Turbulent heat transfer from urban surfaces

Name
Wagner Nogueira Neto, Janet F Barlow, Jake Hacker, Michael Holmes, Andrew White

Thesis topic
Turbulent Heat Transfer from Urban Surfaces

Doctoral study area
Urban Meteorology

University, Award
University of Reading, PhD

Group:
Meteorology (UoR), Advanced Technology + Research (Arup)

Date of study:
2010 - 2013

Wagner Nogueira Neto

Thermal comfort in urban areas is an important consideration in contemporary urban design and new experimental methods and mathematical models are required to explain how building shape and layout affect it. This work modifies and improves Arup's ability to model outdoor comfort by incorporating simple models of complex flow processes.

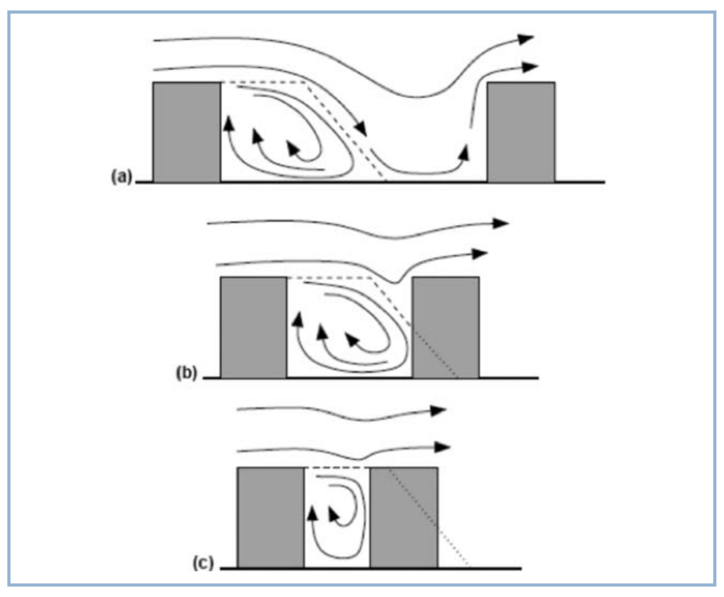

Figure 1. Flow patterns around street canyons for different aspect ratios (building height to street width, H/W) (Harman et al, 2004; Oke, 1987). From a) to c), the flow regimes represented are the isolated roughness regime, the wake interference and the skimming flow regime, respectively.

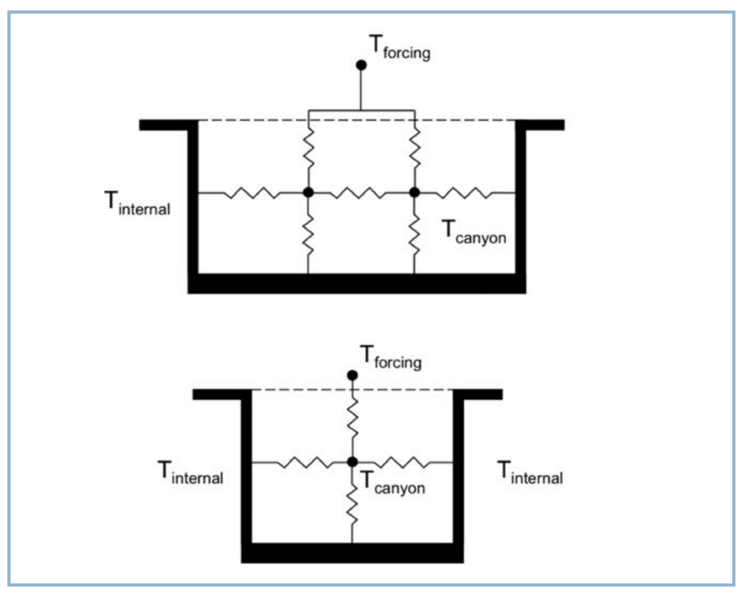

Figure 2. The Arup OutdoorRoom (ODR) resistance network model for heat transfer in a street canyon. Internal, canyon and forcing temperatures are indicated.

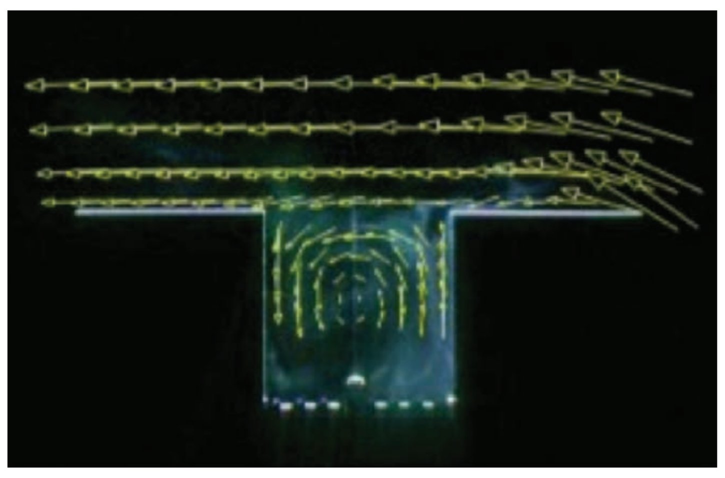

Figure 3a. Flow visualisation for a street canyon with flat roofs. Mean velocity field indicated by the arrows.

