The Influence of Solar-Induced Wall Heating on the Flow Regime within Urban Street Canyons

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Introduction

The wind flow in street canyons has been studied by many workers because of its role in the transport of pollutants. Wind speed, temperature, and stability conditions have been investigated in field studies (e.g. Nakamura and Oke (1988), Vachon (2000)), as well as in wind tunnel studies (Ogawa et al. (1981), Uehara et al. (1997a), Uehara et al. (2000)). In addition, dispersion of pollutants has been investigated within street canyons in stratified urban canopy layers (Uehara et al. (1997b). The influence of different buoyancy effects due to wall heating in wind tunnels is still under investigation because it is a difficult matter to match the necessary similarity laws for velocity and temperature. As it is still in question how the thermal influence may change the existing flow features, an investigation has been set up to study the effect of different Froude numbers on the velocity field in order to find out whether there is a threshold value below which thermal effects cannot be neglected.

Methodology

An investigation has been conducted in a wind tunnel where the effect of solar induced wall heating has been simulated by heating of the windward facing wall. For this purpose, a nominally 2-D cavity of fixed depth and height, H=W=285mm, was set up in the boundary layer wind tunnel at the EnFlo Research Centre at the University of Surrey (Fig. 1). Different buoyancy conditions have been simulated by a variation of the temperature of the windward facing wall and different velocities of the oncoming flow, resulting in Froude numbers Fr ranging between 0.28 and 2.03. The Froude number is defined as $Fr=U_{ref}^2/(gH(T_w-T_{ref})/T_{ref})$, where T_w denotes the heated wall temperature, T_{ref} the ambient reference temperature and g the acceleration due to gravity. Five vertical profiles have been measured inside the cavity, as shown in Fig. 3. The boundary layer was fully developed with a height of δ=1000mm (δ/H=3.51) (Fig. 3), a roughness length between z_0=1 and 1.6mm, a displacement height d=0mm and a friction velocity u_*/U_{ref}=0.064 to 0.070, based on changing the free-stream velocity from U_{ref}=0.5 to 2m/s. The resulting Reynolds number was 9.5 to $19\text{x}10^3$, based on the cavity depth. The velocity measurements were conducted with a DANTEC Laser-Doppler Anemometer, which gives the two mean wind components u (horizontal) and w (vertical). The temperature measurements were performed with thermocouples and platinum resistance thermometers. All of the measurements were conducted on 5 vertical profiles, principally along the streamwise centreline but also at other cross-sections in the cavity. The flow quality, especially the 2-dimensionality, has been controlled by endplates to give optimum test conditions. The sampling rate of the anemometer system, which is dependent on the seeding, was up to approximately 100 Hz (slightly less inside the cavity) and a sufficient number of samples guaranteed stationary and repeatable values.

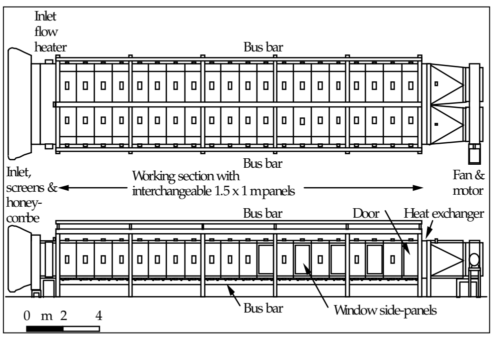

Fig. 1 Description of the wind tunnel.

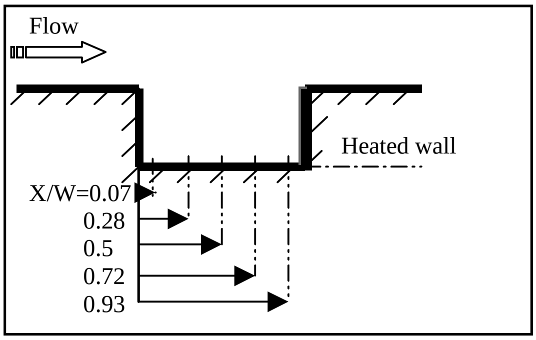

Fig. 2 Description of the measured profiles within the cavity.

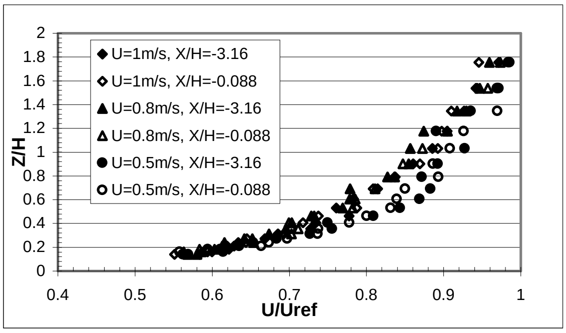

Fig. 3 The oncoming mean velocity profiles, taken at 3 different velocities and 2 different upstream positions.

The heating of the wall was controlled by a set of thermocouples providing the same temperature along the whole wall with a deviation of about 3-4° from the mean.

