Thermal comfort conditions in outdoor spaces

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ABSTRACT

The present paper describes a process for designing and applying several techniques based on bioclimatic architecture criteria and energy conservation principles in order to improve the microclimate in an outdoor space located in the greater Athens area. The thermal comfort conditions were used as an indicator for the microclimatic improvements in the tested area. For that reason, the thermal comfort conditions in twelve different outdoor space points have been calculated using two different thermal comfort bioclimatic indices developed to be used for outdoor spaces. The used indices were the following: a. COMFA, which is based on estimating the energy budget of a person in an outdoor environment and b. Thermal Sensation TS, based on the satisfaction or dissatisfaction sensation under the prevailing climatic conditions of the outdoor spaces. Calculations were performed during the summer period and two different scenarios of the constructed space parameters have been considered. The first scenario consists of a conventionally constructed space while the second one includes various architectural improvements according to the bioclimatic design principles. Furthermore a comparison between the calculated results of the two bioclimatic indicators is presented in order to achieve a better understanding of the thermal comfort conditions in the above mentioned outdoor space locations as well as the effect of the bioclimatic design architectural improvements on the human thermal comfort sensation.

1.INTRODUCTION

The present paper aims at describing an application of bioclimatic techniques in an open urban space in order to improve microclimate. Thermal comfort conditions have been considered to be an indicator of the prevailing microclimatic conditions. Thus, two different methods of thermal comfort conditions calculations and for two different scenarios including a conventionally constructed space and a bio-climatically designed area, in the experimental outdoor space have been presented and used in the present paper. The results of both methods were compared and several conclusions were achieved related to the influence of bioclimatic design architectural improvements on the thermal comfort conditions in the outdoor spaces.

2. MODELING THE THERMAL COMFORT CONDITIONS IN OUTDOOR SPACES

2.1 Estimation of the thermal comfort in outdoor spaces using Givoni method

The thermal comfort sensation in outdoor spaces is a factor that significantly influences the human activities in outdoor areas. Actually the degree and intense of such activities depend on the level of satisfaction or dissatisfaction under the prevailing climatic conditions of the outdoor spaces. Givoni et al described and presented the results of an experimental study conducted in Japan in 1994-1995 (Givoni and Noguchi, 2000). The objective of this research was to determine the quantitative effect on the outdoor comfort of Japanese persons. The amount and intensity of any human outdoor activity is affected by the level of discomfort experienced

Table 1: The seven levels of the thermal sensation scale (Givoni et al., 2002).

Level	Sensation
1	Very Cold
2	Quite Cold
3	Cold
4	Comfort
5	Hot
6	Quite Hot
7	Very hot

by the inhabitants when they are exposed to the climatic conditions in the outdoor spaces. The research utilised a questionnaire surveys on the subject's sensory responses and included physical measurement of outdoor climate data. The questionnaire was mainly concerned with the following two elements: a. thermal sensation, and b. overall comfort. Thermal sensation is the perception of heat or cold, on a scale of one, (very cold), to seven, (very hot). The scale of the overall comfort is from one, (very uncomfortable), to seven, (very comfortable). Level four is neutral, when somebody does not feel any thermal discomfort, to correspond with level four of the thermal sensation.

In Table 1 can be seen the seven levels of the thermal sensation scale of Givoni method. Thermal comfort level is strongly related to the thermal sensation. Thermal comfort could better be defined just as the absence of any sense of discomfort. The experiments were performed under controlled solar insolation and wind speed in order to understand how these physical factors influence the thermal sensation and the comfort level of Japanese persons staying in outdoor spaces. The main sites selected for the experiments were a grassed open space as well as an asphalt parking area in a park in Yokohama city. The investigation was performed in different seasons, from summer 1994 to summer of 1995. The following climatic parameters were measured during the experiment: a. ambient air temperature in the shade, (T_a, in ˚C), b. horizontal solar radiation, (SR, in W/m^2), c. wind speed, (WS, in m/sec), d. relative humidity, (RH, %), and e. the surrounding ground surface temperature, (ST, in ˚C).

After analysing the measured data, a formula has been developed which can predict the thermal sensation of people staying outdoors.

The developed multi-factor regression formula, which expresses the thermal sensation, (TS), in outdoor spaces as a function of the five above mentioned climatic parameters can be written as follows (Givoni and Noguchi, 2000):

$$TS=1.7+0.1118*Ta+0.0019*SR-0.322*WS-0.0073*RH+0.0054*ST \quad (1)$$

With an R^2, (regression coefficient), value of 0.8792.

