# CFD SIMULATIONS FOR THE STUDY OF THERMAL EFFECTS ON FLOW AND POLLUTANT DISPERSION IN URBAN GEOMETRIES

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## ABSTRACT
The impact of thermal effects on pollutant dispersion in street canyons with different aspect ratios is investigated. Several tests are performed using the CFD code FLUENT to study flow and pollutant dispersion. The modelling is based on the Reynolds Averaged Navier-Stokes (RANS) flow equations. The thermally induced flow is combined with the mechanically induced flow and affects the flow pattern and the pollutant dispersion in the street canyon. It is found that the street geometry plays an important role in the relative influence of buoyancy with respect to inertial forces.

## INTRODUCTION
Traffic emission in urban areas has become a major source of air pollution despite significant improvement in fuel and vehicle emission control techniques. On the other hand, cities are characterized by narrow and deep street canyons, which make difficult the dilution of pollutants emitted by ground sources. Several parameters affect the pollutant dispersion in street canyons, such as the ambient wind direction and speed, the building geometry, the street canyon aspect ratio, the air-building temperature difference, etc. Among the methods to study flow and dispersion in urban areas and in street canyons, Computational Fluid Dynamics (CFD) modelling plays an important role, as it allows the study of flow characteristics and concentration patterns at a building-resolving scale. Until now, the effect of building geometry and dimensions without thermal effects has been extensively studied in wind tunnel experiments and by means of numerical models (*Ahmad, K. et al.*, 2005; *Di Sabatino, S. et al.*, in press; *Vardoulakis, S. and E. Bernard*, 2003). Thermal effects result mainly from variations in the solar heating of the street canyon walls and the ground surface during the day; with the temperature differences influencing the in-canyon flow and its vertical transport capabilities (*Sini, J.F.*, 1996; *Kim, J.J. and J.J. Baik*, 2001). *Xie, X. et al.* (2005) evaluated the effect on flow in street canyons having walls with different temperatures. Recently, *Santese, F. et al.* (2007) compared CFD simulations of urban street canyons with heated walls with wind tunnel data; they reported a good agreement in terms of the qualitative behaviour of temperature profiles using the *k-e* turbulence model. In this paper we extend this work by performing several computational experiments using the CFD code FLUENT (*FLUENT 6.2*, 2005) to study the effect on dispersion in street canyons of heated walls using street canyons with different aspect ratios *W/H* (where *W* is the width and *H* the height of the canyon). The present work is part of our current research on air quality and pollutant dispersion modelling in urban street canyons.

## FLUENT SIMULATIONS
The standard *k-e* turbulence model is used for all simulations. At the inlet to the flow domain we use a constant velocity; U=1m/s. The Boussinesq approximation is assumed and the temperature differences are small compared with the absolute temperature. The CFD modelling was undertaken using a similar set-up to that in *Solazzo, E. et al.* (2005). Cases with and without solar radiation at different locations, such as heating at ground level, the leeward and windward sides of buildings are analyzed. The thermal stratification of the inflow

is neutral and the ambient air temperature at ground level is 27°C. The temperature of the ground, the leeward wall or the windward wall is set to 37°C (Fig. 1). The remaining boundary conditions (surface roughness representation, symmetry conditions etc.) are those specified in *Di Sabatino, S. et al.* (in press). For dispersion modelling, in FLUENT the diffusion term in the pollutant transport equation is modelled using

$$J = -\left( rD + \frac{m_t}{Sc_t} \right)\nabla Y \qquad (1)$$

where $D$ is the diffusion coefficient for the pollutant in the mixture, $\mu_t$ = ½($C_\mu k^2/e$) is the turbulent viscosity, $Y$ is the mass fraction of pollutant, $r$ is the mixture density. $Sc_t = \mu_t/(½D_t)$ is the turbulent Schmidt number, where $D_t$ is the turbulent diffusivity. A line source has been simulated by separating a volume in the geometry on the ground at the centre of the street canyon and by setting a source term for this volume. The source has dimensions L=40m (length of the street canyon) in the direction transversal to wind and 1m in the direction parallel to wind. The emission rate of a passive pollutant is set at Q=10g/s over the length of the release. Mean concentrations are expressed as dimensionless values $K$ defined as:

$$K = (CUH)/(Q/L) \qquad (2)$$

where $C$ is the calculated concentration, $U$ is the wind speed at the inlet and $H$ the height of the building (equal to 10m).

