On the Turbulence Structure over Different Surface Roughness: A Perspective from Wind Tunnel Measurements

Ziwei MO and Chun-Ho LIU*
Department of Mechanical Engineering
The University of Hong Kong

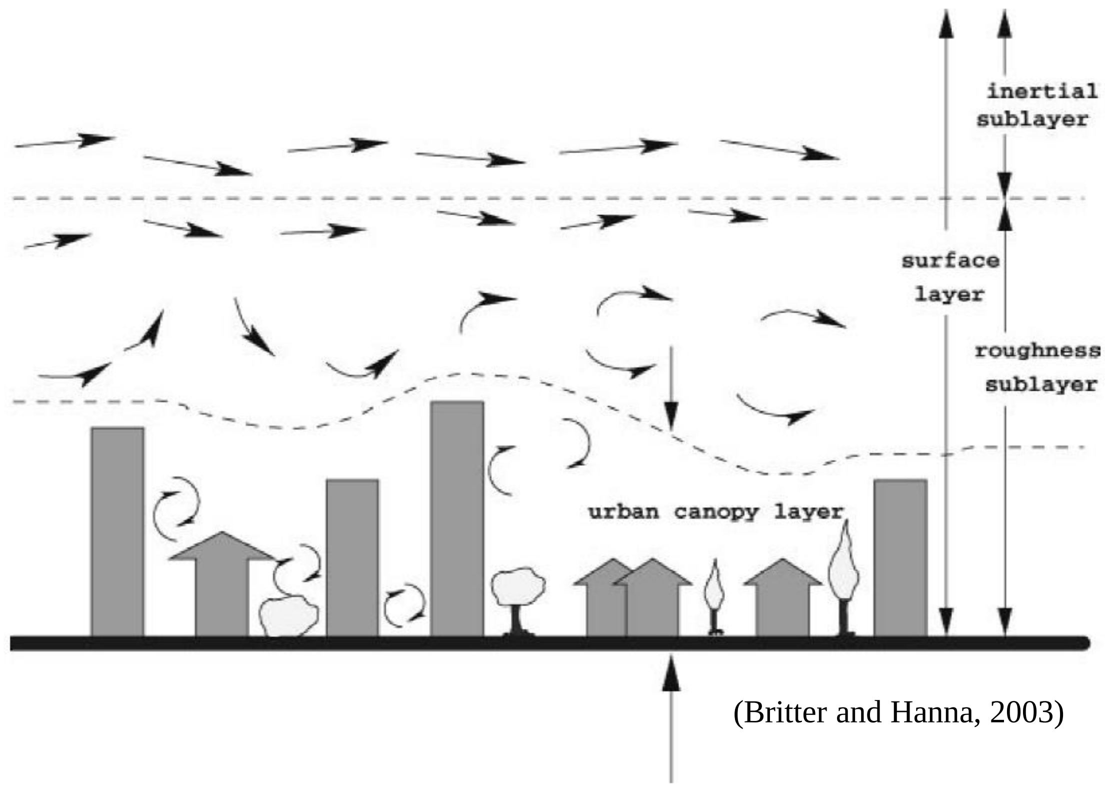
9:45 AM Monday, 26 May 2017, Session III – Urban effects – modeling
Mr & Mrs Ho Chun Hung Lecture Theatre (LT-12),
Yeung Kin Man Academic Building, City University of Hong Kong

Corresponding Author:* **Chun-Ho Liu; Department of Mechanical Engineering, 7/F Haking Wong Building, The University of Hong Kong, Pokfulam Road, Hong Kong; *Tel:* +852 3917 7901; *Fax:* +852 2858 5415; liuchunho@graduate.hku.hk

Outline

1. Background and motivation
2. Experimental methodology
3. Results and discussion
    - Velocity profiles in the turbulent boundary layer
    - Relation between friction factor and roughness sublayer (RSL), roof level ventilation

