees Cover in Urban Spaces at Constantine City Center -Hot-Dry Climate-

LOUAFI BELLARA SAMIRA[1], ABDOU SALIHA[1], REITER SIGRID[2]

[1]Laboratory Bioclimatic Architecture & Environment "ABE", University Constantine3, Constantine, Algeria
[2]Local Environment Management & Analysis LEMA, University of Liege, Liege, Belgium

ABSTRACT: In urban environments, vegetated spaces have proven to act as ameliorating factors of some climatic features related to heat stress, reducing their effects and providing comfortable outdoor settings for people. The consideration of the thermal and visual outdoor conditions in cities is increasingly important for the well-being of man and the use of public spaces. Tree shaded areas can reduce the heat effect by amelioration of microclimate and human outdoor thermal comfort. The objective of this research is to investigate thermal and visual comfort and perception in tree shaded area in open urban spaces and to compare the performance of areas shaded by different types of tree coverage, including an open area without vegetation, located in a hot and dry climate. The methodology is based on a combination of an investigation conducted by structured interview, microclimate measurement. Measurements of air temperature, air humidity, wind speed, solar global radiation, luminance and the sky view factor combined with comfort surveys were performed during summer in different areas in the city center of Constantine in Algeria (a hot and dry climate). The results indicate that the percentage of tree coverage of a space is a highly important metric to assess outdoor comfort in a hot-dry climate and that it influences mainly the use of outdoor recreational areas. Dense vegetation cover optimises the microclimatic environment for pedestrians' thermal and visual comfort in urban spaces, under these climatic conditions.
Keywords: tree cover, thermal sensation, visual sensation, solar energy, outdoor public space

INTRODUCTION

The shade is in general the outside required principal effect during overheating periods for the areas under hot and dry climate. In urban environments, green spaces have proven to act as improving factors of some climatic features related to heat stress, reducing their effects and providing comfortable outdoor settings for people (Nikolopoulou, 2001). The mineralization of outdoor spaces, replacing vegetation and humid zones with concrete and asphalt contributes to the appearance of the harmful effects on the environment and human well-being. It develops, in summer, more and more problems related to microclimatic phenomena of urban heat island. The shade reduces considerably solar flows, by limiting the heating of surfaces which normally should be sunny; it also reduces thermal radiative flows.

It is well known that the presence of vegetation modifies the microclimate (light, heat, wind, and humidity) and influences the perception of urban spaces by the users (Nikolopoulou et al, 2001; Nikolopoulouet al, 2003; Reiter et al, 2003). Trees and vegetation embellish the cities and improve the citizens quality of life. Trees planted along the streets and in the parks, around the houses or shops or in the green areas throughout the city also improve the quality of the air and water. The urban green areas offer the possibility of recreation, and make the districts more pleasant (Marjury, 2007). Vegetation can modify urban microclimates shading and evapotranspiration, the use of plants to improve urban heating is one strategy that has generated significant interest (Sreetheran et al, 2006; Sailor, 1998). Trees and buildings existing singly or in clusters create strong spatial variability in local heat transfer fluxes that define urban microclimates within the urban canopy layer (Simpson and McPeherson, 1998).

In a hot-dry climate, Grimmond; Oke and Cleugh found in that the temperature in a tree-vegetated suburban area in Sacramento was 5°C to 7°C cooler than in mineral areas (Jo and McPeherson , 2001).

It is therefore important to account for, on the other hand, the shading effect of trees on thermal comfort, the influence of reflected and transmitted solar infrared radiation on the energy budget of humans and buildings in their surroundings (Oke,1989; Grimmond et al, 1993). Some studies detailed the relationship between physical environmental factors in green areas, thermal sensation, and the psychological condition. Tada and Fujii (2006) evaluated the visual comfort of plant shades through their influence on the psychological state. Takayama et al. (2005) focused on the optical environment of forests and

LOUAFI BELLARA Samira, ABDOU Saliha, REITER Sigrid, 2016. Thermal and visual comfort under different trees cover in urban spaces at Constantine city centre - hot and dry climate. In: La Roche P., Schiler M., Proceedings of the 32nd International Conference on Passive and Low Energy Architecture. PLEA 2016: "Cities, Buildings, People: Towards Regenerative Environments", Vol. II: 1037-1043. Los Angeles.

