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M Santamouris, N Papanikolaou, I Koronakis, C Georgakis, D N Asimakopoulos

University of Athens
Building Environmental Studies
Department of Applied Physics
University Campus
Building PHYS-5
157 84 Athens
GREECE

E-mail: msantam@atlas.uoa.gr

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M. Santamouris, N. Papanikolaou, I. Koronakis, C. Georgakis and D. N. Assimakopoulos

Group of Building Environmental Studies, Section of Applied Physics, Physics Department, University of Athens, Building of Physics - 5, 157 84, University Campus, Athens, Greece.
e-mail : msantam@atlas.uoa.gr

Abstract

The present paper discusses issues related to the potential of natural ventilation techniques when applied to urban environment and in particular to buildings located in canyons. The paper discusses the specific phenomena related to air flow processes in urban canyons and presents some of the existing methods to calculate the wind speed distribution into the canyons.

Wind speed and temperature data have been collected through experiments carried out in ten different urban canyons presenting different characteristics, during summer 1997. The collected data have been used to evaluate the potential of natural ventilation in the ten canyons for single and cross ventilation configurations. It is found that, mainly during the day period, this is seriously reduced because of the important decrease of the wind speed inside the canyon. Air flow reduction may be up to ten times the flow that corresponds to undisturbed ambient wind conditions.

1. Introduction

Air flow around isolated buildings is well known. This is characterized by a bolster eddy vortex due to flow down the windward facade, while behind there is a lee eddy drawn into the cavity of low pressure due to flow separation from the sharp edges of the building top and sides, and further downstream is the building wake characterized by increased turbulence but lower horizontal speeds than the undisturbed flow.

The air flow patterns in urban canyons has received important attention during the last years. Natural Ventilation of buildings located in urban canyons is seriously reduced because of important decrease of the wind velocity inside the canyons.

Natural ventilation of buildings is due either to the wind forces or to the temperature difference between the indoor and outdoor environment or in a combination of both. Design of urban buildings to improve natural ventilation potential should consider the appropriate wind data and not routine meteorological observations collected in open fields. Also, the specific temperature regime in a canyon should be considered.

Knowledge of the air speed inside urban canyons is of high importance for passive cooling applications and especially for naturally ventilated buildings. Various methods, simplified or detailed have been proposed to calculate the wind speed inside a canyon.

Nakamura and Oke, (1989), have suggested the following simple linear form to calculate the mean horizontal wind speed, u_h, inside a canyon :

$$u_h = p\, u_{roof}$$

where p is a diminuation factor which depends on H/W and the measurement levels. They show for wind speeds up to 5 m/sec, with H/W = 1, and canyon centre and above roof measurements at heights of about 0.06 H and 1.2 H respectively that p=2/3. They also found that at smaller H/W, p approaches unity and shelter is lost.

Nicholson, (1975), has proposed a simple model to calculate the vortex circulation produced in street canyons when wind blows perpendicular to the street. By applying mass conservation techniques in the layer of air between the building's height, h_b, and the height at which the effects of the canyon on the overlying flow become negligible h', he proposed the following expression to calculate a representative speed of the upward-current of the vortex, w_m, :

$$w_m=2(h'-h_b)([u]_B - [u]_A) / W$$

where the '[ ]' symbol implies an average value across the layer from h_b to h', W is the canyon width and subscripts A and B refer to the locations.

According to Mills, (1993), h', may be calculated from :

$$h'=(0.15\ d + z_o\ h_b) / (0.15+z_o)$$

where d is the zero plane displacement. Also, values of z_o can be obtained from Tables.

Yamartino and Wiegand, (1986), has proposed a more representative canyon velocity calculated from the following expression :

$$V_c = (w_m{}^2 + u_m{}^2)^{0.5}$$

where w_m is wind speed due to vortex and u_m represents the along canyon flow at mid canyon height, (Mills, 1993), shows the relationship between V_c ,w_m and u_m with ambient wind azimuth.