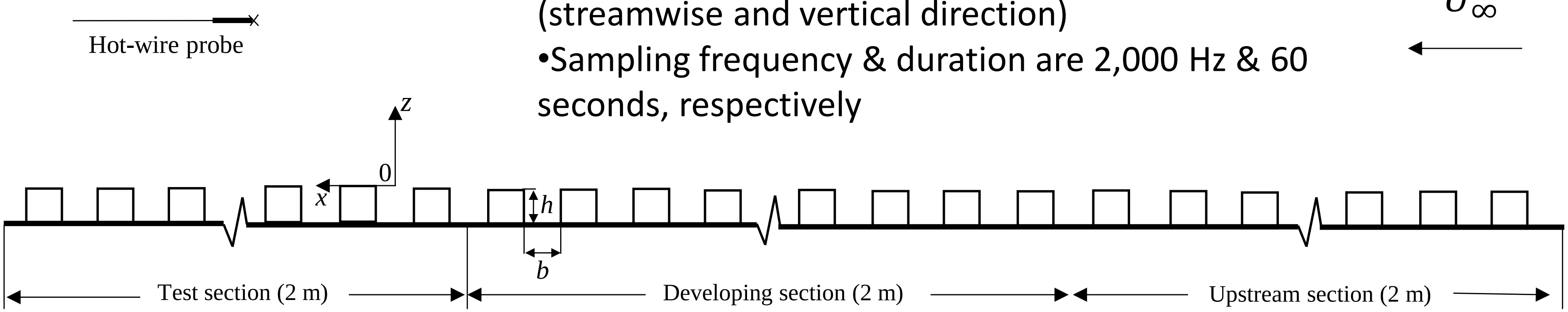
1. Background



(Britter and Hanna, 2003)

- How the surface roughness influences the wind flow in the atmosphere surface layer?
- Can we parameterize the ventilation and pollutant dispersion based on the aerodynamic resistance induced by the surface roughness?

2. Methodology——Wind tunnel measurements



- Measurement of two-component velocities (streamwise and vertical direction)
- Sampling frequency & duration are 2,000 Hz & 60 seconds, respectively

