Sensitivity of turbulent flow and dispersion around a 3-D regular building array to urban boundary-layer stability

Guangdong DUAN[1*], Tetsuya TAKEMI[1], Keith NGAN[2]

1. DPRI, Kyoto University, Japan; 2. City University of Hong Kong, Hong Kong SAR

Introduction

Turbulent flow and dispersion around a regular building array are analyzed for a wide range of thermal stratifications (the bulk Richardson number, Rb=-0.52~0.31) using large-eddy simulation. The mean flow and turbulence statistics change abruptly at Rb=0, indicating a flow-regime transition and a change of ventilation routes. For unstable stratification, the decay time scale of the mean concentration, τ, scales linearly with the canyon circulation time scale, T_c; however the linear relationship breaks down for stable stratification. Knowledge of the flow regime transition and the change of ventilation pathways are relevant to the modelling and parameterization of pollutant dispersion for different stratified urban turbulent boundary layers.

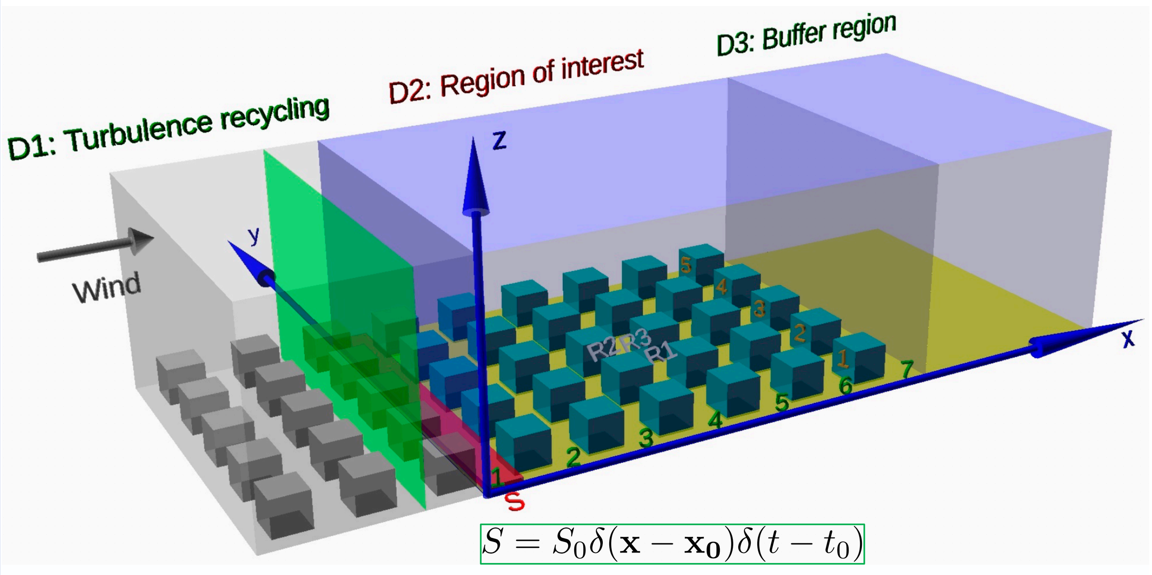

Fig.1 3-D schematic diagram of the computational domain

$$\mathrm{Rb} = \left(\frac{g}{T}\frac{T_H - T_o}{H}\right) \Big/ \left(\frac{U_{\mathrm{ref}}}{H}\right)^2$$

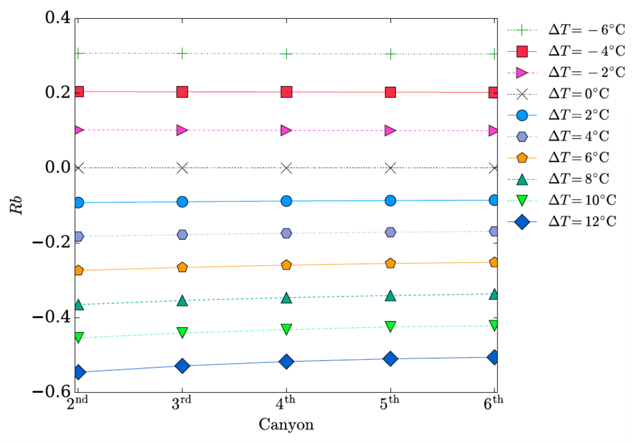

Fig.2 Rb (ensemble averaged for the spanwise canyon units, R1)

Mean flow

- The vortices are perturbed as ΔT is varied.

