THERMO-HYDRAULIC MEASUREMENTS IN URBAN ENVIRONMENT

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ABSTRACT

Measurements of wind speed and wind direction, air temperature inside and outside an urban canyon also infrared radiation in buildings have been measured on summer 2001 in Athens, in five different urban canyons, in the frame of Urbvent project. Urban canyons with different geometrical characteristics and orientation were placed in five different neighborhoods in Athens.

Measurements took place in four different height levels inside each canyon, in the facades of them, also in the top of each canyon. Measurements lasted three days per canyon, twelve hours per day. Extra terminal weather phenomena took place, during experimental period, in Athens establishing air and temperature distribution in urban canyons under hot, windy or common weather conditions. Experimental data were collected and storage every 30 seconds.

The aim of these experiments was to develop design guidelines by using measurements of meteorological data in canyon streets. Gathering and processing these data also comprising with the theoretical predictions, evaluates to the accuracy of the developed models for wind and temperature distribution in urban canyons. Such differences, if any, will be analyzed in order to determine their causes.

KEYWORDS

Wind speed; wind direction; air temperature; infrared radiation measurements.

1. INTRODUCTION

Very few field studies of flow have been performed in real urban street canyons, De Paul and Sheih (1986), Santamouris et al. (1999). Most of the studies relative to wind flow inside an urban canyon focus on the development of models for the flow, turbulence of the pollutant concentration fields within the street canyon.

Air circulation and temperature distribution within urban canyons are significant for the energy consumption of buildings, pollutant dispersion studies, and heat and mass exchange between the building and the canyon air and are therefore of interest in studies on the energy potential of natural ventilation techniques for buildings, pedestrian comfort, etc.

This present experimental study adds to the knowledge and understanding of wind distribution inside street canyon, with respect to the relations between air temperature values, wind (speed and direction) values inside and outside canyon, together with the development of infrared canyon temperature.

2. FIELD EXPERIMENTS

In the frame of the European Commission Project Urbvent, experiments have been performed during summer of 2001 in five different pedestrians streets downtown Athens located in give different neighborhoods. The geometrical characteristics of each canyon street and the thermo metrical measurements are given in Table 1.

The meteorological station of the University of Athens was placed in the center of each urban canyon for three days, for twelve hours per day respectively. The mobile meteorological station was parted from: a) a vehicle and b) a telescopic mast PT8 Combined Collar Mast Assembly with extended height of 15.3 meters, retracted height 3.43 meters and maximum head load 15 kgr. On the telescopic mast at four different heights (3,5 – 7,5 – 11,5 – 15,5 meters) anemometers and thermometers were placed in order to record and storage every 30 seconds the following magnitudes:

a) Air temperature measurements inside the canyon. These miniature thermometers were placed on the telescopic mast at four different heights (3,5 - 7,5 - 11,5 and 15,5 meters), measured and recorded air temperature every 30 seconds. The miniature screen formed a housing for a range of temperature sensing elements, proving weather protection while allowing the free passage of air.

b) Wind speed and direction measurements inside the center of the canyon. These anemometers were placed on the telescopic mast at four different heights (3,5 - 7,5 - 11,5 and 15,5 meters), measured and recorded wind speed and direction every 30 seconds. Pulse output anemometer 10 Hz per knot, for recording the air wind speed inside the canyon and W200 Porton Windwane, $\pm 300^0$ ranges for recording the wind direction respectively.

Simultaneously wind speed in the three different axis was measured near the facades of the canyon, also the air temperature and wind speed and direction outside the canyon. Every hour measurements of the infrared temperature of the materials of the canyon facades were recorded. The above types of measurements have been performed, with the following instruments:

c) Air temperature measurements outside the canyon. Miniature ambient air temperature sensors were placed in the top of each canyon, on the roof of one building. The sensors were shielded inside a white painted wooden cylinder opened from the two parts to permit air circulation.

d) Surface temperature measurements. An infrared thermometer equipped with a laser beam was been used. The surface temperatures of the exterior facades of the buildings were measured every 1meter. All measurements were performed from the street level. The pavement and road temperature were measured as well at different points along the width of the canyon in both sections defined above. All measurements were performed in an hourly basis during the twelve experimental hours.

e) Wind speed measurements near canyon facades. A three-axis anemometer was used to measure the three components of the wind speed inside the canyon near the facades of the canyon. The anemometer was mounted on the exterior façade of a building in the canyon and in distance of 1-2 m from the wall.

f) Wind speed and direction measurements outside the canyon. A cup anemometer has been placed on the top of the canyon in a distance of 6 m from its top level to measure the wind speed and direction out of the canyon.