performed measurements in forest and urban areas, evaluating the influence of light on thermal sensation and the psychological condition. Park et al. (2011) examined the correlation between psychological responses and the physical environment in forests. Furthermore, this study, the simultaneous measurement of the thermal environment, thermal sensation, and the mental state of subjects was performed to examine the effects of the type of coverage and density one

In the present article, the aim is to assess whether people located under tree shade experience comfort or stress in open spaces during hot-dry season. The specificity of this study is to use a quantitative analysis through site measurements together with a qualitative analysis through comfort observation. The detailed objectives of this study are to:

1) Investigate the effects of three different spaces on thermal and visual conditions in outdoor spaces.
2) Discuss whether trees shade affects people's thermal comfort in hot-dry climate, and evaluate outdoor thermal comfort based on comfort indexes "predict equivalent temperature" (PET) and "mean radiant temperature" (Tmrt).
3) Try to highlight the role of presence of trees shade and cover on the use of spaces in hot-dry climate.

SITE INVESTIGATION

The investigation was conducted in Constantine City (Algeria), which is located at 36.17 North and 07.23 East. The altitude is approximately 687 m above sea level. This city is characterised by a semi-arid climate that is hot and dry in the summer, cold and humid in winter. Temperature can reach a maximum value of 36°C and the relative humidity is quite low until a value of 25%. Solar radiation is intensive and the sky is very clear and sunny for a large portion of the day. The prevailing winds come from North, with an average speed of 2.1 m/s. All these factors contribute to the climatic harshness of the city. The selected site is located in the city centre (figures 1 and 2).

It concerns a recreational and transitional area. The square is characterised by different types of tree cover and a mineral open area is beside it. Note that in one zone of the square, there is also a water fountain.

Figure 1: View of the vegetal square (left) and the mineral area (right) investigated line drawings are essential.

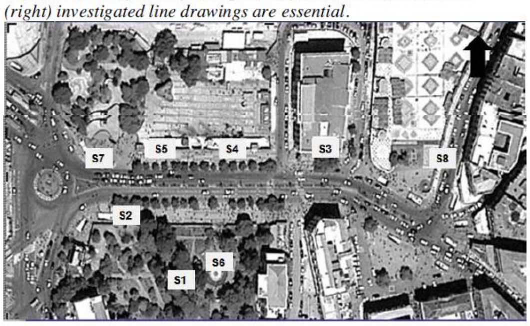
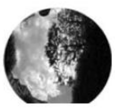


Figure 2: The different stations of the measurements and surveys drawings are essential and Different views of stations investigated.

Table 1 Sky view factor (SVF) related to the percentage of tree coverage

Station	Fish-eye photo	Station	Fish-eye photo
Station 1 ***Dense tree cover*** *Percentage of tree cover =* ***85%*** *SVF =* ***0.10***		Station 2 *Dense tree cover* *Percentage of tree cover =* ***65%*** ***SVF =*** *0.38*	
Station 3 *Dense tree cover* *Percentage of tree cover = 70%* *SVF = 0.40*		Station 4 *Medium tree cover* *Percentage of tree cover =* ***45%*** ***SVF =*** *0.50*	
Station 5 **Low tree cover** *Percentage of tree cover = 50%* *SVF = 0.55*		Station 6 **Very low tree cover and** *presence of a water fountain* *Percentage of* ***tree cover =***	

1038

LOUAFI BELLARA Samira, ABDOU Saliha, REITER Sigrid, 2016. Thermal and visual comfort under different trees cover in urban spaces at Constantine city centre - hot and dry climate. In: La Roche P., Schiler M., Proceedings of the 32nd International Conference on Passive and Low Energy Architecture. PLEA 2016: "Cities, Buildings, People: Towards Regenerative Environments", Vol. II: 1037-1043. Los Angeles.