Paciuk, (1975), based on wind tunnel experiments trying to identify the effects of building height and distances between buildings on the wind speed in the open spaces between the buildings, when the buildings are perpendicular to the wind direction, has developed a formula predicting the relative wind speed.

$$V_{r(u,h)} = 10 + (66(1-e^{-0.08h}))e^{-0.18D/W}$$

where :

$V_{r(u,h)}$ is the relative wind speed expressed as the percent of the wind at the same height well in front of the first line of buildings.

D is the distance traveled by the wind in meters, D=n(b+W)-0.5W

b is the depth of the buildings in meters

n is the serial number of the space, (downwind)

h is the height of the buildings in meters

and W is the width of the spaces between buildings in meters.

The formula indicates that as the wind approaches an urban area of long buildings with uniform height perpendicular to the wind direction, the initial turbulence 'agitation' over the first lines of buildings declines gradually toward a uniform wind speed in the spaces between the buildings. The analysis of the data suggested that the rate D/W is what determines the rate of drop in the air velocity towards an asymptotic value of about 10 % of the 'free' wind speed.

2. Air Flow In Urban Canyons

Urban canyons are characterized by three main parameters, H, the mean height of the buildings in the canyon, W, the canyon width, and L the canyon length. Given these parameters, the geometrical descriptors are limited to three simple measures. These are the ratio H/W, the aspect ratio, L/H and the building density j=Ar/A1 where Ar is the plan of roof area of the average building and A1 is the 'lot' area or unit ground area occupied by each building. Air flow phenomena associated with urban canyon are extensively discussed in (Santamouris, 1999)

When the predominant direction of the airflow is approximately normal (say ± 30 degrees), to the long axis of the street canyon, three type of air flow regimes are observed as a function of the building (L/H), and canyon (H/W), geometry. When the buildings are well apart, (H/W>0.05), their flow fields do not interact. At closer spacing, the wakes are disturbed and the flow regime is known as "Isolated Roughness Flow". When the height and spacing of the array combine to disturb the bolster and cavity eddies, the regime changes to one referred to as wake inteference flow. This is characterized by secondary flows in the canyon space where the downward flow of the cavity eddy is reinforced by deflection down the windward face of the next building downstream. At even greater H/W and density, a stable circulatory vortex is established in the canyon because of the transfer of momentum across a shear layer of roof height, and transition to a "skimming" flow regime occurs where the bulk of the flow does not enter the canyon.

Skimming regime is the most common in urban areas. Under these conditions the air flow in the canyon can been seen as a secondary circulation feature driven by the above roof imposed flow. If the wind speed out of the canyon is below some threshold value the coupling between the upper and secondary flow is lost, and the relation between wind speeds above the roof and within the canyon is characterized by a considerable scatter. According to many studies, carried out in almost symmetrical canyons where 1<H/W <1.4, the threshold value is between 1.5-2 m/sec. In all these studies higher wind speeds have been found to produce a stable vortex circulation within the canyon. For lower wind speeds thermal as well as mechanical influences may play an important role in the canyon circulation.

Parallel ambient flow generates a mean wind along the canyon axis, with possible uplift along the canyon walls as airflow is retarded by friction by the building walls and street surface. Regarding the relation between the free stream wind speed, U, and the along canyon velocity, v, it is reported that the along canyon wind component, v, in the canyon is directly proportional to the above roof along canyon component, through the constant of proportionality that is a function of approach flow azimuth.

The more common case in the urban environment, is that where the air flows at a certain angle relative to the long axis of the canyon. Unfortunately the existing research on this topic is considerably smaller compared to the scientific information for perpendicular and along the canyon flows, but it is known that when the flow above the roof is at some angle of attack to the canyon axis, a spiral vortex is induced along the length of the canyon, similar to a cork -screw type of action For intermediate angles of incidence to the canyon long axis, the canyon airflow is the product of both the transverse and parallel components of the ambient wind, where the former drives the canyon vortex and the later determines the along canyon streching of the vortex.

3. Experimental Procedure

Experiments have been performed in ten different canyon presenting dissimilar layout, orientation, anthropogenic heat and vegetation. The characteristics of the canyons are given in (Santamouris et al, 1997). Measurements have been performed between June and September 1997.