2.2 The COMFA method

Understanding thermal comfort in outdoor spaces is a basic requirement for microclimatically oriented urban design including the design of green urban structures (Scudo, 2002). For outdoor activities, traditional thermal indices can be used in combination with simplified tools in order to evaluate the influence of physical parameters of the surrounding already existing or designed environment on thermal comfort, taking always into account the interaction between physical, physiological and psychological parameters (Hoppe, 2002).

The COMFA method mainly consists of the following basic formula expressing the energy budget of a person in an outdoor environment (Brown and Gillespie, 1995):

$$Budget=M+Rabs-Conv-Evap-Tremitted \quad (2)$$

where

- M: the metabolic energy used to heat up the person
- R_{abs}: the absorbed solar and terrestrial radiation
- Conv: the sensible heat lost or gained through convection
- Evap: the evaporative heat loss
- $TR_{emitted}$: the emitted terrestrial radiation

When the budget is near zero, a person can be expected to be thermally comfortable. If the budget presents a large positive value, the person receives more energy than lost, so overheating could occur and the person would be uncomfortably warm. Moreover, if the budget is negative the person could be cool. Table 2 shows the human comfort feelings related to the budget values.

Table 2:The human comfort feelings related to the budget values (Brown and Gillespie, 1995).

Budget (W/m2)	Sensation
Budget<-150	Would prefer to be much warmer
-150<Budget<-50	Would prefer to be warmer
-50<Budget<50	Would prefer no change
50<Budget<150	Would prefer to be cooler
150<Budget	Would prefer to be much cooler

3. IMPROVING MICROCLMATE IN AN OUTDOOR SPACE IN THE GREATER ATHENS

3.1 Investigation of the area microclimatic conditions in its existing situation

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

Primarily, the scenario of the already existing microclimatic situation was considered.

The climatic elements of the air temperature Ta, and of the air velocity w, have been selected using the numerical simulation model PHOENICS 2.1 (1999). Simulations were performed for twelve different points of the selected outdoor space primarily in its already existing microclimatic situation, for the Summer period and for a North wind of 2m/sec. Furthermore, in order to estimate the thermal comfort conditions in the selected area and for the existing situation scenario, the two thermal comfort calculation methods presented in chapter 2, were used.

Table 3 shows the calculated thermal comfort conditions values for the twelve different considered points of the selected outdoor space in its existing situation using Thermal Sensation TS and COMFA methods. From this Table it can be observed the high values for both thermal sensation and energy budget for the majority of places, resulting in quite poor thermal comfort conditions.

Table 3: The thermal comfort conditions values for the twelve points of the selected outdoor space in its existing situation.

Number of Place	TS (1st)	Budget (1st)
1	6.80	105.15
2	6.79	104.46
3	6.82	104.68
4	6.81	102.20
5	7.32	121.79
6	7.65	120.13
7	6.70	98.88
8	6.42	97.08
9	7.27	108.68
10	6.99	107.14
11	7.07	107.04
12	7.09	101.79

Figures 1, 2 show the spatial variation of the thermal sensation and energy budget, calculated using Thermal Sensation TS and COMFA methods, for the first scenario and it is obvious that the microclimate should be improved.

3.2 Improving the microclimate

An alternative scenario was proposed in order to

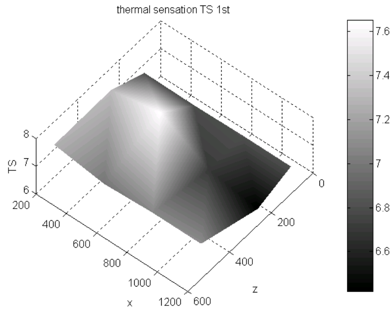

Figure 1: The spatial variation of the thermal sensation, for the first scenario.