METHODOLOGY

This article aims in one hand, to highlight the variation of the climatic parameters that vegetation induces on outdoor thermal and visual comfort during overheating periods in hot-dry urban environments on the other hand it measure the effects of tree coverage on the use of recreational spaces. The method consists of comparing different areas in Constantine City (Algeria) using site measurements and comfort surveys. The measurements dynamically assessed five physical parameters (air temperature, relative humidity, wind speed, global solar radiation and luminance) and also gave a mean value for the sky view factor. The thermal and visual comfort surveys were undertaken with recreational users.

Six stations were chosen to represent the different vegetal environments encountered in this area (see figures 1 and 2). Two stations represent the open space without vegetation cover.

The measurements and the surveys were collected from eight stations that were selected based on the variation of the percentage of vegetation coverage in the square: S1 = 85%, S 2 = 65%, S3= 70%, S4 = 45%, S5=40% S6= 20% and S7, S8 = 0% (Fig 1 and Table1).

They were carried out in summer during the month of July 2014, representing the hottest period. Measurements were carried out simultaneously over four weeks. One typical daily cycle was selected in this article to represent the forth-week period to show detailed monitoring results.

Air temperature, relative humidity, wind speed, solar radiation and luminance were collected using digital instruments (Multifunction instrument (LM800), Pho-radiometer HD2302.0 with several probes). The measurements were taken at a height of 1.5m and were recorded every 2 hours at each station from 6h00 to 20h00 each day. To determine the sky view factor, fish-eye photographs were taken at each station 1.5m above ground with a Nikon 8mm fish-eye lens with a picture angle of 180°.

Field comfort surveys of 500 interviewees were conducted at the site selected stations throughout summer 2014. One aim of these surveys was to obtain a better understanding of human outdoor thermal comfort; response under different types of tree coverage. Moreover, it aims to evaluate using an adaptive comfort model for spaces shaded by vegetation in hot-dry summer climates, which will be detailed in a following paper. Qualitative data on the visual and thermal perception of the interviews were recorded using a questionnaire (see table 2) that was adapted from those used in recent ANSI/ASHRAE indoor studies with some specific items added (ASHRAE, 2004). For example, the questions that enquired about sun/shade preferences were not part of the ASHRAE questionnaire.

Table 2 Questionnaire used in this research

Thermal comfort	Very cold	Cold	Neither cold or hot	Hot	Very hot
What do you think of the sun at this time?	Prefer more		Neutral		Too much sun
What do you think of the wind at this time?	Calm	Weak wind	Neutral	Windy	Too much wind
What do you think of moisture at this time?	Wet		Neutral		Dry
What do you think of the luminosity of this space?	Very dark	Dark	Neither dark or bright	Bright	Very bright

RESULTS AND DISCUSSION

Outdoor thermal and visual comfort in urban spaces is an important indicator of the quality of life in urban environment. This study provides new insight into the role of trees on microclimate and human thermal comfort in a local urban area through field measurements and survey.

Trees behave in different ways on microclimate due to mainly distinct features of each species and planting strategies, especially in the hot and dry climate.

Appropriate vegetation used for shading is essential to mitigate heat stress and can create better human thermal comfort. Observed weather conditions were clustered to investigate the differences in cooling and glare effect of trees cover was analysed. The results from both measurements show that trees significantly altered the surrounding summer microclimate in relation to degree of coverage.

Figure 3 shows the air temperature evolution during a typical summer day at the eight measurement stations. This typical summer day presents the average values measured during a few continuous days. The figure shows that the two open spaces without trees cover are warmer from 10h00 to 20h00, than the vegetal areas under different tree covers, which is consistent with previous studies.

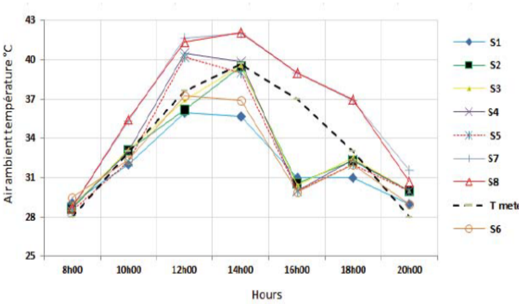


Figure 3: Average Air temperature at the various stations of measurement during few continuous summer days

Figure 3 also shows that the denser of vegetation cover, the more about air temperature is reduced during the overheating period of the day. One exception is that air temperature measured at station 6 (with 20% of tree cover) is equivalent to the air temperature measured at station 2 and 3 (with 45% of tree cover), and is even lower at 14h00. This is due to the presence of a water fountain and the proximity of tree's mass near the station 6. So, they participate in lowering the air temperature.