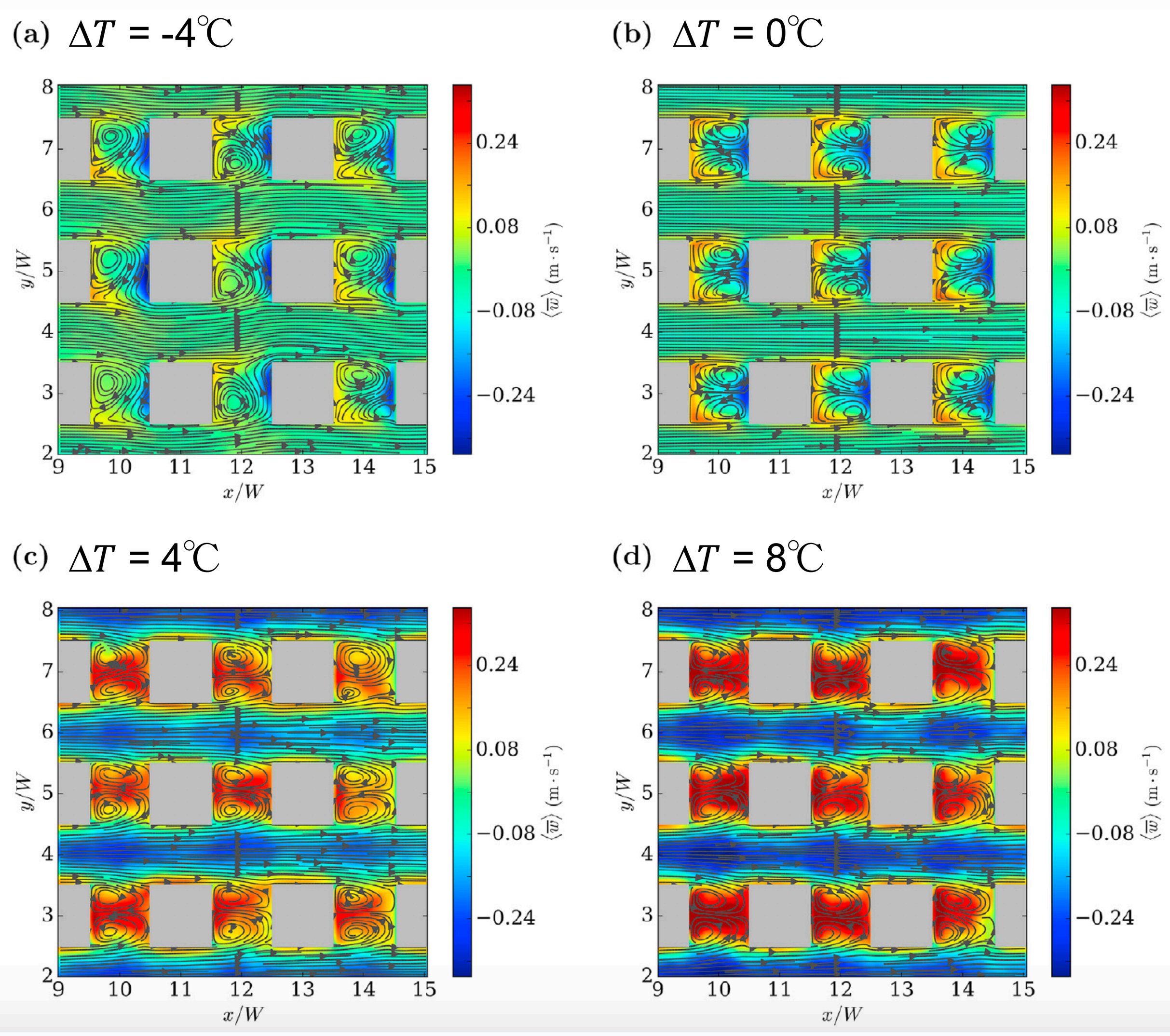

Fig.3 Time-averaged streamlines in the horizontal (x-y) plane

- For Rb>0, the primary vortex oscillates about the centreline, $y = W_y/2$.
- For Rb=0, the vortices are symmetrically arranged around the centreline [1].
- For Rb<0, well-defined counter-rotating vortex pairs persist, but the vortices are displaced towards the leeward wall.