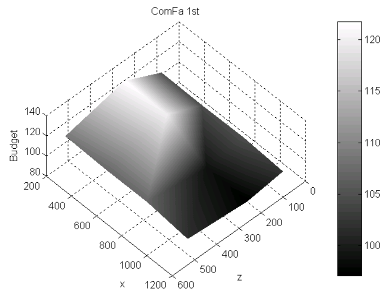

Figure 2: The spatial variation of the thermal sensation, for the second scenario.

improve microclimate and specifically the thermal comfort conditions. The main objectives identified in the urban planning for improving microclimate in outdoor spaces can be summarized as follows:

- Promotion of all forms of passive natural devices according to the potential effects of minimizing localized pollution problems and enhancing urban microclimate.
- Increase of permeable surface in the outdoor spaces.
- Improvement of natural cooling minimizing solar heat gains.
- CO_2 absorption by plants and urban pollutant dispersion by natural ventilation.

For the alternative scenario, and in order to meet the above objectives, in the investigated open space, the following improvements have been proposed:

- Dense vegetation with evergreen trees along the Northern area of the space in order to avoid high values of wind velocity and to create simultaneously a green space in the area.
- Pergolas with deciduous plants along all streets of the area in order to achieve solar control and to create a pleasant cooling feeling during the summer period.
- Low and average vegetation in the park and everywhere between the buildings.
- Small water sources in the park, which can create a feeling of coolness especially where high temperature values have been measured.
- Use of construction materials with high emissivity and reflectivity values.

Also, for the second scenario, PHOENICS 2.1 was used for simulating the air temperature and wind velocity. Simulations were performed for the twelve different points, for the summer period and for a North wind of 2m/sec.

Table 4 shows the calculated thermal comfort conditions values for the twelve different considered points of the selected outdoor space and when the alternative scenario was applied using Thermal sensation TS and COMFA methods. From this Table it can be seen that the thermal comfort has been significantly improved in the second scenario.

In Figures 3 and 4 it can be seen the spatial variation of the thermal comfort, as calculated using both methods, for the second alternative scenarios, with application of the improvements. As shown, the thermal comfort conditions values calculated using both methods, are remarkably lower than those of the first scenario.

The application of both methods has shown that the thermal comfort conditions were improved in the second scenario. This is mainly caused by the existence of green and water

Table 4: The thermal comfort conditions values for the twelve points of the selected outdoor space for the second-alternative scenario.

Number of Place	TS (2^{nd})	Budget (2^{nd})
1	6.47	61.60
2	6.48	62.37
3	6.46	60.13
4	6.45	58.55
5	6.68	75.65
6	6.65	66.23
7	6.50	63.85
8	6.50	63.84
9	7.07	88.74
10	6.43	51.40
11	6.51	59.67
12	6.65	64.15

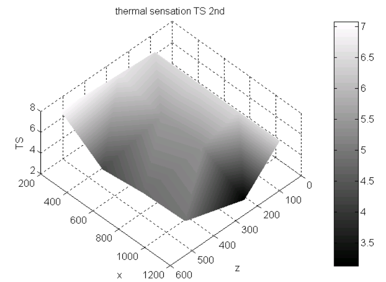

Figure 3: The spatial variation of the thermal sensation, for the second scenario.

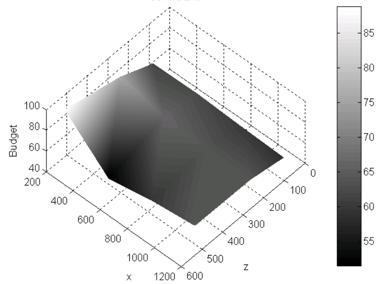

Figure 4: The spatial variation of COMFA, for the second scenario.

spaces as well as by the use of materials of high emissivity and reflectivity values. From the application of both thermal comfort conditions methods it was observed that the energy budget of a person when the second scenario was applied, was reduced in an average 40%, while in the majority of places an improvement of the hot sensation in an average of 6% was achieved with the application of the second scenario.

4.CONCLUDING REMARKS

An integrating alternative scenario for improving microclimate in an open space area located in Athens is presented in this paper. Thermal comfort conditions were used as an indicator of the microclimatic situation. Thus, the thermal comfort conditions in twelve different outdoor space places of the investigated area for the Summer period were calculated using two different methods, the COMFA method and the Thermal sensation TS one. For the calculation of the thermal comfort conditions, two different scenarios have been considered. The first one includes the investigated area as it is, while the second one includes various architectural improvements according to the bioclimatic design principles. Both bioclimatic indices showed that the thermal comfort conditions were significantly improved with the use of the second scenario, mainly because of the use of green spaces and water spots as well as because of the use of construction materials with high emissivity and reflectivity values.

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