According to analyses of the results, the mean temperature differences between the open space and the six vegetal areas are presented in figure4. The temperature differences are the most significant during the hottest period of the day, between 10h00 and 16h00. These values are in consistent with the results of a previous study on urban vegetal areas in the hot-dry climate mentioned above (Tsiros, 2010; Spangenberg et al, 2008; Toy and Yilmaz 2007). Figure 4 shows that the space with the highest tree coverage is 7°C cooler than the open space at 12h00 and is 4°C cooler at 14h00. Note also that the presence of a water fountain combined with a tree coverage of 20% can lower the air temperature by 2,2°C at 12h00 and 2,4°C at 14h00 compared with the open space.
Figure 5 shows that the air temperature has a negative correlation (R=0,819 à 12h00) with the percentage of tree coverage.

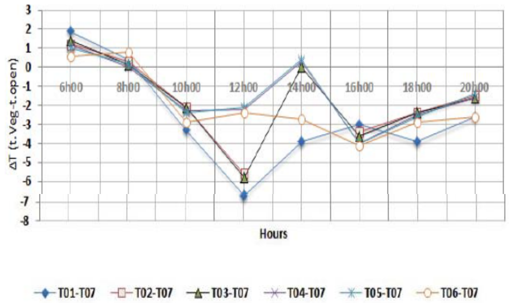


Figure 4: Average Air temperature at the various stations.

The effect of solar radiation on the human thermal balance is particularly dominant outside. The amount of global solar radiation measured at 12h00 was approximately 1707 W/m² in sunshine and varies between 79 W/m² and 160 W/m² according to tree coverage during the experimental period. The difference in global solar radiation between the open space and the dense vegetal areas can thus reach approximately 1600 W/m² at 12h00.

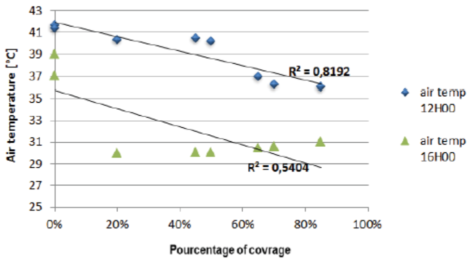


Figure 5: Air temperature and percentage of coverage correlation

From figure 6, it can be seen that in all measured stations, the mean global solar at 12h00 has a negative correlation (R^2= 0,887) with the percentage of tree coverage. Dense coverage minimises direct solar radiation transmission and increases the amount of shade. Thus, a high percentage of tree coverage can create more comfortable thermal conditions because of the effects of the tree coverage on global solar radiation.

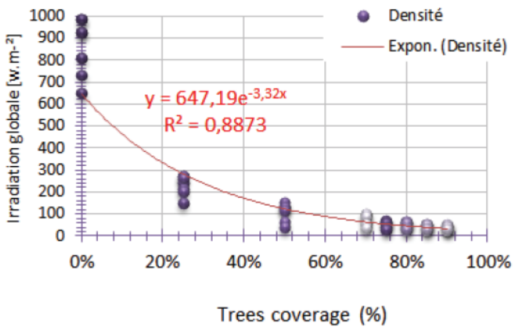


Figure 6: Global solar radiation and tree cover correlation

LOUAFI BELLARA Samira, ABDOU Saliha, REITER Sigrid, 2016. Thermal and visual comfort under different trees cover in urban spaces at Constantine city centre - hot and dry climate. In: La Roche P., Schiler M., Proceedings of the 32nd International Conference on Passive and Low Energy Architecture. PLEA 2016: "Cities, Buildings, People: Towards Regenerative Environments", Vol. II: 1037-1043. Los Angeles.

