A study of temperature and wind distribution inside two urban street canyons in Athens

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ABSTRACT

An experimental campaign was organized inside and outside two urban street canyons during summer 2002 in Athens. The experiments consisted of air, as well as, of surface temperature measurements on building walls and on asphalt street together with wind velocity measurements at different heights in the centre of canyon, near opposite building facades and outside canyon. This study presents the analysis and the conclusions regarding the variation of air and surface temperatures and the observed wind speed characteristics inside the two studied canyons. Besides, the observed differentiations of wind and temperature distribution are discussed in order to get a better sight of the urban canyon microenvironment, which has been shown to have a direct impact on the ventilation performance in urban buildings.

1. INTRODUCTION

Air circulation and temperature distribution within urban canyons is important for outdoor comfort, pollutant dispersion (Kukkonen et al., 2001; Vardoulakis et al., 2003; Xie et al., 2003; Longley et al., 2004) and for the performance of natural and hybrid ventilation in buildings (Santamouris et al., 2001; Niachou et al., 2005). Several theoretical (Kovar-Panskus et al., 2002; Jeong and Andrews, 2002; Assimakopoulos et al., 2003) and experimental street canyon studies are reported in the literature (DePaul and Sheih, 1986; Nakamura and Oke, 1988; Santamouris et al., 1999; Vachon et al., 2000; Louka et al., 2000, 2002; Brown et al., 2003; Bourbia and Awbi, 2004). In the framework of the RESHYVENT European research programme (2002), an urban measurement campaign was organized in two urban street canyons and three typical building apartments very near to the centre of Athens. Air and surface temperature, wind velocity and outdoor air characteristics (TVOC's, CO_2, CO and NO_x) together with ventilation and air quality measurements were performed inside building apartments. The present work focus on the field measurements. The aim is to present the major conclusions regarding the temperature distribution and wind speed in two different urban canyons during summer weather conditions. The present analysis constitutes an essential step forward the understanding of the impact of the urban street microenvironment on the potential of natural and hybrid ventilation in urban buildings (Niachou et al., 2005).

2. SITE DESCRIPTION AND FIELD MEASUREMENTS

The field measurements were performed every 30secs during the 24-hour period for a number of 3 to 5 consecutive days at Ragavi and Ag. Fanouriou streets and they are illustrated in Figure 1.

The two studied canyons are different, in terms of geometrical characteristics and orientation (Table 1). Namely, Ragavi street is an almost regular and asymmetric street canyon, whereas Ag. Fanouriou is a deep and symmetric canyon.

Considering as canyon length, L, the distance between two main intersections and canyon height, H, the average height of buildings (Vardoulakis et al. 2003), then both canyons can be

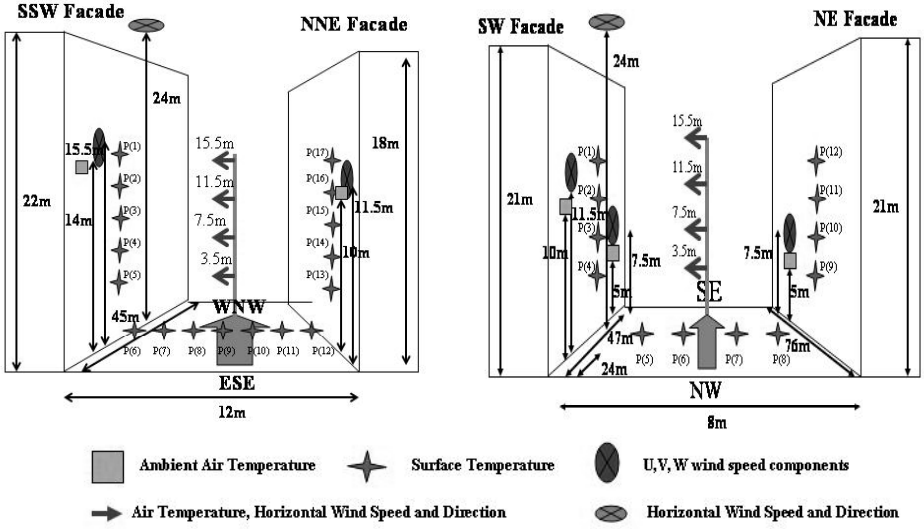

Figure 1: A schematic representation of the field measurements performed inside and outside the two urban canyons (left is Ragavi and right is Ag. Fanouriou canyon).