Three types of measurements have been performed :

a) Air temperature measurements. Miniature ambient air sensors have been used. The sensors were shielded inside a white painted wooden cylinder opened form the two parts to permit air circulation. The length of the cylinders was 20 cm while their internal and external diameter was 9 and 8 cm respectively. Sensors were completely protected from solar radiation. The cylindrical wooden boxes including the sensors have been fixed in the exterior facades of the buildings and in various heights in the canyon. The distance between the cylindrical box and the exterior wall was between 5 cm to 2 m, thus the temperature sensors were between 12 to 205 cm from the walls. Measurements were performed every 15 minutes. In some canyons, ambient temperature measurements were also performed using a digital hand thermometer at the mid width of the canyon on an hourly basis.

b) Surface temperature measurements. An infrared thermometer equipped with a laser beam has been used. The surface temperature of the exterior facades of the buildings, through a cross section of the canyon where the air temperature sensors were placed, is measured, (default section). Measurements are performed from the bottom to the top of both facades of the canyon using a step of 3-3.5 m. Additional measurements have been performed in some cross sections of the canyon where different than the default section materials are used. All measurements have been performed from the street level. The pavement and road temperature were measured as well at five different points along the width of the canyon. All measurements have been performed in an hourly basis during day and night.

c) Wind speed measurements. A three axis anemometer has been used to measure the three components of the wind speed inside the canyon. The anemometer was mounted on the exterior facade of a building in the canyon and in distance of 1 - 2 m from the wall. A cup anemometer has been also placed on the top of the canyon and in a distance of 6 m from its top level to measure the wind speed and direction out of the canyon. Measurements have been performed every 12 seconds.

The exact type of measurements performed in each of the ten canyons are given in (Santamouris et al, 1997).

4. Results

Experiments in ten deep canyons during the summer 1997, have shown that mean wind speed inside the canyon rarely exceeds 1 m/sec, independently of the free wind speed above the buildings. Figure 1, shows as an example, the variation of the air speed inside and outside a canyon having an aspect ratio close to one, during the whole experimental period.

In order to evaluate the natural ventilation potential of urban buildings, as well as its possible decrease because of the canyon related phenomena, simulations of the air flow processes have been carried for ten different canyons where wind speed and temperature data have been collected. Two configurations have been considered. A single as well as a cross ventilation configuration. A typical zone of 36 square meters, and 144 m3, having a window of 1.5 x 1.5 m, in each canyon facade is also considered.

Two types of simulations have been performed for each configuration. The first was based on the wind and temperature data measured inside the canyon, while the second one was based on the undisturbed temperature and wind speed measured over the buildings. Comparison of both simulation results should permit to assess the decrease of the natural ventilation potential in urban canyons.

Simulations have been performed using the AIOLOS natural ventilation simulation code, (Allard, 1998). The used software is well validated in the frame of the PASCOOL research project against a high number of experiments, (Limam K., Allard F., Dascalaki E, 1997).

Figures 2-3, give the air flow rate for the ten canyons, and for the single side and cross ventilation configuration respectively. The two flow rates, one when the ambient temperature and wind speed is used, and the second corresponding to the inside canyon measured data, are given. Analysis of the results permits to extract the following conclusions.

a) During the day time, when the ambient wind speed is considerably higher than wind speed inside the canyon and inertia phenomena dominate the gravitational forces, the natural ventilation potential in single and cross ventilation configurations is seriously decreased inside the canyon. In practice this happens when the ambient wind speed is higher than 4 m/sec. For single side ventilation configurations the air flow is reduced up to five times, while in cross ventilation configurations the flow is sometimes reduced up to ten times.

b) During the day time and when the ambient wind speed is lower than 3-4 m/sec, gravitational forces dominate the air flow processes. In this case the difference in wind speed inside and outside the canyon, do not play any important role and especially in single side configurations.

c) During the night time the ambient wind speed is seriously decreased and is comparable to the wind speed inside the canyon. In this case the air flow calculated for inside and outside the canyon is almost the same.

d) The calculated reduction of the air flow inside the canyon is mainly a function of the wind direction inside the canyon. When the ambient flow is almost vertical to the canyon axis, the flow inside the canyon is almost vertical and parallel to the window. In this case a much higher pressure coefficient correspond to the conditions outside the canyon, and thus a much higher flow is calculated when the ambient conditions are considered and inertia forces are dominating. When the ambient flow is parallel to the canyon axis, a similar flow is observed inside the canyon, thus the pressure coefficients are almost similar.