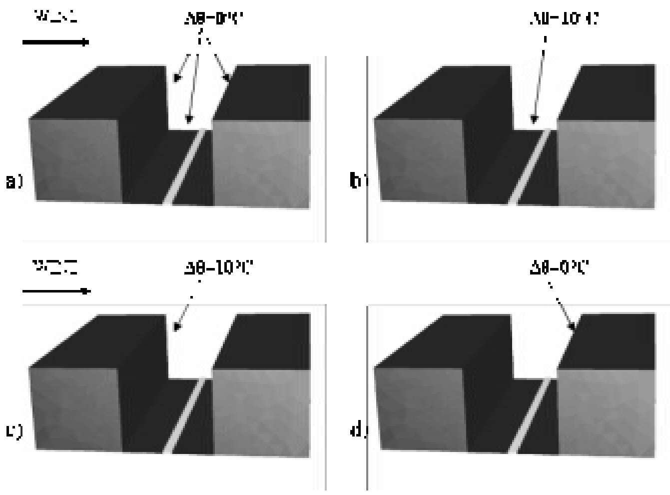

*Fig 1; Idealized street canyon configurations considered with the line source positioned on the ground. a) no surfaces heated (Dq=0°C); b) ground heated (Dq=10°C); c) leeward heated (Dq=10°C); d) windward heated (Dq=10°C).*

**RESULTS**

The impact on pollutant dispersion in street canyons with heated walls is examined. Heating the wall surface or the ground makes the in-canyon air temperature higher than that of the air outside the street canyon. This leads to a strong buoyancy force close to the heated wall or ground and affects the flow structure and the pollutant dispersion. The importance of the buoyancy effects compared with mechanical effects is governed by the Richardson number

$$Ri = ((g\ (T_w - T_a)\ /\ T_a)*(H))\ /\ (U*U)$$

and this is constant at 3.27, and significant, for all the results presented in this paper.

If there is no difference in temperature between the walls and the air, a clockwise vortex within the street canyon and higher concentration at leeward side of building has been found in previous studies. We present and discuss results when $U$=1m/s and the temperature difference is 10°C for all the aspect ratios. Concentrations are plotted as a function of $z/H$ in two positions within the street canyon: at a dimensionless distance from the leeward *x/W*=0.25 and at a dimensionless distance from the windward *x/W*=0.25. Overall the in-canyon concentrations decrease from the case *W/H*=0.5 to *W/H*=2, as the modification of the vortex system due to the street canyon aspect ratio is the main factor of the street ventilation and therefore contributes to the final concentration at street level. The deeper street canyons (those with smaller aspect ratio) are characterized by a skimming flow regime that creates more stagnant conditions.

**Influence of ground and leeward heating**

Fig. 2 shows concentrations profiles with leeward wall and ground heating. For each *W/H*, we note that when the sun shines directly on the building on the leeward side of the street canyon or the ground level, the pollutant concentration near the leeward side is larger than near the windward side. On the leeward side, the pollutant concentration decreases from the floor to the roof of the upstream building, while the pollutant concentrations are almost constant on the windward side. As an example, Fig. 3 shows velocity vector for the *W/H*=1 case. The airflow structures are similar to the case without heating, so pollutant concentrations are comparable to the isothermal case. Similar results are obtained for the *W/H*=0.5 and *W/H*=2 cases.