- The mean flow exhibit a slope break at Rb=0.

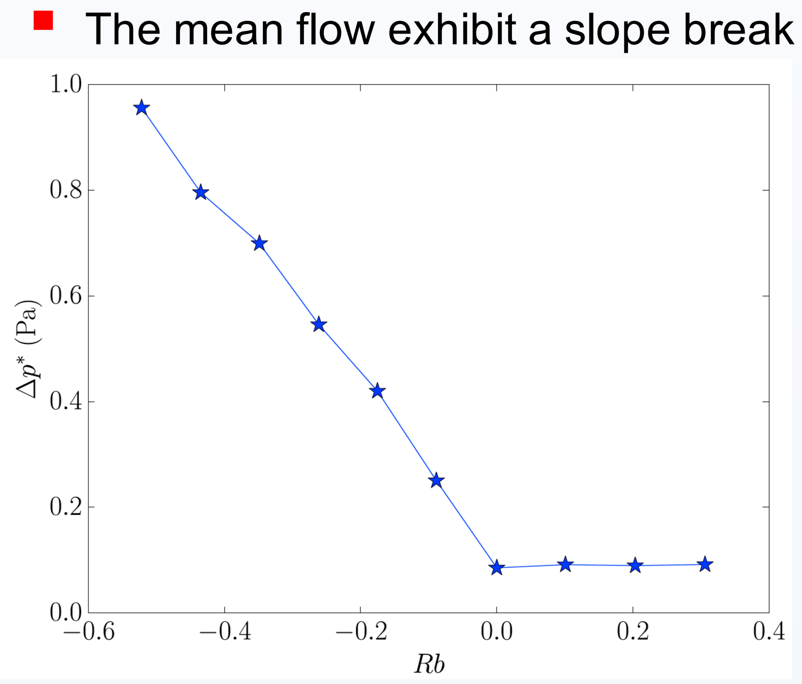

Fig.4 Time-averaged perturbation pressure difference, ΔP^*, between the leeward and windward walls versus Rb

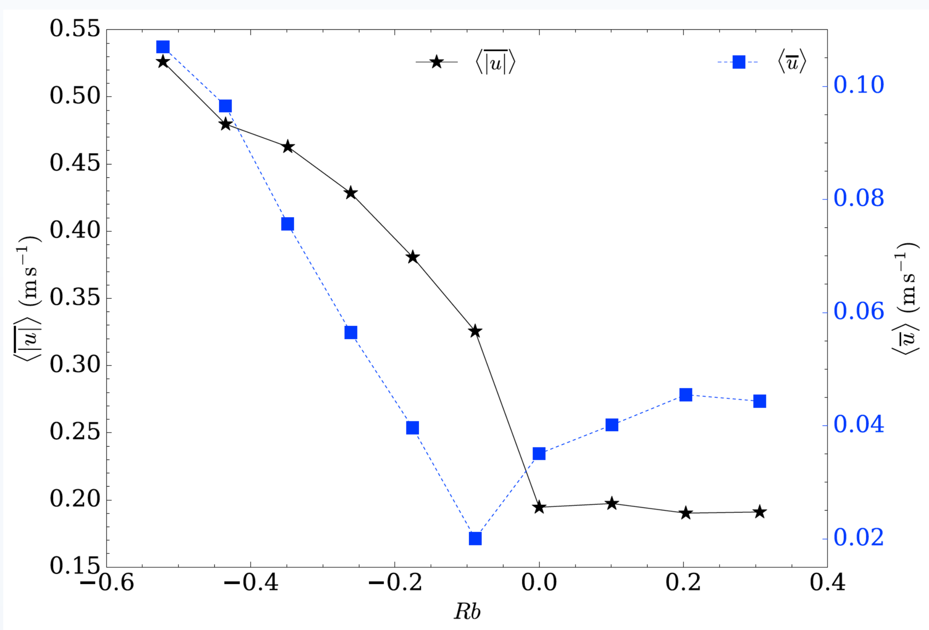

Fig.5 Spatial (R1) averages of the time-mean streamwise velocity: $\langle \bar{u} \rangle$ and the L1 norm, $\langle |\bar{u}| \rangle$, versus Rb

Turbulence statistics

- Homogeneous turbulence statistics can not be expected in the vertical for $\Delta T \neq 0$.