TABLE 1
Description of the experimental sites, definition of the measurement points, the experimental period and the thermo measurements of every canyon

Canyon		Ermou	Miltiadou	Voukourestiou	Kaniggos	Dervenion
Orientation from the North	(degree)	92	45	45	12	327
Canyon Width	(meters)	10	5	10	9	7
Canyon Length	(meters)	200	100	100	70	200
Canyon Height	(meters)	20	15	15	22	23
Canyon Aspect Ratio	(H/W)	2	3	1.5	2.5	3.3
Air temperature measured inside the canyon	(meters from ground)	3,5 – 7,5 –11,5 –15,5	3,5 – 7,5 –11,5 –15,5	3,5 – 7,5 –11,5 –15,5	3,5 – 7,5 –11,5 –15,5	3,5 – 7,5 –11,5 –15,5
Wind speed and direction inside the canyon	(meters from ground)	>>	>>	>>	>>	>>
Height of the two Three-axis anemometer	(meters from ground)	7.5-10.5	8.0-8.0	5.0-12.0	5.0-10.0	20.0-9.0
Height of the Wind speed and direction anemometer, outside the canyon	(meters from ground)	20	17	20	22	23
Mean Air temperature inside canyon, near the facades	(^{0}C)	North wall 32^0C South wall 34^0C Ground 45^0C	N-W wall 33 ^{0}C S-E wall 55 ^{0}C	N-W wall: 39 ^{0}C S-E wall: 52 ^{0}C Ground 30-60 ^{0}C	West wall: 37 ^{0}C East wall: 39 ^{0}C Ground 39 ^{0}C	West wall: 40^0C East wall: 40^0C Ground 45^0C
Mean Air temperature distribution inside canyon at Morning – Noon - Afternoon	(^{0}C)	25 ^{0}C 32^0C 28 ^{0}C	29^0C 35^0C 32^0C	32^0C 38^0C 32^0C	25^0C 35^0C 30^0C	25 ^{0}C 30^0C 26 ^{0}C
Mean Air temperature distribution outside canyon at Morning – Noon - Afternoon	(^{0}C)	25 ^{0}C 50^0C 32 ^{0}C	29^0C 39^0C 32^0C	32^0C 46^0C 34^0C	25^0C 50^0C 30^0C	31 ^{0}C 32^0C 31 ^{0}C
Duration of the experiment	(days)	28/6-29/6-3/7	31/7-2/8-3/8	7/8-9/8-10/8	27/8-28/8-29/8	4/9-5/9-6/9

3. HYDRAULIC MEASUREMENTS AT CANYONS

3.1.Wind speed and direction measurements at Voukourestiou canyon

Three different cases are studied regarding the incidence angle of the free stream wind to the canyon axis, for every urban canyon:

- Flow along the canyon (incidence angle: 0^o or $180^0 \pm 20^o$)

The wind speed and direction anemometer, which was placed on the top of the Voukourestiou canyon recorded as maximum wind speed outside the canyon 8 m/s. When the undisturbed wind speed outside the canyon was higher than 4 m/s the wind direction inside the canyon was parallel as the undisturbed flow. When the wind speed values outside canyon were less than 4 m/s wind direction inside canyon was along canyon but from both sides. This was due to the end effects. The two three-axis anemometers which, were placed at near the facades of the canyon, recorded very small wind speed values with direction towards canyon center, with an uplift flow. The uplift flow was observed along the walls as a function of the temperature of the walls and the conservation of momentum. Also, wind speed in the center of canyon varies as a function of height.