Table 1: Characteristics of the two urban canyons.

Canyon	Measurement Period	Orientation from North	Length, L (m)	Width, W (m)	Height, H (m)	H/W	L/H
Ragavi	19/07-23/07/02	100	45	12	20	1.7	2.3
Ag. Fanouriou	28/08/-2/09/02 11/09-15/09/02	137	76	8	21	2.6	3.6

characterized as relative short (L/H≈3), while its facades are complex consisting of balconies projecting to a distance of 1m from building walls. The canyon walls are made of concrete covered with white plaster, while the ground surfaces are made of asphalt with dark pavement tiles on each of street. Both canyons are typical with regard to the surrounding urban scale. Nevertheless, they present a different microclimate, as it will be discussed in the following paragraphs.

3.TEMPERATURE DISTRIBUTION INSIDE CANYONS

3.1 Air Temperature Distribution

The air temperature distribution, based on the 5-min mean air temperature values, doesn’t seem to show significant variations with height near the centre of canyon (Fig. 2). However, estimation of the air temperature lapse rates (^{o}C/100m) between 3.5m and 15.5m (Fig. 3) resulted in a number of interesting remarks. During the day period, a temperature inversion was observed around 8:00-10:00LT reaching almost 7.2^{o}C/100m in both studied sites. The temperature inversion observed during the morning is much higher than the average normal gradient (-0.6^{o}C/100m). Besides, it coincides with the minimum of temperature differences between the asphalt street and the air layer at 3.5m from the ground. Later in the morning the atmosphere starts to become unstable, as a result of the direct solar heating of asphalt street and building walls. As shown in Figure 3, the instability presents its maximum intensity, up to -8^{o}C/100m, around noon time period, when the maximum surface-air temperature differences reached 30^{o}C in Ragavi canyon, while in Ag. Fanouriou canyon, the corresponding differences were less than 8^{o}C. Moreover, air temperature inversions were also observed during noon time period

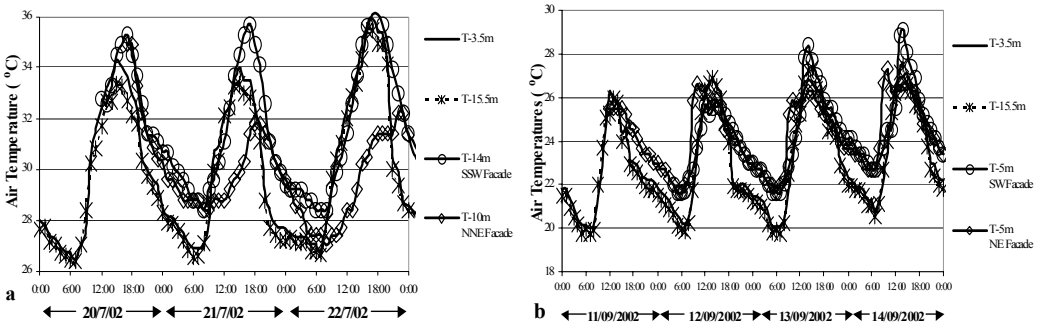

Figure 2: Air temperature distribution in the centre of a) Ragavi and b) Ag.Fanouriou canyons at different heights (at 3.5m and 15.5m) and near opposite building facades during summer 2002 in Athens.

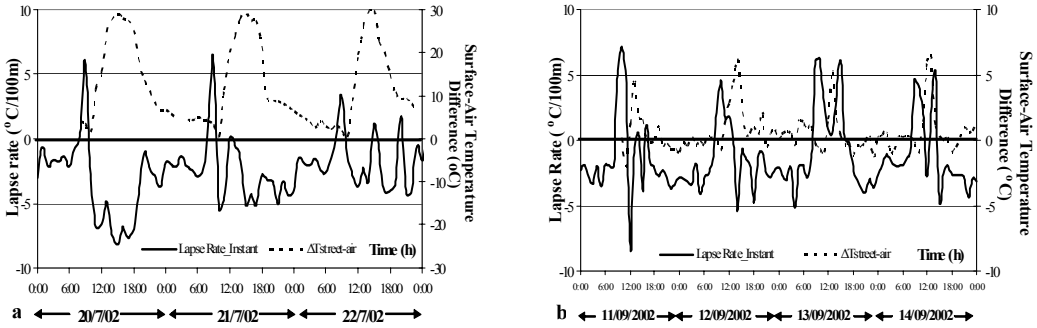

Figure 3: Surface-air temperature differences and lapse rates (°C/100m, between 15.5m and 3.5m) in the centre of a) Ragavi and b) Ag.Fanouriou canyons during summer 2002 in Athens.