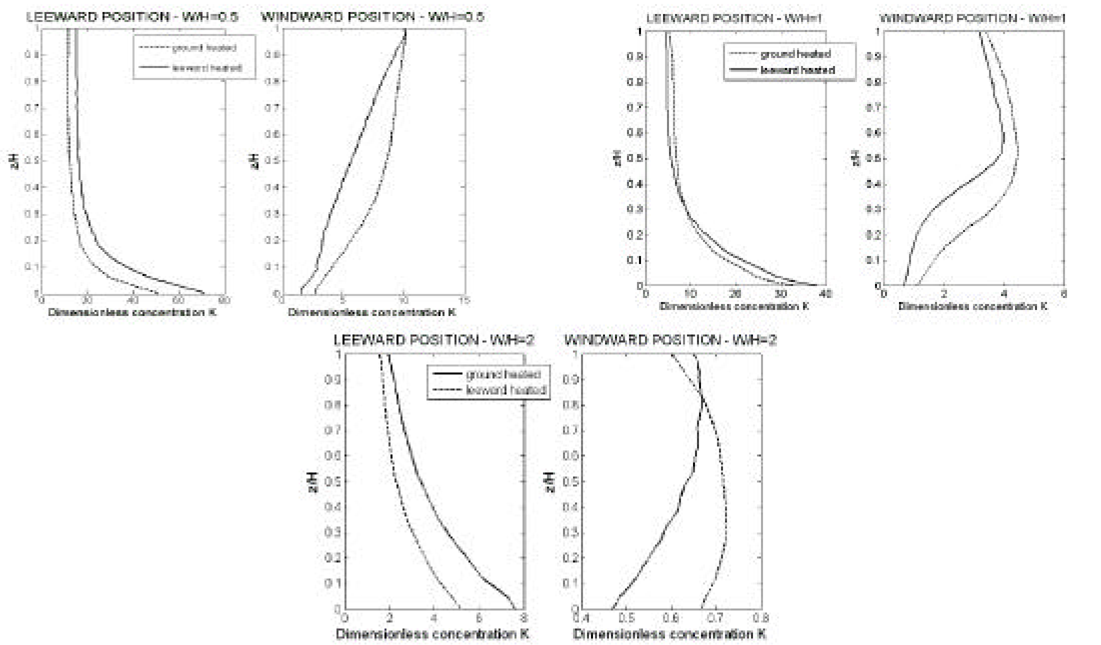


*Fig. 2; Dimensionless concentrations in the street canyons with W/H=0.5, 1 and 2; leeward heated and ground heated.*

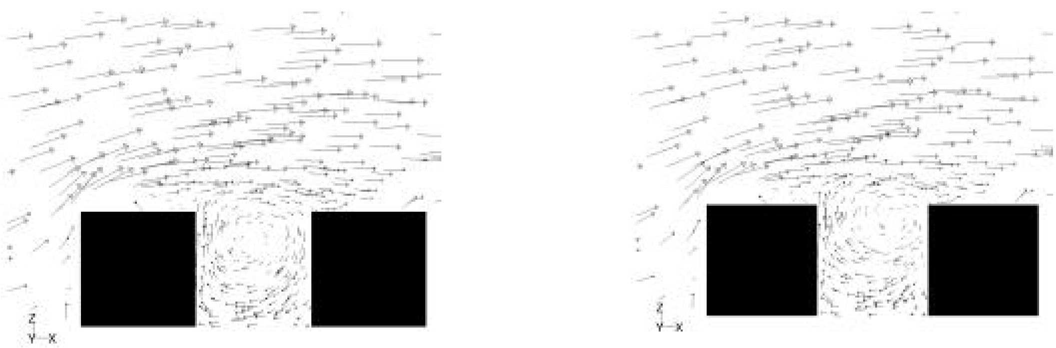

*Fig.3; Velocity vectors for the W/H=1 case; ground heated (left) and leeward heated (right).*

**Influence of windward heating**

In the case when the windward side of the street canyon is at the higher temperature the situation is different (Fig. 4). The pollutant concentration near the windward side is larger than those near the leeward only for the *W/H*=0.5 and in the lower part of the canyon. Moreover, a further difference between street canyons with *W/H*=1 or 2 and street canyon with *W/H*=0.5, is that for the first on the leeward side the pollutant concentration decreases from the floor to the roof, while is almost constant on the windward side; for the latter the situation is exactly the opposite. Fig. 5 shows velocity vectors for the *W/H*=0.5 (left) and *W/H*=1 (right) cases. An upward buoyancy flux opposes the downward advection flux along the windward wall, so that pollutants are accumulated at the windward for the *W/H*=0.5 case. This effect is less evident for the *W/H*=1 and *W/H*=2 cases, where pollutant concentrations are larger at the leeward side as previously discussed in Fig. 4.