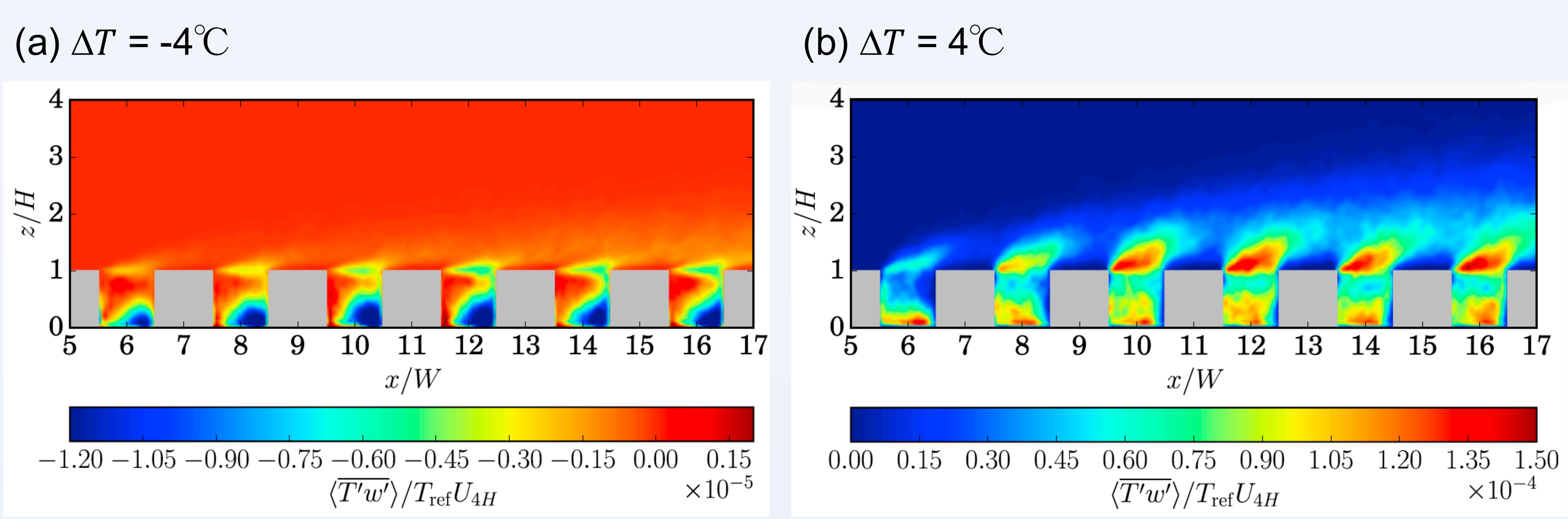

Fig.6 Spatially and temporally averaged thermal flux, $\langle \overline{T'w'} \rangle$

- Both the $\langle \overline{u'w'} \rangle_H$ and $\langle \overline{TKE} \rangle$ show a sharp transition at Rb=0.