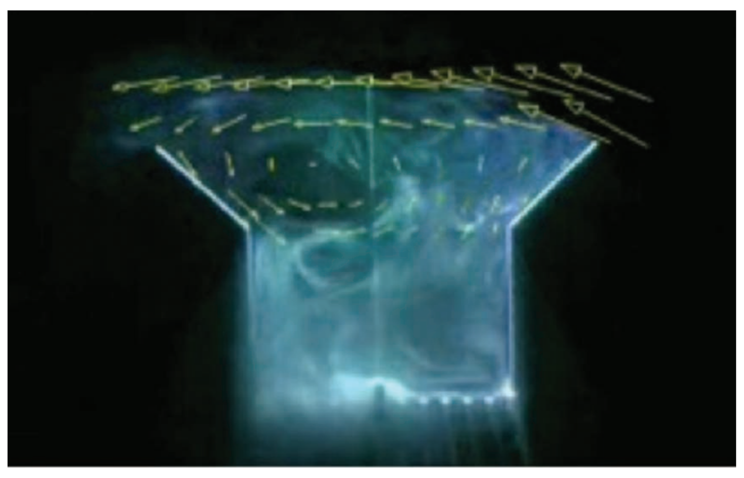

Figure 3b. Flow visualisation for a 45° pitched roof. The roof level vortex can be clearly seen. The indication of poorer ventilation can be noted by the higher concentration of tracer gas near the surface. (Thanks to B. Leitl at University of Hamburg for use of wind tunnel facilities).