(around 14:00-15:00LT), especially in Ag. Fanouriou canyon, when higher air temperatures were measured above the canyon and for almost isothermal conditions near the bottom of canyon.

Finally, the simultaneous study of the above canyon wind speed and direction indicated that the air temperature lapse rate is independent of the wind flow characteristics outside the urban canyon.

3.2 Air Temperature Near Canyon Facades

Air temperature measurements were measured near the opposite building walls, as shown in Figure 1. The measured air temperature differences between the two facades vary, as a function of the canyon layout and the surface characteristics. As it was expected, the air temperature close to SSW facade is higher than near NNE in Ragavi canyon. The mean value of the instantaneous temperature differences between the two opposite facades during the day period is close to 3°C, while the absolute maximum air temperature difference is 5.4°C. The highest differences are observed during the early afternoon hours around 16:00-17:00 LT and the lowest in the early morning around 7:00 LT (Fig. 2a). In Ag. Fanouriou canyon the instantaneous air temperature differences reached 4°C during the day period, due to convection phenomena from adjacent walls. Higher air temperature values are recorded near NE wall during morning and lower during afternoon in comparison with the air adjacent to SW facing wall (Fig. 2b).

3.3 Wall Temperatures

Surface temperatures were measured on the opposite building walls from the ground level up to the forth floor, on an hourly basis. As it has been expected, the thermal behaviour of the two opposite walls is more complex due to parameters affecting the thermal balance of building materials (physical properties and canyon geometry) and due to incident solar and emitted

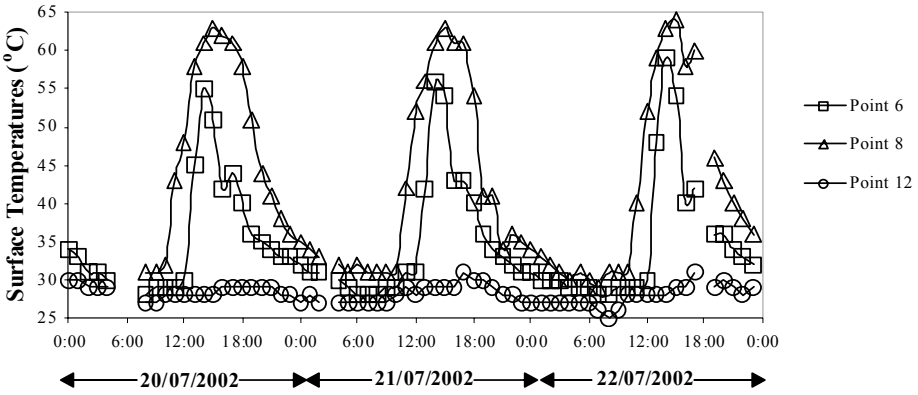

Figure 4: Hourly distribution of street temperatures in Ragavi canyon (points 6,12: on the side walks near SSW and NNE facades, point 8: on the asphalt street).

infrared radiation. In general, it has been observed that during day period the SSW or SW façades presents greater temperatures than the opposite walls. In case of Ragavi canyon, the measured temperature differences between the opposite canyon walls during the day are higher at the forth floor, up to 6°C, because of the increased solar radiation and at the ground floor, up to 5°C, as a result of the higher ground temperatures and the reduced wind effect. In Ag. Fanouriou canyon the maximum temperature differences, up to 12°C, are measured between opposite walls at second floor, around 15:00LT during August 2002, as result of the direct solar heating of SW facade. During the night period the simultaneous temperature differences are seriously reduced and the maximum differences are observed between the ground floors and rarely exceed 3°C in both studied canyons.