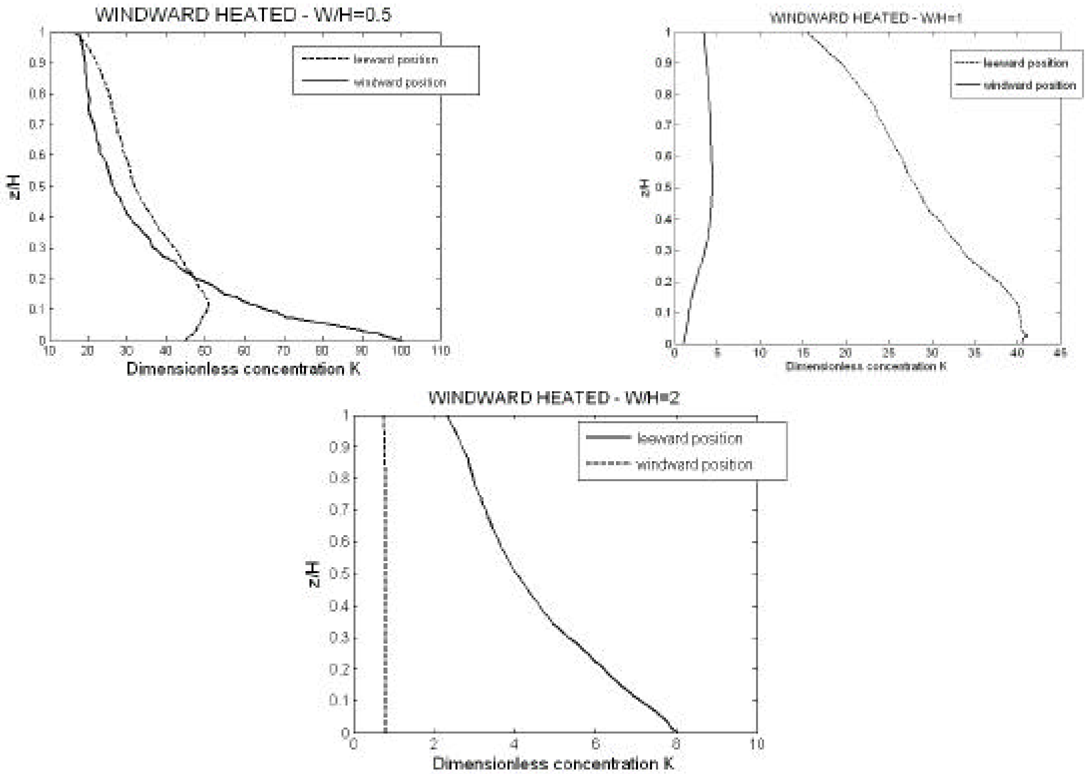


*Fig. 4; Dimensionless concentrations in the street canyons with W/H=0.5, 1 and 2; windward heated.*

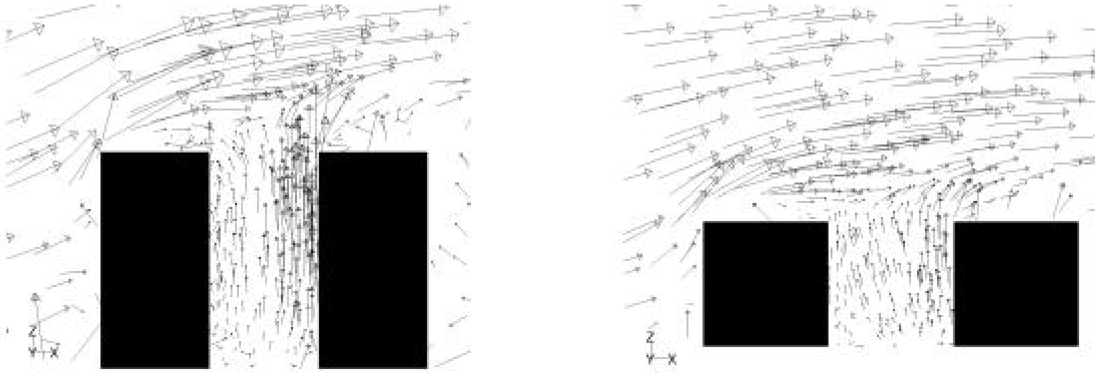

*Fig 5; Velocity vectors for the W/H=0.5 (left) and W/H=1 (right) cases; windward heated.*

## CONCLUSIONS

The effects on flow and pollutant dispersion in street canyons of different aspect ratios with heated walls are studied. The heat from the wall surface or ground makes the air temperature inside the street canyon larger than that of the air outside it. Temperature difference creates a buoyancy force close to the wall or ground ,that receives direct solar radiation and this affects the transport of pollutants within the street canyon It is found that, in general, solar heating has an important effect on the airflow structure especially when the windward wall is heated, while when the leeward or the ground are heated, pollutant concentrations are similar to those found in the isothermal case. In particular, when the windward is heated, the vortex flow is disturbed by the upward flux due to the vertical buoyancy flux near the wall. Consequently the pollutant concentration near the windward side is lower than in the leeward side and on the leeward side the pollutant concentration decreases from the floor to the roof, while is almost constant on the windward side. The situation is the opposite for the street canyon with W/H=0.5. This work could be useful for air quality improvement in urban areas by street planning. Further research is ongoing to understand the thermal effects in irregular canyons and other complex building configurations.

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