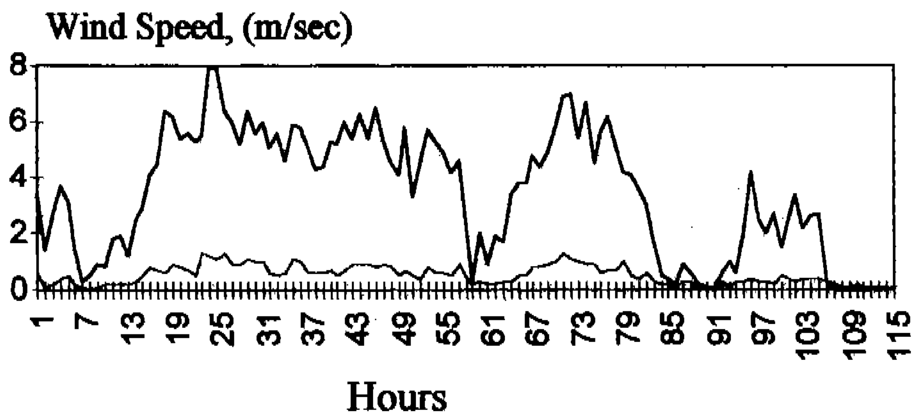

Figure 1. Measured wind speed inside and outside a representative urban canyon in Athens.