3.4 Street Temperatures

The ambient temperatures during the first measurement period are much higher than the average air temperatures of the last five years in Athens. Thus, the instantaneous maximum street temperatures, on an hourly basis, were observed in Ragavi canyon. Maximum surface temperatures on the asphalt street exceed 60°C, during midday, due to the vertical incidence of solar radiation, as shown in Figure 4. The pavement near the SSW facade presents maximum temperatures up to 55°C, which are measured one hour before the maxima on the street centre. On the contrary near the NNE façade, the street temperature ranges between 25°C-30°C. This favors the overheating of lower air levels and thus resulting in the development of upward movements near the south facing canyon wall. Under these favorable weather conditions, the predominant airflow characteristics indicate the existence of a clockwise direction vortex inside the canyon (Niachou et al., 2004). However, much lower absolute maximum street temperatures have been recorded in Ag. Fanouriou, up to 43°C on the asphalt street, as a result of canyon orientation and geometry and ambient weather conditions.

4. WIND DISTRIBUTION

4.1 Wind Flow Out Of Canyon

The synoptic wind conditions, etesian winds (with a prevailing N to NE direction in Athens), are typical for the summer period in Greece. However, different wind directions values have been recorded above the two canyons during the measured periods. The horizontal wind speed and direction was recorded above the two canyons at a distance of 24m from the ground. Measurements have been performed every 30s and the 5-min mean values were used for the analysis. During the first experimental period (19-23/7/2002), almost 55% of the measured wind speeds above canyon are from South to West orientations. From the total wind speeds, the 25th and 95th percentiles correspond to 2.6m/s and 7.2m/s, while the average wind speed is 3.8m/s. During the second period (28/8/-2/9/2002) the two third of the measured

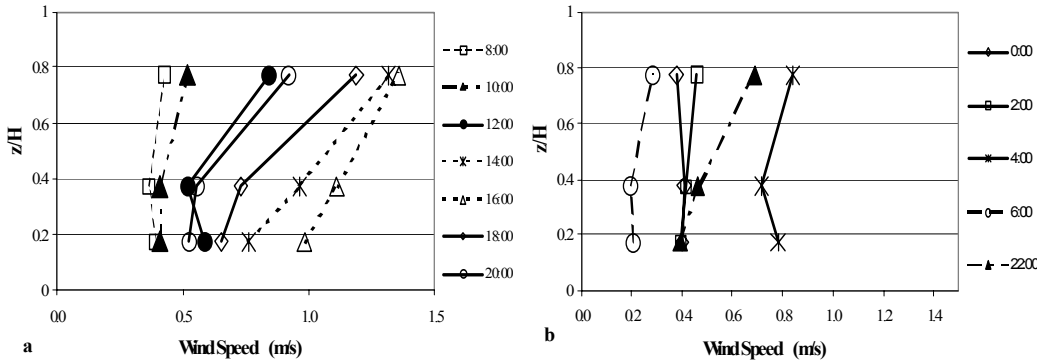

Figure 5: Vertical wind speed profile in the centre of Ragavi canyon on 20/7/02 during a) day and b) night period.

wind directions are again from South to West orientations. Lower wind speeds have been measured in comparison with Ragavi canyon, while the 95% of the values is lower than 4.7m/s and the average value is equal with 2.3m/s. Finally, almost 79% of the measured wind speeds during the third measurement period (11-15/9/2002) are from Southwest to West orientations. This period is characterized by the lowest wind speeds values above the canyon, since the average wind speed is 1.6m/s and the 95th percentile is equal to 3.9m/s.

4.2 Wind Flow Inside Canyon

4.2.1 Vertical Wind Profile

The wind speed profile was measured inside the canyons at four different heights from the ground (3.5m, 7.5m, 11.5m and 15.5m) near its main axis. Figure 5 shows the vertical wind speed profile on 20/7/02, during day and night period in Ragavi street canyon. The plots are based on the 5-min mean wind speed values for each hour. The observed maximum vertical wind speed differences are of the order 0.5-0.6m/s and are measured during noon and afternoon hours (13:00-16:00LT) under unstable meteorological conditions. The absolute maximum differences of wind speed within the whole measurement period are measured between the lowest (3.5m) and upper (15.5m) layers, up to 1.5 m/s respectively. In general, it can be concluded that vertical wind speed profile in the centre of Ragavi canyon cannot be characterized either as logarithmic or exponential, but it tends more to linear (Table 2). Similar results were found for Ag. Fanouriou canyon (Fig. 6).

4.2.2 Wind Distribution Across Canyon

The distribution of horizontal wind speed was measured across the canyon near opposite building facades and the centre of canyon.

Higher wind speed values have been recorded near the street centre in more than 87% of the total wind speeds in both canyons.