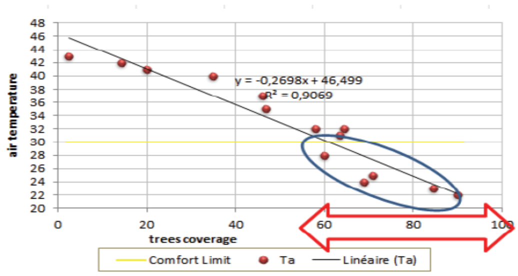


Figure 7: tree cover recommended for comfort

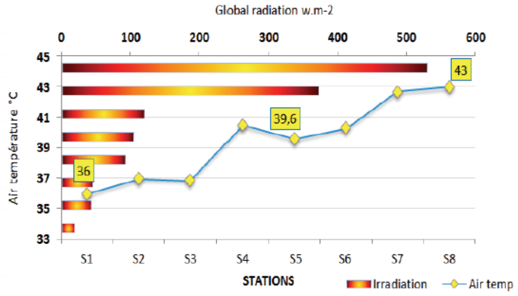


Figure 8: Relationship between air temperature and quantity of irradiation at 12:00

From Figure 9, it is showing the relationship between the luminance sans sky view factor (SVF); at the selected stations (Table 2). Daylight has a major impact on physical performance and visual comfort in open spaces.

We note that the highest value of luminance (15430cd/m² at mid-day) due to the light reflected from urban materials and direct light in the visual field. The lowest luminosity value was recorded in S1, S2 and S3, which are the areas with the most dense tree coverage (SVF=0,1and albedo value =0.1) and with the lowest value of luminance (202 cd/m² -250 cd/m² at 12:00). To reduce glare, it is recommended that the luminance values remain below 1500cd/m² in the visual field (Reiter and al, 2004), meaning that the sky view factor of these areas should remain below or equal to 0.4, which corresponds to tree coverage of at least 50% of the space.

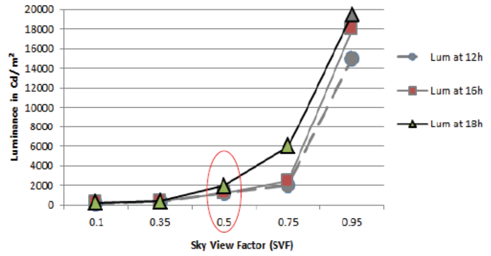


Figure 9: Relationship between the luminance and the sky view factor (SVF) at the measurement stations.

COMFORT INDEX (PET)

The index of thermal stress was calculated from measured meteorological data in the studied sites to evaluate thermal comfort in the different areas based on radiative and convective pedestrian – environment energy exchanges and sweat efficiency, and expressed on a thermal sensation scale ranging from 'comfortable' to 'very hot'.

Thermal comfort on the level of different station is evaluated according to the index of comfort "Physiology Equivalent Temperature" (PET), which is based on the human energy balance, takes into account the effects of solar radiation, air temperature, air humidity, wind velocity and mean radiant temperature of the surroundings Tmrt (Matzarakis et al, 2002). Figure 10 gives the PET values at the different stations for a typical summer day and the thermal sensations associated. The highest values of the PET were recorded at S7 and S8, which are open spaces with no tree coverage, and correspond to an extremely hot sensation between 10h00 and 18h00. The lowest values of PET were recorded in station 1, which is the area with the most dense tree coverage, and correspond to a lightly hot station (31.2 °C at 12:00 and 31.3°C at 14:00).

The difference in terms of PET values between stations1 and 5 with the most different types of coverage varies between 2°C and 7°C (at 14:00), which means a significant comfort improvement in areas shaded by trees, having a significant percentage of coverage.

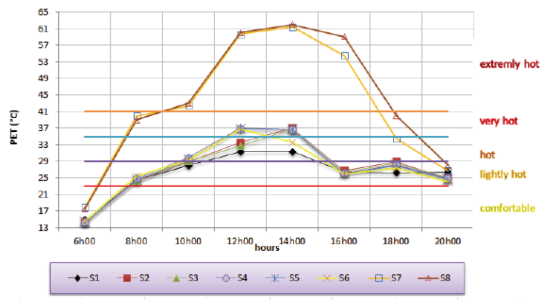


Figure 10: Physiology Equivalent Temperature (PET) at the measurement stations and thermal sensations levels.