Square Ribs

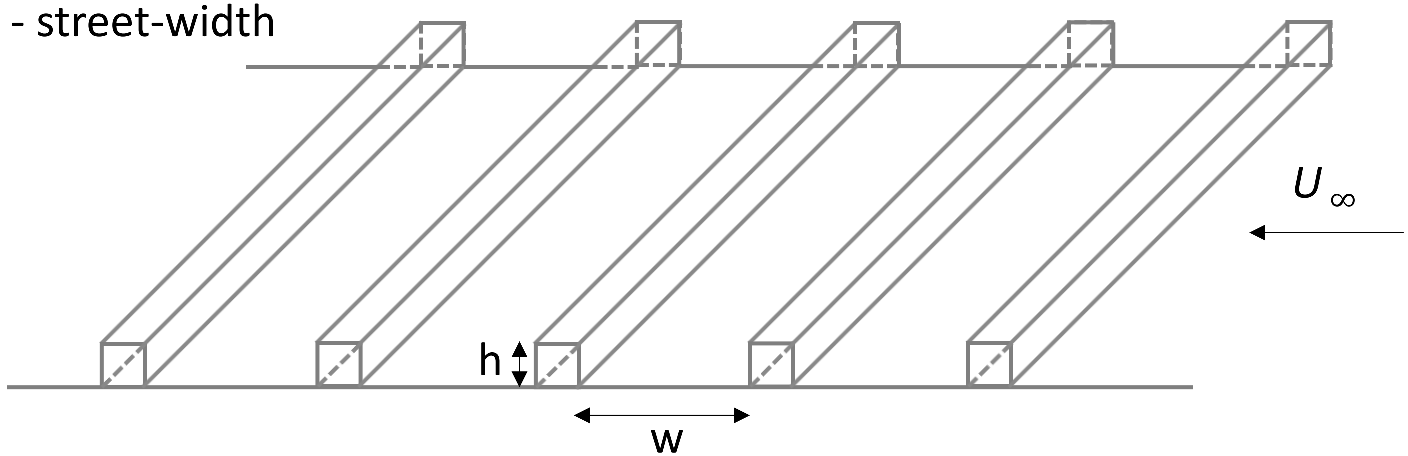
LEGO Bricks

Square ribs

Building - height - to - street-width (aspect) ratio

$AR = h/w$

$h = 19mm$

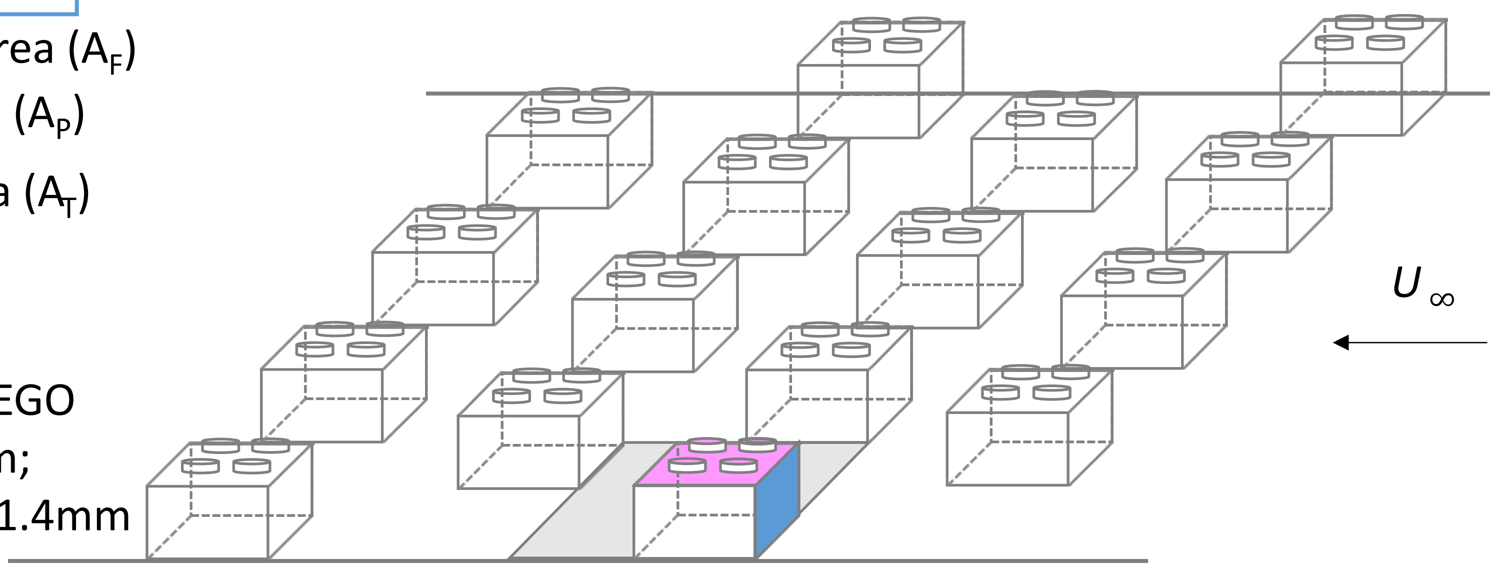


LEGO bricks

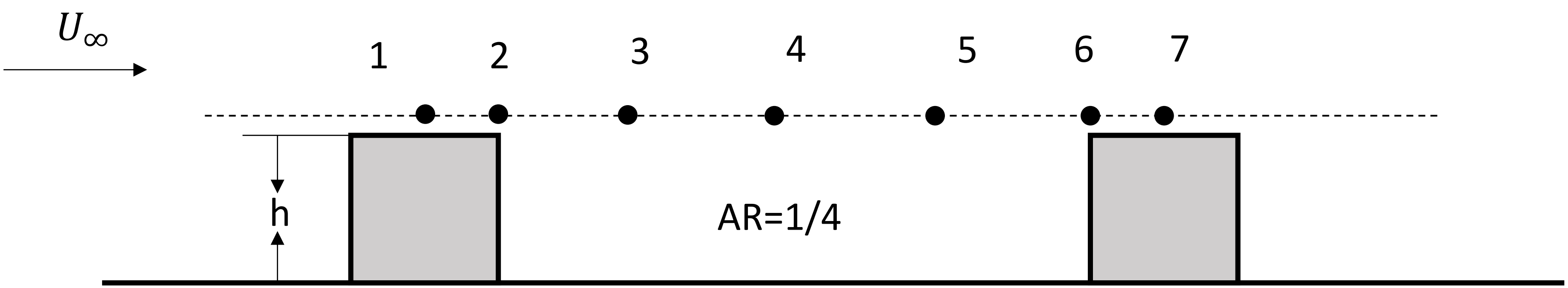
- Frontal area (A_F)
- Plan area (A_P)
- Total area (A_T)

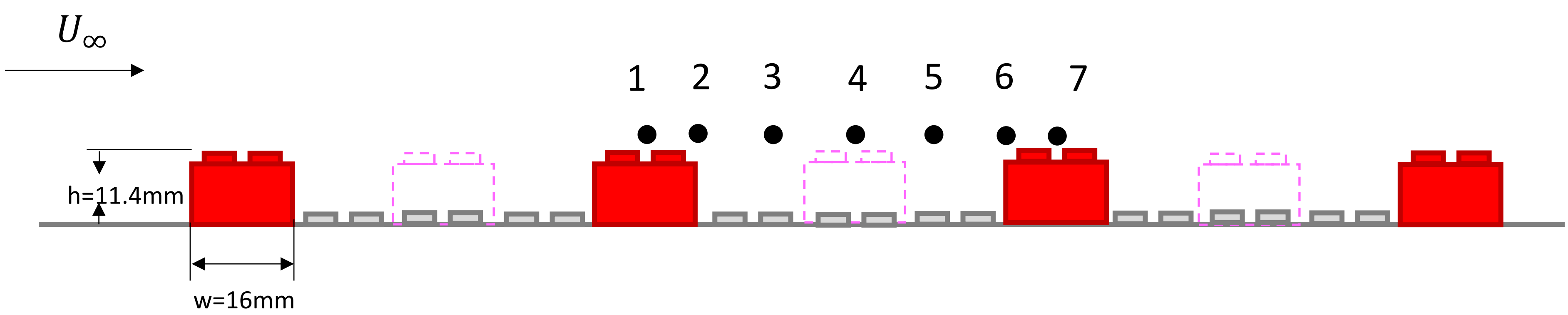
$\lambda_F = A_F / A_T$
$\lambda_p = A_P / A_T$