Results and Discussion

The influence of the temperature due to the wall heating seems, in general, to be very small. The overall feature of a single main vortex in the cavity remains for all four different Froude numbers (Fig. 4-7), but the magnitude of the velocity vector changes (Reference vector is 1m/s). From the cases of the lowest (80°) and the highest temperature (120°C) taken at the same velocity (1m/s), it can be concluded that it is the velocity which is the driving force for the vortex and that the temperature only has a very small influence. Also, at the lower velocities of 0.5 and 0.8m/s and a temperature of 120°C there are no signs of an updraft resulting from the warmer air close to the heated wall. For those two cases it is found that at the very bottom of the cavity there is a weak flow in the freestream direction, indicating a motion that is weakly connected to the flow above. However, as the oncoming flow velocity is lower than the threshold value necessary for establishing a main vortex inside of the canyon with a flow perpendicular to the oncoming flow on the ground (DePaul and Sheih (1986)), it must be considered that this secondary flow is due to the small velocities and not to the temperature gradients. This is also supported by the fact that the temperature distribution inside the canyon is very similar for all the cases taken at the same temperature (Fig. 8-11). Only for the case with a velocity of 1m/s and the lower temperature of 80°C is the mean temperature in the flow field slightly lower, although it still has the same distribution. This, again, indicates that the velocity is still the driving force for the flow features inside the canyon, with very little influence of the temperature. Nevertheless, a threshold value can be seen between a Froude number of 0.73 and 1.20 where the flow velocity changes its magnitude and its direction at the lowest level inside the canyon.

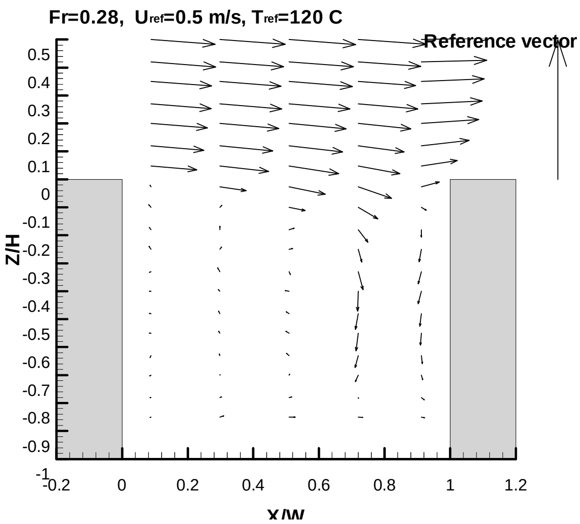

Fig. 4 Velocity vectors inside cavity, Fr=0.28.

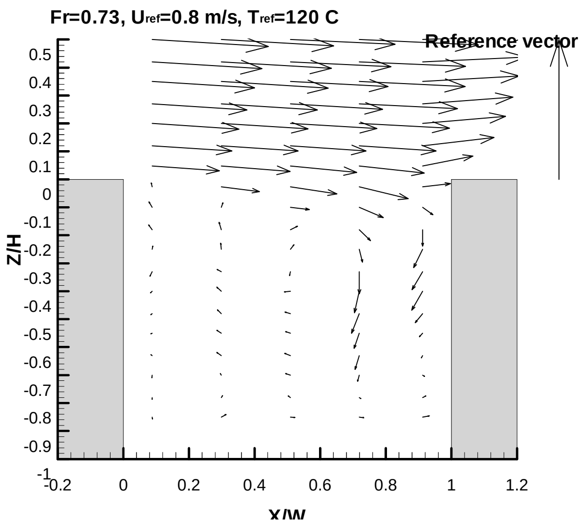

Fig. 5 Velocity vectors inside cavity, Fr=0.73.

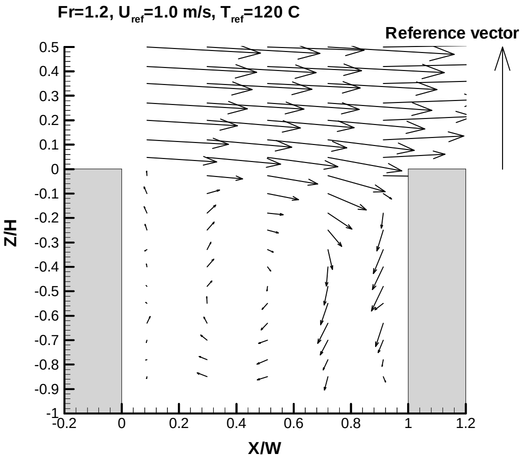

Fig. 6 Velocity vectors inside cavity, Fr=1.20.

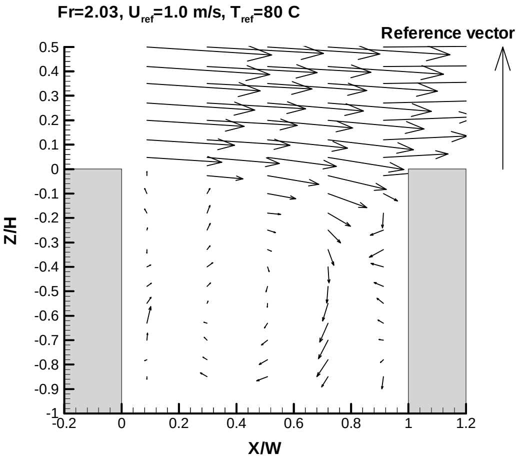

Fig. 7 Velocity vectors inside cavity, Fr=2.03.