SURVEY RESULTS

The survey results presented in figure 11 show that a majority (70%) of the users located under a tree coverage felt a neutral thermal sensation during the morning (at 6h00, 8h00 and 10h00), whereas 50% of the people located in the open space with full solar radiation felt a hot sensation at the same time, which means a comfort improvement under shaded areas early in the morning.

From the survey, we can also observe that the feeling of wellbeing and comfort dominates in the vegetal areas of the square. The global assessment of the environment is also particularly positive there. The microclimate is considered pleasant because of the shade and the soft daylight of the space. However, in the mineral area, the feelings of discomfort, heat and glare are marked, and the global assessment of the environment is negative.
global assessment of the environment is negative.

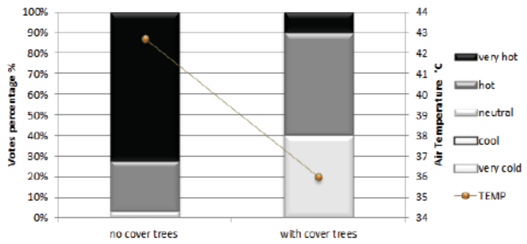


Figure 11: Global perception of the interviewees according to their vote percentages and tree cover correlation.

Solar radiation that falls directly on a person significantly affects his/her perception of thermal and visual comfort. The survey results show that with tree coverage, the sun's radiation is perceived as neutral by 75% to 100% of the interviewees, whereas with no tree cover, 60% to 90% think there is too much sun.

Finally, the vegetated areas are used more frequently and are perceived as more comfortable than the mineral ones.

CONCLUSION

The vegetation can affect the microclimate in many ways, in particular reducing the air temperature, luminance compared to stations without trees, while getting shades.

The vegetation makes esthetic improvements to an environment differently dominated by asphalt and the concrete.

The presence of the vegetation reduces the effects of solar radiations on thermal and visual comfort sensation in outdoor spaces, air temperature and the relative humidity.

A comprehensive field measurement has been conducted to study the microclimate condition under different areas. The effects of vegetation on human thermal stress in a hot-arid region were tested in different spaces with various degrees of coverage. The result of good shading provided by the dense foliage cover, which is able to intercept much more incoming solar radiation.

The results from both the measurements showed that trees significantly altered the surrounding summer microclimate. The comparison of the measurements between the shaded and unshaded area showed that the daily maximum air temperature differed by 2.5 °C to 3°C. Significant spatial variations were caused by the trees. Trees considerably improved the thermal comfort level through reducing the 'very hot' and 'hot' thermal conditions in the study area.

The percentage of tree coverage of a space is a highly important metric to assess outdoor comfort in a hot-dry climate and that it influences mainly the use of outdoor recreational areas. Dense vegetation cover optimizes the microclimatic environment for pedestrians' thermal and visual comfort in urban spaces, under these climatic conditions.

The measurements indicated that a correlation between the percentage of tree coverage and the amount of global solar radiation, which affects the pedestrians' visual and thermal comfort. There is a correlation between the air temperature, and physiologically equivalent temperature (PET) in hot seasons, which influences the quality of perception

Moreover, the percentage of tree coverage of a space is a highly important metric to assess outdoor comfort in a hot-dry climate; which influences the use of outdoor recreational areas. The denser tree cover, the lower the air temperature and the solar radiation, the higher relative humidity, and the better the thermal and visual comfort of pedestrians.

Trees very often constitute an important component of the opened external space, which strongly contributes to the environmental quality.

In addition, the trees increase the well-being perception of external space and thermal comfort perceived on period of heat stress in this type of climate.

REFERENCES

ANSI/ASHRAE.; (2004). Standard 55-2004: "thermal environmental conditions for human occupancy". Atlanta, Georgia: American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE).

Grimmond, C., Oke, T., and Cleugh, H. (1993) "The role of rural" in comparison of observed suburban-rural flux difference," in Exchange Processes at the Land Surface for a

Range of Space and Time Scales, Proceedings of the Yokohama Symposium,(July 1993).