- Perpendicular flow (incidence angle: 90^o or $270^o \pm 20^o$)

The wind speed and direction anemometer, which was placed on the top of the canyon, recorded as maximum wind speed for this incidence angle of the wind 5 m/s, but 95 % of values were less than 4 m/sec. When the undisturbed wind speed was lower than 2 m/sec, the flow was along the canyon but from both sides, with a chaotic characteristic. This was due to the impact of the end effects. The wind speed anemometers, which were placed on the telescopic mast at four different heights, recorded wind speed less than 2 m/sec, and proved that wind speed increases as function of height. The three-axis anemometers, which were placed near the facades of the canyon, recoded very small values towards to canyon center (size of 1 m/s), with an uplift component. So there was an indication of a reverse vortex in both directions, that is regulated by the temperature of the walls.

- Flow at an angle to the canyon axis (all other cases)`When the wind speed and direction anemometer outside the canyon recorded values greater than 4 m/s, the flow inside the canyon was mainly along the canyon axis from the upper part, as expected. An uplift flow close to the walls occurred because of the temperature of the walls and the possible vortex. When the wind speed and direction anemometer outside the canyon recorded values less than 3 m/s, flow inside the canyon was mainly along the canyon axis, with an uplift and downlift flow close to the walls because of the temperature of the walls and the possible vortex.

3.2.Wind speed and direction measurements at Miltiadou canyon

Three different cases are studied regarding the incidence angle of the free stream wind to the canyon axis, for every urban canyon:

- Flow along the canyon (incidence angle: 0^o or $180^0 \pm 20^o$)

The wind speed and direction anemometer, which was placed outside the canyon recorded as maximum wind speed values up to 6 m/s, but almost all values were less than 3m/sec. Since the wind speed values inside the canyon were up to 5 m/s, but almost all values were less than 2 m/s the wind direction inside the canyon was from all sides. The flow seemed to be chaotic because of the low wind speed values outside the canyon.

- Perpendicular flow (incidence angle: 90^o or $270^o \pm 20^o$)

The same phenomenon like for the parallel flow occurred for the vertical incidence of wind outside the canyon. Wind speed values outside canyon were very low, less than 4 m/s. The simultaneous values inside canyon at four different heights on the telescopic mast were less than 2 m/s. Wind speed values near the facades were also very low up to 1 m/s, with direction towards the center of the canyon. The wind

direction inside canyon was from all sides mainly because the low wind speed out of the canyon, and there was no connection with the ambient wind flow.

- Flow at an angle to the canyon axis (all other cases)

For all other wind incidence angles, except of parallel and vertical, the wind speed values outside canyon were also below 2.5 m/s and the simultaneous values inside canyon were less than 1.5 m/s. So, there was no coupling between the ambient and the flow inside the canyon. An almost chaotic flow was observed.

3.3.Wind speed and direction measurements at Kaniggos canyon

- Flow along the canyon (incidence angle: 0^o or $180^0 \pm 20^o$)

The wind speed and direction anemometer, which it was placed outside the canyon recorded as maximum wind speed value 6 m/s, but 55% from the data were less than 2 m/sec. Only 3% of the wind speed data outside the canyon were higher than 4 m/s. Near the facades of the canyon the wind speed mean value was 2 m/s, with an uplift component near the left wall of the canyon and a downlift near the right wall. The wind direction inside canyon was not clarified, because of the low wind speed values outside canyon. When wind speed outside canyon was more than 4 m/s the flow inside the canyon was from the same direction, with maximum wind speed values up to 6 m/s. At the same time an indication of a reverse vortex in both directions regulated by the temperature of the walls.

- Perpendicular flow (incidence angle: 90^o or $270^o \pm 20^o$)

The wind speed and direction anemometer which, it was placed outside the canyon recorded as maximum wind speed outside canyon 12 m/s, but 97% of the recorded data were less than 4m/s. The maximum wind speed in the center of canyon was 4.5 m/s. The flow inside canyon was parallel to the axis of the canyon from both sides, with an uplift and a downlift near the facades due to the temperature differences of the walls.