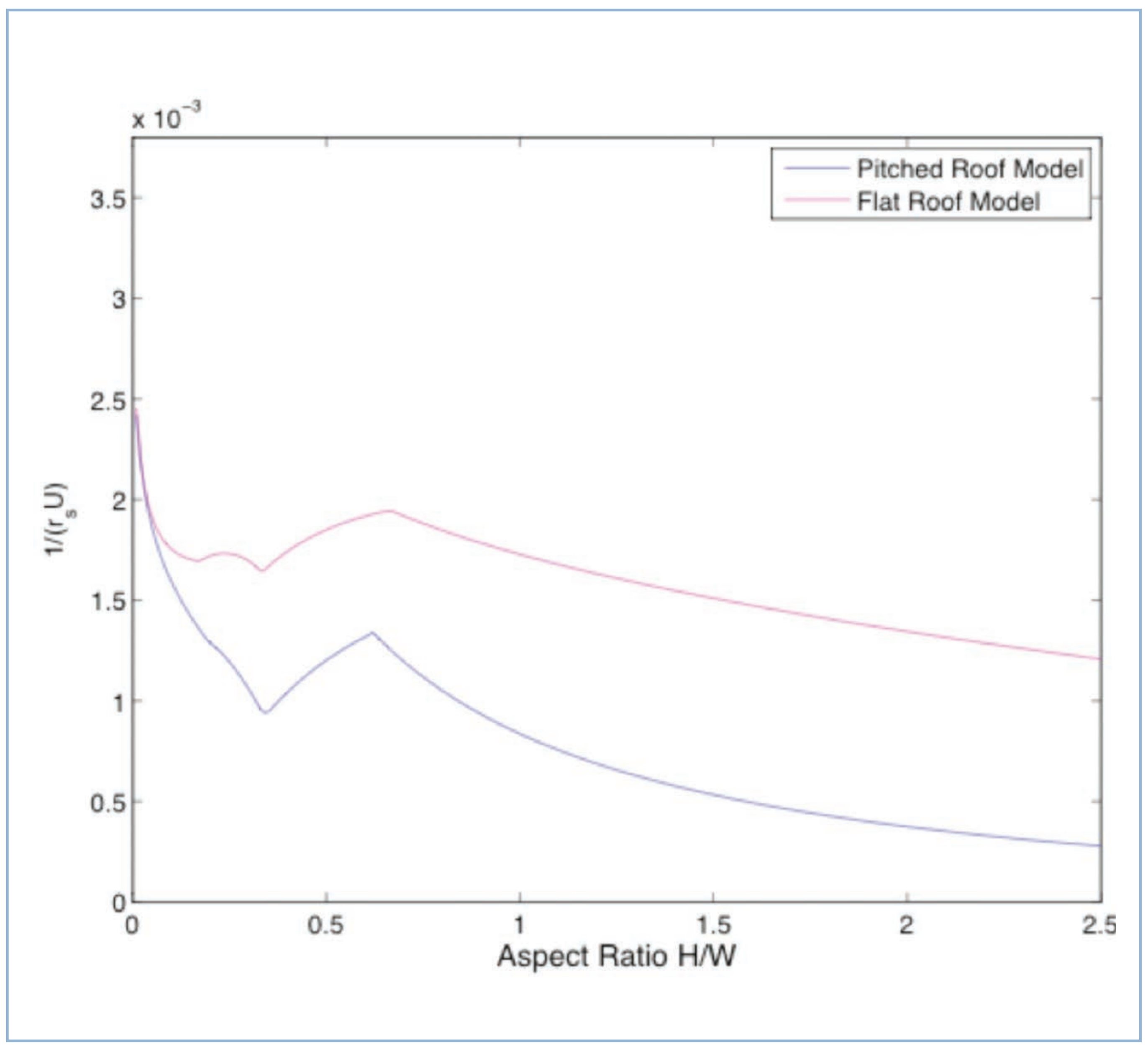

Figure 5. The influence of changed roof pitch on the resistance to heat transfer. The magenta line depicts the inverse of the resistance (non-dimensionalised by wind-speed U) for transfer from the street surface with a flat roof (Harman et al. 2004) and the blue line represents the results with the new pitched roof parameterisation.

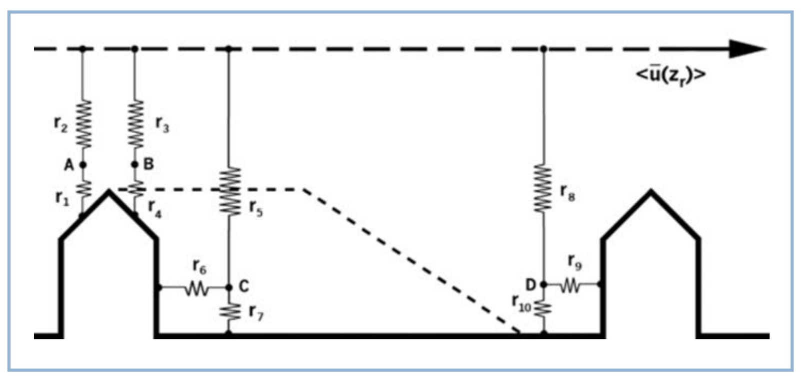

Figure 4. The new resistance network for a steeply pitched roof. For the street surface, only the resistances 5, 7, 8 and 10 are active.

Value

- Outdoor thermal comfort is highly relevant to planning policy, so providing methodologies to quantify the influence of building morphology and materials on thermal comfort/heat transfer is crucial.
- This research will lead to an enhanced ODR model capable of capturing a broader range of geometries and physical processes.
- The models developed will also help to improve meteorological models that can be used to forecast the urban heat island of cities.

Abstract

The air and surface (radiant) temperatures experienced in an urban environment are dependent on turbulent heat transfer from urban surfaces to the surrounding air. This is highly complex: however, Harman et al. (2004) modelled turbulent transfer from street canyons in a relatively simple way, by accounting for flow recirculation and ventilation regions (see Figure 1).

Figure 2 shows turbulent transfer as a series of resistances in Arup's OutdoorRoom model (ODR), which is based on the Harman scheme. The outdoor environment is coupled with Arup's Room model, which models the fabric of the buildings and allows the buildings of the canyon to play a role in conducting/radiating heat away from the surface.

Flow in a street canyon with a flat roof is a well-studied area, but typical urban morphology is more complex than this. Figures 3a and 3b show a flow visualisation study (Barlow, pers. comm.) and differences between the flat and pitched roof set up. For a pitched roof, the dynamics of the flow depart from a single vortex within the canyon to a double vortex within the recirculation region. This change in flow dynamics means that the air travels a longer distance before impinging on the street surface, slowing it down and, thus, increasing the resistance and reducing the flux. In order to take the model one step forward, a pitched roof parameterisation was implemented. Figure 4 shows the new resistance network and Figure 5 indicates a significant decrease in ventilation at street level due to the addition of a roof to the canyon.

Conclusions & next steps

A better understanding about the dynamics of flow around buildings is necessary in order to develop simple models to represent more complicated processes. Simple changes in morphology of buildings can have a rather large impact on the processes occurring at street level, such as heat fluxes.

A stand-alone version of the resistance network model was formulated for a street canyon with a 45° pitched roof. This parameterisation was formulated by observing the change in flow dynamics from a single to a double vortex flow regime, where the vortex at roof level acted to slow down flow near to the surface. In turn, this caused a significant decrease in heat fluxes from the street canyon, leading to higher street level temperatures and decreased thermal comfort.

The next step of this work is to validate the model against wind tunnel measurements, which is currently being done at the University of Reading. This parameterisation will be implemented to Arup's ODR model and test runs will be done with real atmospheric data.

ARUP