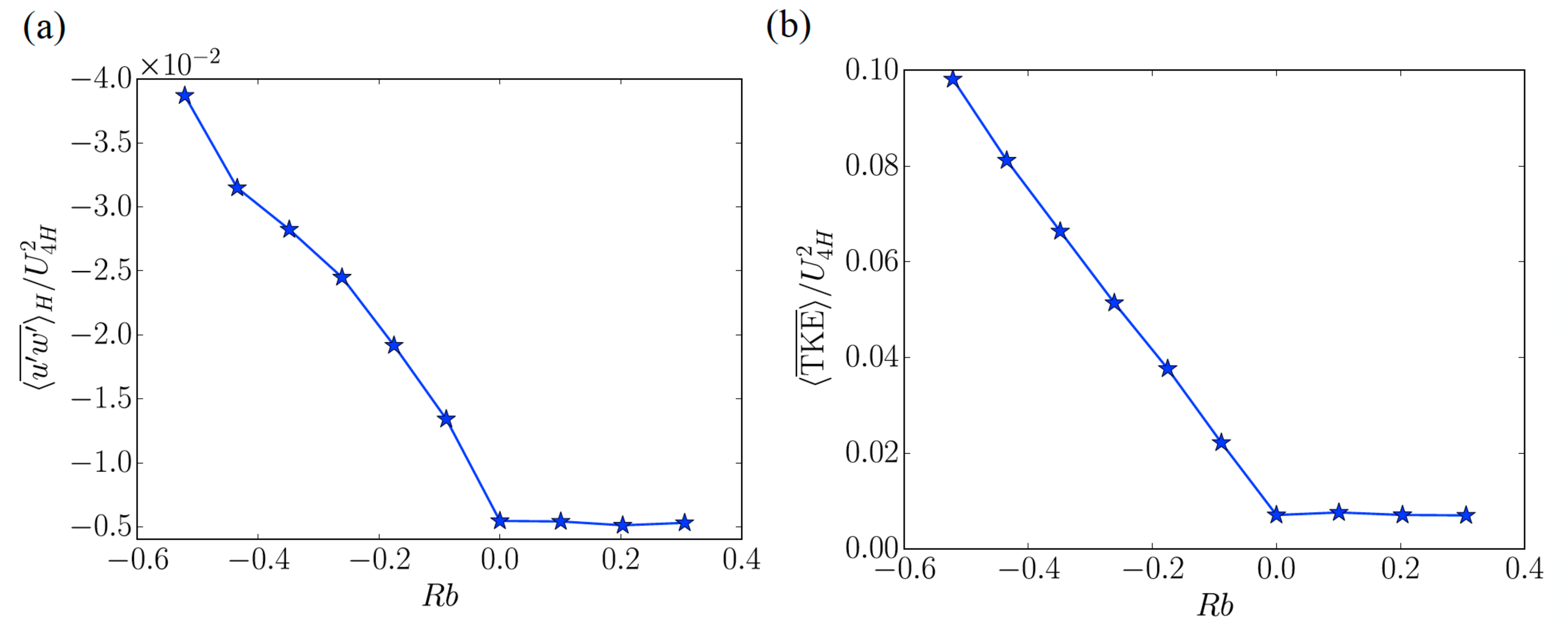

Fig.7 Turbulence statistics of (a) roof-level average, $\langle \overline{u'w'} \rangle_H$, and (b) canyon average, $\langle \overline{TKE} \rangle$, versus Rb

- Lateral flux exchanges, $\langle \overline{u'v'} \rangle$, concentrate more on the canyon sides when Rb>0.