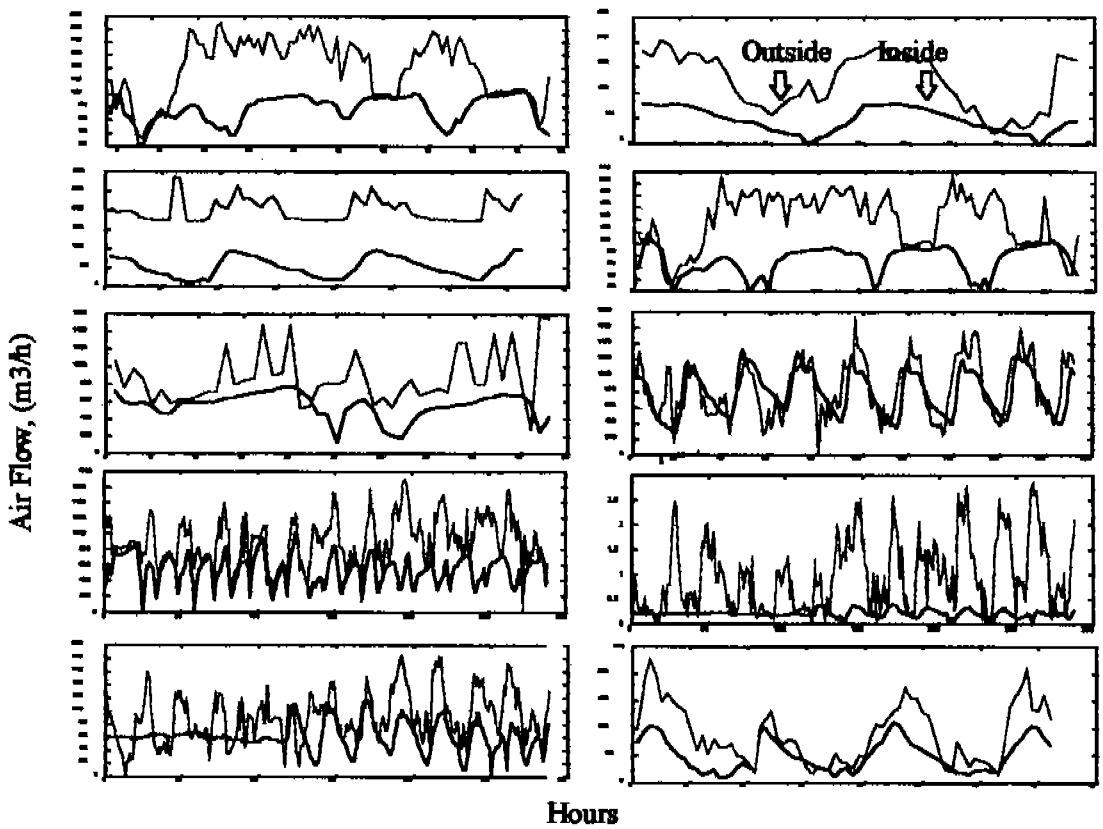

Figure 2. Air flow rates calculated for ten different canyons and for single side building configurations.

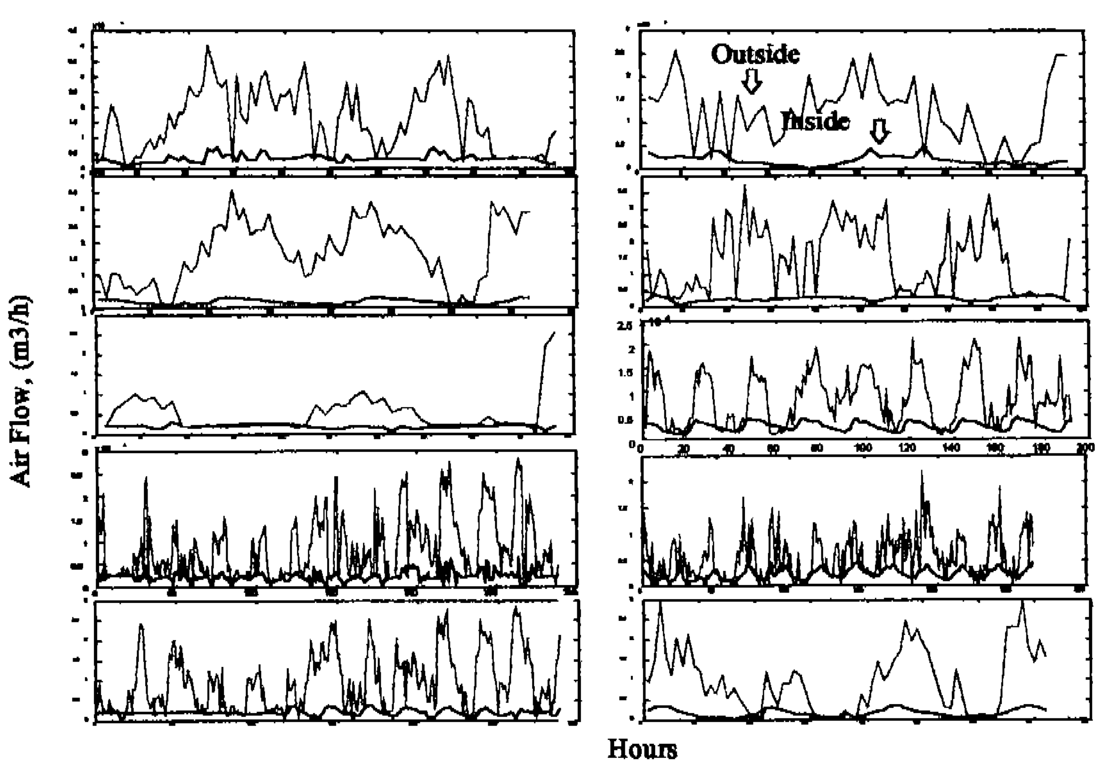

Figure 3. Air flow calculated for ten different canyons and for cross ventilation configurations

5. Conclusions

An assessment of the potential of natural ventilation in urban areas and in particular in urban canyons are presented. Calculations are based on air flow and temperature measurements taken in ten different canyons in Athens. A very serious reduction of the natural ventilation potential inside canyons is calculated especially during the day period. Compared to the air flow rates when undisturbed ambient meteorological data are used, air flow rates inside canyons may be reduced up to ten times. Further research work to better understand air flow processes in urban canyons is necessary.

6. Acknowledgment

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