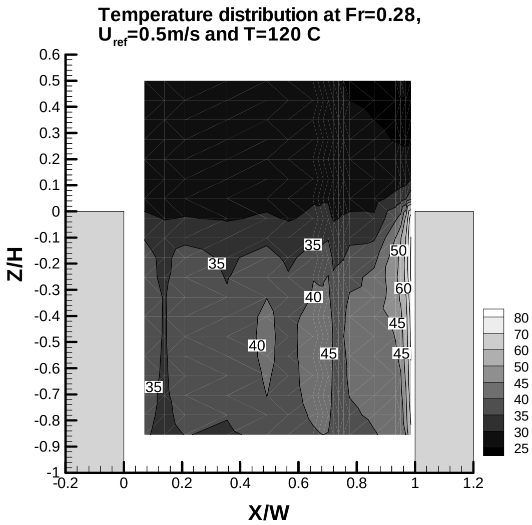

Fig. 8 Temperature distribution, Fr=0.28.

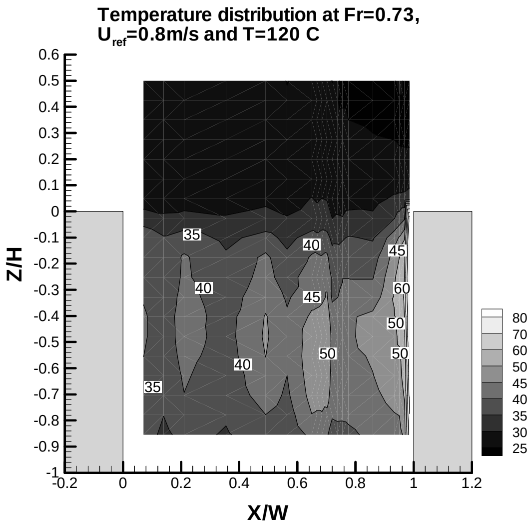

Fig. 9 Temperature distribution, Fr=0.73.

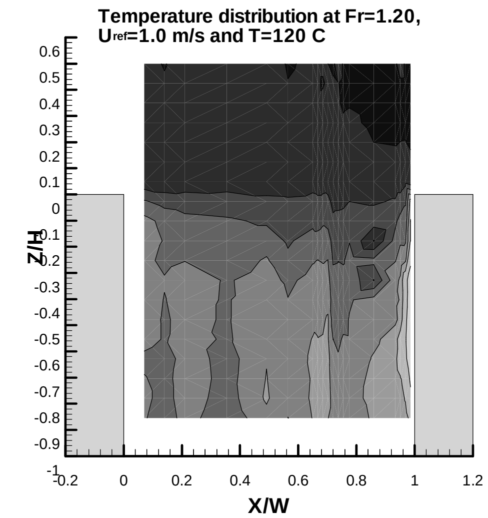

Fig. 10 Temperature distribution, Fr=1.20. Contours as in previous figure.

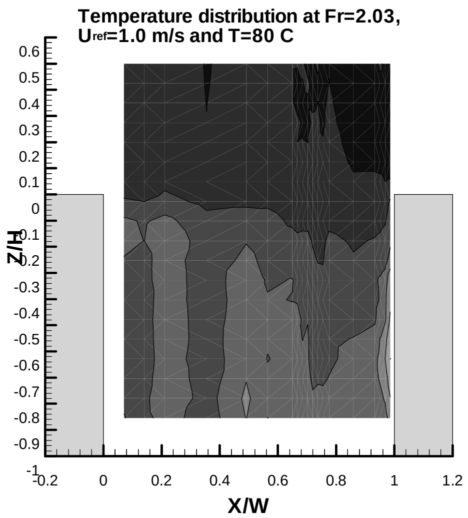

Fig. 11 Temperature distribution, Fr=2.03. Contours as in previous figure.

Concluding Remarks

A nominally 2D cavity with an aspect ratio of 1 has been set up in a wind tunnel, permitting uniform heating of the windward facing wall. The experiments indicate that the velocity is the driving force for the establishment of the vortex and that the temperature does not greatly affect the overall features. A threshold Froude number can be seen between 0.73 and 1.20 but the data still need to be analysed further. In a second stage a comparison of the wind tunnel data will be conducted with numerical simulations carried out by ECN in France with the numerical code CHENSI (Sini et al. (1996)) and by LHTEE in Greece with the numerical code CFX-Tascflow (Raw et al. (1989) and Raw (1994)). These will be discussed in the full paper.

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Acknowledgements

The authors gratefully acknowledge funding from the EU within the TMR project TRAPOS (Contract ERBFMRXCT97-0105). The authors should also like to thank Dr P Hayden, and Mr T Lawton from EnFlo and Mr T Renouf, Dr P Louka, Dr P G Mestayer, Mr X Mestayer from ECN for their contributions to this research.