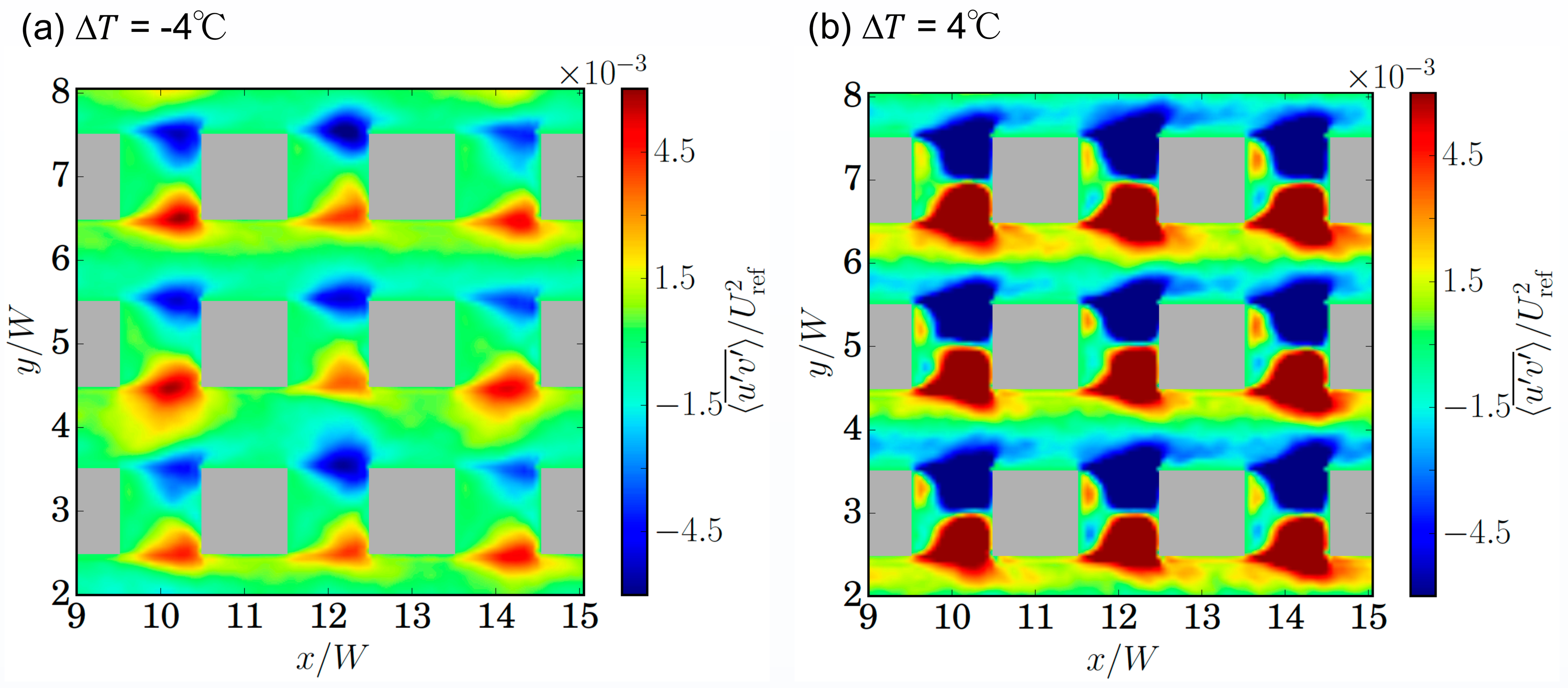

Fig.8 Lateral turbulent moment fluxes, $\langle \overline{u'v'} \rangle$

Ventilation

- The mean concentration, $\langle C \rangle_{\mathcal{D}}$, decays exponentially in time.

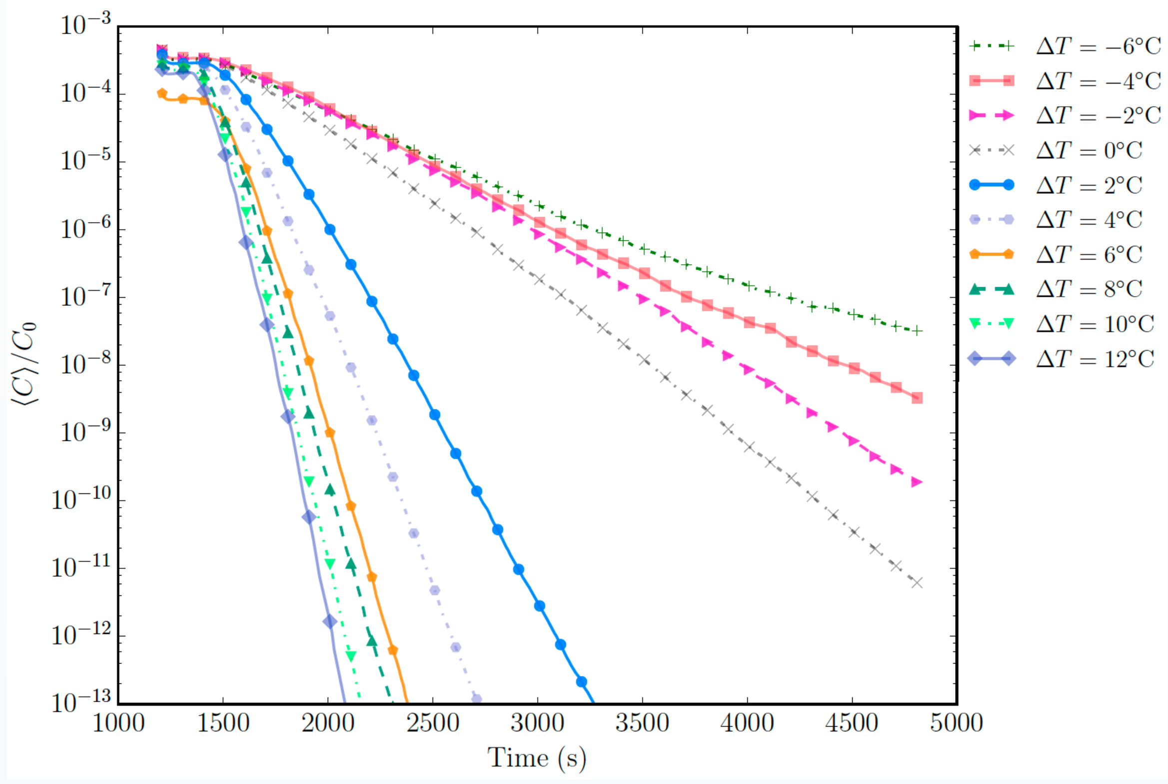

Fig.9 Decay of the mean concentration for the entire domain, $\langle C \rangle_{\mathcal{D}}$

Ventilation diagnostics [2]:

- Decay of the mean concentration (Fig.9, Fig.10 *left panel*)
- Mean tracer age (Fig.10 *right panel*)

The departure of the decay from the exponential for Rb>0 indicates a change of ventilation pathways (implied in Fig.8).