Namely, in case of Ragavi canyon the differ-

Table 2: Slopes of the linear regression between horizontal wind speeds at different measured levels near the centre of canyon for parallel, perpendicular, oblique and all wind incidence angles above canyon.

Ragavi Canyon-19-23/9/02				
Linear Correlation	Parallel	Perpendicular	Oblique	All
$WS_{3.5m,x}$-$WS_{7.5m,y}$	1.071	1.002	1.022	1.028
$WS_{7.5m,x}$-$WS_{15.5m,y}$	1.082	0.869	1.064	1.033
Pagrati Canyon-28/8-02/9/02				
$WS_{3.5m,x}$-$WS_{7.5m,y}$	1.058	1.103	1.104	1.114
$WS_{7.5m,x}$-$WS_{11.5m,y}$	1.080	0.986	1.048	0.997
$WS_{11.5m,x}$-$WS_{15.5m,y}$	1.129	1.145	1.131	1.142
Pagrati Canyon -11-15/9/02				
$WS_{3.5m,x}$-$WS_{7.5m,y}$	0.954	1.037	1.016	1.032
$WS_{7.5m,x}$-$WS_{11.5m,y}$	1.041	1.027	1.057	1.039
$WS_{11.5m,x}$-$WS_{15.5m,y}$	1.175	1.097	1.128	1.119

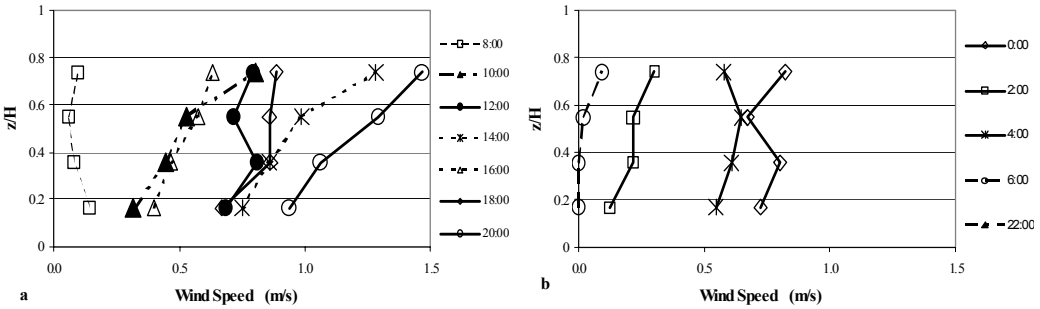

Figure 6: Vertical wind speed profile in the centre of Ag. Fanouriou canyon on 30/8/02 during a) day and b) night period.

ences of horizontal wind speed between the centre of canyon and building facades was almost lower than 1m/s, in 95% of the measured values. Besides, in Ag. Fanouriou canyon the corresponding wind speed differences were lower than 0.6m/s in 95% of the measurements and the absolute maximum values didn't exceed 1m/s (Fig. 6). A linear correlation has been found between the wind speed near building walls and the street centre. The correlation coefficients of the linear regression for all wind incidence angles above canyon (parallel, perpendicular and oblique) are given in Table 3.

5. CONCLUSIONS

The analysis of temperature and wind distribution in two urban street canyons has been performed on a 24-hour basis, during an extensive measurement campaign in Athens in summer 2002.

The present study gives an insight of the meteorological conditions in two street canyons under different summer weather conditions, which is very important in order to interpret the potential of natural and hybrid ventilation in urban buildings.

Table 3: Correlation coefficients of the linear regression between horizontal wind speeds across the street canyon for parallel, perpendicular, oblique and all wind incidence angles above canyon.

Ragavi Canyon -19-23/9/02				
Linear Correlation	Parallel	Perpendicular	Oblique	All
$WS_{Centre,x}$-$WS_{SSW,y}$	0.74	0.57	0.84	0.79
$WS_{Centre,x}$-$WS_{NNE,y}$	0.59	0.66	0.64	0.63
Pagrati Canyon-28/8-02/9/02				
$WS_{Centre,x}$-$WS_{SW,y}$	0.64	0.79	0.86	0.84
Pagrati Canyon-11-15/9/02				
$WS_{Centre,x}$-$WS_{SW,y}$	0.58	0.64	0.76	0.69
$WS_{Centre,x}$-$WS_{NE,y}$	0.86	0.83	0.86	0.85

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