Iohannis, X and Tsiros. (2010) Assessment and energy implications of street air temperature cooling by shade tress in Athens (Greece) under extremely hot weather conditions. *Renewable Energy*, 35: 1866–1869.

Jo, H. and McPherson, E. G., (2001) "Indirect carbon reduction by residential vegetation and planting strategies in Chicago, USA"; Journal *of Environmental Management*, vol. 61, pp. 165-177.

Kotzen, B., (2003) "An investigation of shade under six different tree species of Negev desert towards their potential use for enhancing microclimatic conditions in landscape," Architectural development. *Journal of Arid Environments*, vol. 55, pp. 231-274.

Marjury, M., (2007) "Le rôle climatique de la végétation urbaine," Culture et Recherche, no. 113.

Matzarakis. A., Mayer. H., Rutz. F. (2002). Radiation and thermal comfort. 6°Hellenic Conference In Meteorology Climatology And Atmospheric Physics. Loannina 25-28 September. 738-744.

Nikolopoulou, M. and Steemers, K., (2003) "Thermal comfort and psychological adaptation as a guide for designing urban spaces, *Energy and Buildings*, vol. 35, no. 1, pp. 95-101.

Nikolopoulou, M., Baker, N., and Steemers, K., (2001) "Thermal comfort in outdoor urban spaces: Understanding the human parameter," *Solar Energy*, vol. 70, no. 3, pp. 227-235,.

Oke, T. R. (1989) "The micrometeorology of the urban forest," Philosophical Transactions of the Royal Society of London, vol. 324, pp.335-349.

Park B-J et al (2011) Relationship between psychological responses and physical environments in forest settings Landscape and Urban Planning Volume 102, Issue 1, 30 July 2011, Pages 24–32.

Reiter, S. and De Herde, A.,(2003) "Qualitative and quantitative criteria for comfortable urban public spaces," in Proceedings of the 2nd International Conference on Building Physics, A. A. Balkema, Lisse (The Netherlands), pp. 1001-1009.

Reiter, S. and De Herde, A.,(2004) L'éclairage naturel des bâtiments. Presses universitaires de Louvain, Louvain-la-Neuve (Belgium) 2004, p. 265.

Sailor, D. J. (1998) "Simulations of annual degree-day impacts of urban vegetation augmentation," Atmospheric Environment, vol. 32,pp.43-52.

Schmidt, N., (1979) "Desert animals-physiological problems of heat and water," Dover Publication, New.

Shahidan, M. F. and al , (2010) "A comparison of Mesua ferrea L. and Hura crepitans L. for shade creation and radiation modification in improving thermal comfort," *Landscape and Urban Planning*, vol. 97, pp. 168-181.

Simpson; J. E. and Pherson, M. (1998) "Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento," *Atmospheric Environment*, vol. 32, pp. 69-74.

Spangenberg J., Shinzato P., Johansson E. and Duarte D. (2008) Simulation Of The Influence Of Vegetation On Microclimate And Thermal Comfort In The City Of Sao Paulo. Revue SBAU, Piracicaba., V.3, n2, P.1-19.

Sreetheran M., Philip E., Adnan M., and Sitizakiah M .(2006) "A historical perspective of urban tree planting in Malaysia," Unasylva 223, vol. 57, pp. 28-3.

Tada, M., and E. Fujii. 2006. "Physiological and Psychological Responses on Subjects in Plant Shades as Visual Comfortableness." Journal of the Japanese Institute of Landscape Architecture 69 (5): 475-478.

Takayama, N., T. Kagawa, T. Kasetani, B. Park, Y. Tsunetsugu, Y. Oishi, H. Hirano, and Y.Miyazaki. 2005. "The Comfortableness of the Light / Thermal Environment for Bathing in the Forest Atmosphere." Journal of the Japanese Institute of Landscape Architecture 68 (5):819-824.

Toy S, Yilmaz H (2007); Determination of bioclimatic comfort in three different land uses in the city of Erzurum, Turkey. *Building and environment*; 42(3): 1315-1318.