- The linear relationship of ventilation time scales with T_c breaks down for Rb>0.

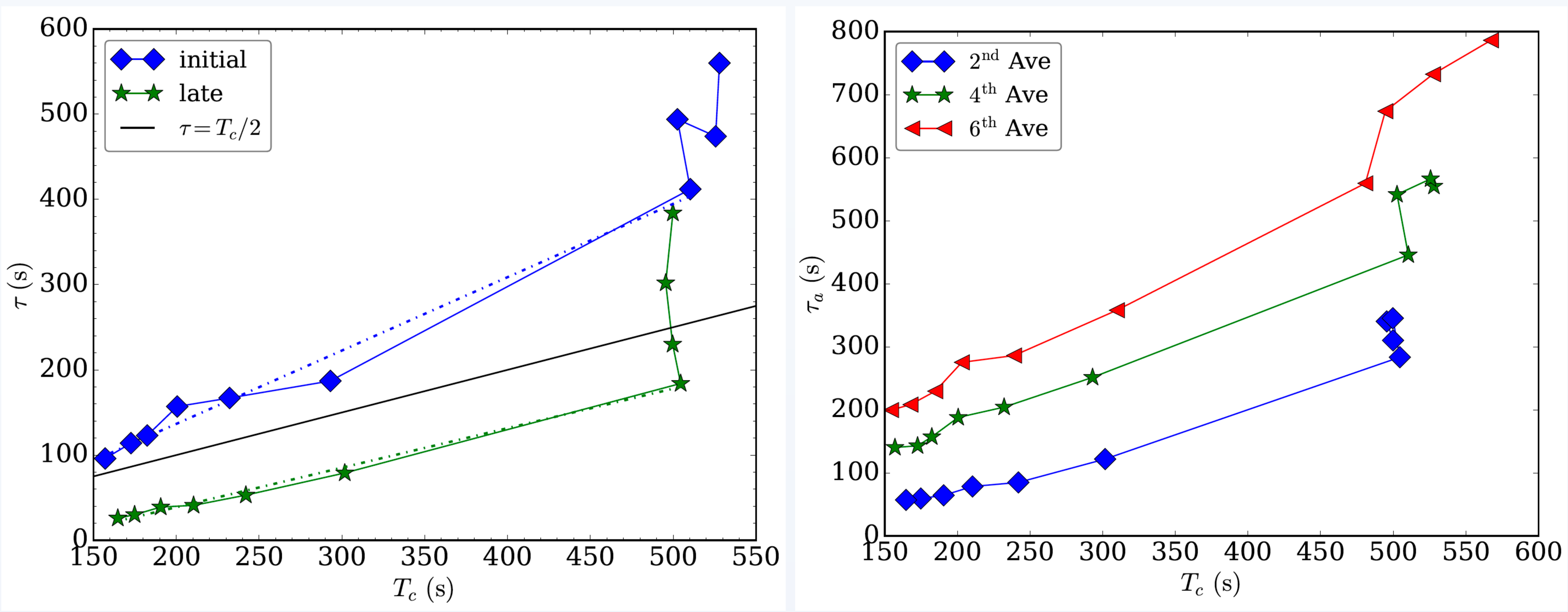

Fig.10 Ventilation time scales versus the mean canyon circulation time scale, T_c. (*left*) For the decay time scale of the mean concentration, τ; (*right*) for the mean tracer age, τ_a

Contact: G. Duan, g.duan@storm.dpri.kyoto-u.ac.jp

More details on the flow and turbulence part can be found in [3].

References

[1] L. Hunter et al., 1992. An investigation of three-dimensional characteristics of flow regimes within the urban canyon. *Atmos. Environ.*

[2] G. Duan et al., 2019. Scalar mixing in an urban canyon. *Environ. Fluid Mech.*

[3] G. Duan & K. Ngan, 2019. Sensitivity of turbulent flow around a 3-D building array to urban boundary-layer stability. *J. Wind Eng. Ind. Aerodyn.*