- Flow at an angle to the canyon axis (all other cases)

The flow inside these occasions was parallel to the axis of the canyon. The mean wind speed in these occasions was less than 4 m/s outside and less than 2 m/s inside canyon. At the same time wind speed near the facades was up to 2 m/sec with direction towards to the center of the canyon, and an uplift and a downlift near the facades due to the temperature differences of the walls.

3.4.Wind speed and direction measurements at Dervenion canyon

- Flow along the canyon (incidence angle: 0^o or $180^0 \pm 20^o$)

The wind speed and direction anemometer, which it was placed outside the canyon recorded as maximum wind speed outside canyon 10 m/s, and plenty of data were higher than 4 m/s. The maximum wind speed near the facades was 8 m/s, but the mean wind speed near the facades was less than 4 m/s, towards to the center of canyon and with an uplift along the facades. The maximum wind speed in the center of canyon was up to 10 m/s, varied as a function of height, and the flow inside canyon was from both directions parallel to the axis of the canyon. When the undisturbed wind speed was lower than 2 m/sec the end effects dominated, when it was higher than 2 m/sec the coupling of the undisturbed wind speed with the flow inside the canyon was clear. Then the flow inside canyon was from the same direction like the undisturbed one. An uplift flow along the walls observed as a function of the temperature of the walls and the conservation of momentum.

Perpendicular flow (incidence angle: 90^o or $270^o \pm 20^o$)

The wind speed and direction anemometer which, it was placed outside the canyon recorded as maximum wind speed outside canyon 8 m/s, but 80% of the recorded wind speed data outside the canyon are less than 4m/s. The maximum wind speed in the center of canyon was 8 m/s. The flow inside canyon was parallel to the axis of the canyon from both sides, due to the end effects. The wind speed near the facades of the canyon was up to 5 m/s with an uplift and a downlift near the facades due to the temperature differences of the walls.

- Flow at an angle to the canyon axis (all other cases)

The parallel flow observed even when the undisturbed wind flow outside canyon was oblique. The wind speed outside canyon for these occasions was up to 8 m/s and inside canyon was up to 6 m/s. The maximum wind speed near the facades was up to 6 m/s.

3.5.Wind speed and direction measurements at Ermou canyon

- Flow along the canyon (incidence angle: 0^o or $180^0 \pm 20^o$)

The wind and speed anemometer outside canyon recorded as maximum wind speed 6 m/s, but all data were less than 4 m/s. The mean wind speed value inside canyon was 2 m/s and with parallel direction to the axis of the canyon. So, there is a clear coupling between the undisturbed wind speed and the one inside the canyon. The wind speed inside increases a function of height.

- Perpendicular flow (incidence angle: 90^o or $270^o \pm 20^o$)

The wind and speed anemometer outside canyon recorded as maximum wind speed 5 m/s, but all data were less than 3 m/s. The mean wind speed value inside canyon was 2 m/s and with direction from all sides of the canyon. The wind direction inside canyon was from all sides mainly because the low wind speed out of the canyon, and there was no connection with the ambient wind flow. The flow for this incidence angle outside canyon seemed to have chaotic characteristics.

- Flow at an angle to the canyon axis (all other cases)

Mean wind speed values outside canyon were below 4 m/s and the simultaneous values inside canyon were less than 1.5 m/s. So, there was no coupling between the ambient and the flow inside the canyon. An almost chaotic flow was observed.

4. CONCLUSIONS

The study of the thermal characteristics in the five pedestrian canyons, with orientation varied from 0^0 up to 92^0, indicated important temperature differences from 10^0C up to 12^0C depend to the orientation of the canyon axis and the materials of the facades. The study of the air flow characteristics pointed out that, for wind speed perpendicular to the axis of the canyon the air flow inside the canyon was mainly characterized by either a circulatory or double vortex, depend of the dimensions of the canyon. When the flow outside canyon was along canyon axis, the flow inside canyon was also parallel to the axis of the canyon. The impact of “end effects” was observed when the wind speed outside canyon was less than a threshold. Further analysis of the experimental data is required in order to evaluate to the accuracy of the developed models for wind and temperature distribution in urban canyons.

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