Dimension of LEGO bricks: L= 16mm; W=16mm; H=11.4mm



Measurement locations of vertical profiles of velocities



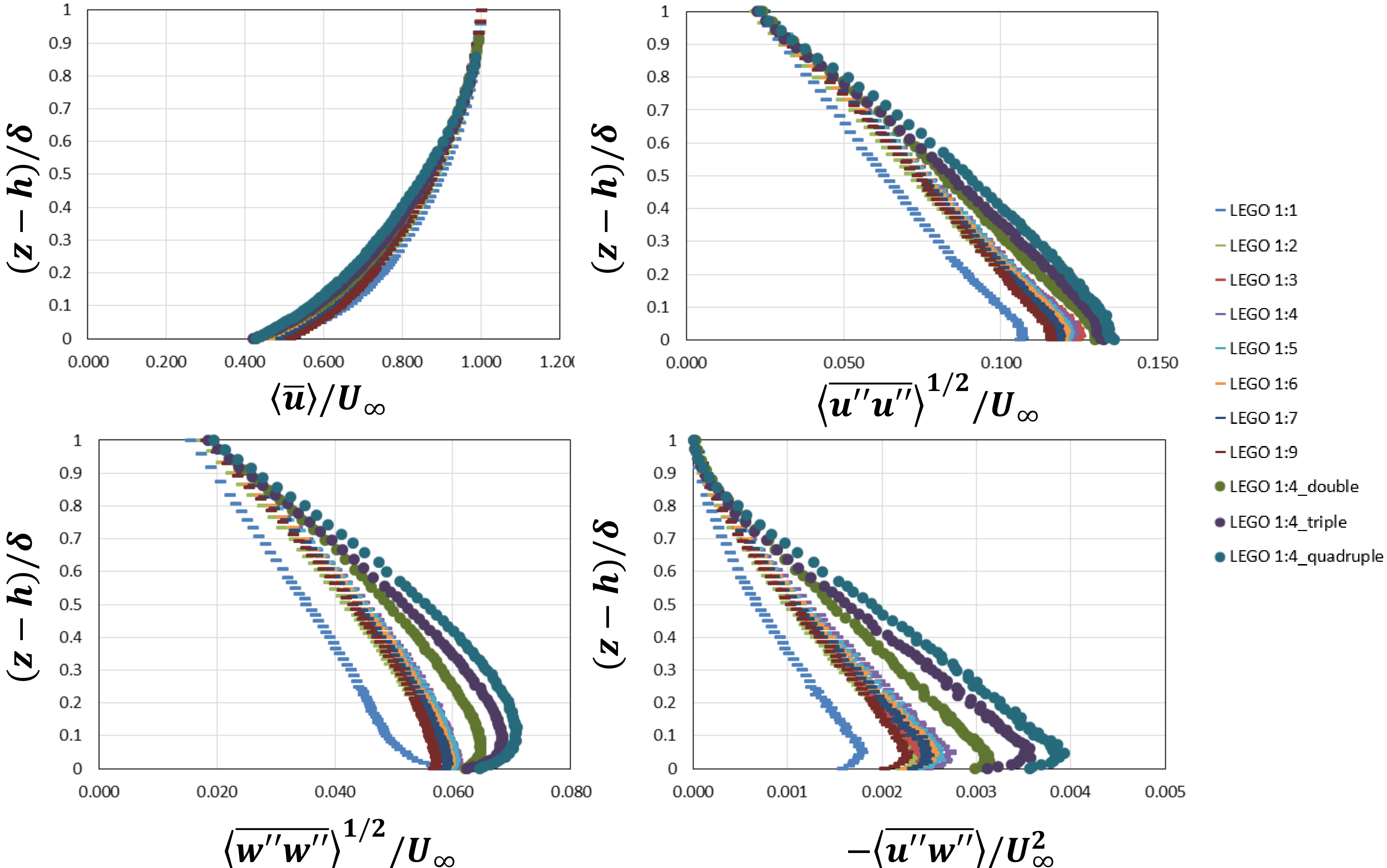


Results and discussion

- Velocity profiles in the turbulent boundary layer
- Relation between friction factor and roughness sublayer (RSL), roof level ventilation

Velocity profiles-LEGO bricks

Note: <●> denotes spatial average
● denotes spatial average
●'' denotes fluctuating component



Velocity profiles-Square ribs

Note: <●> denotes spatial average
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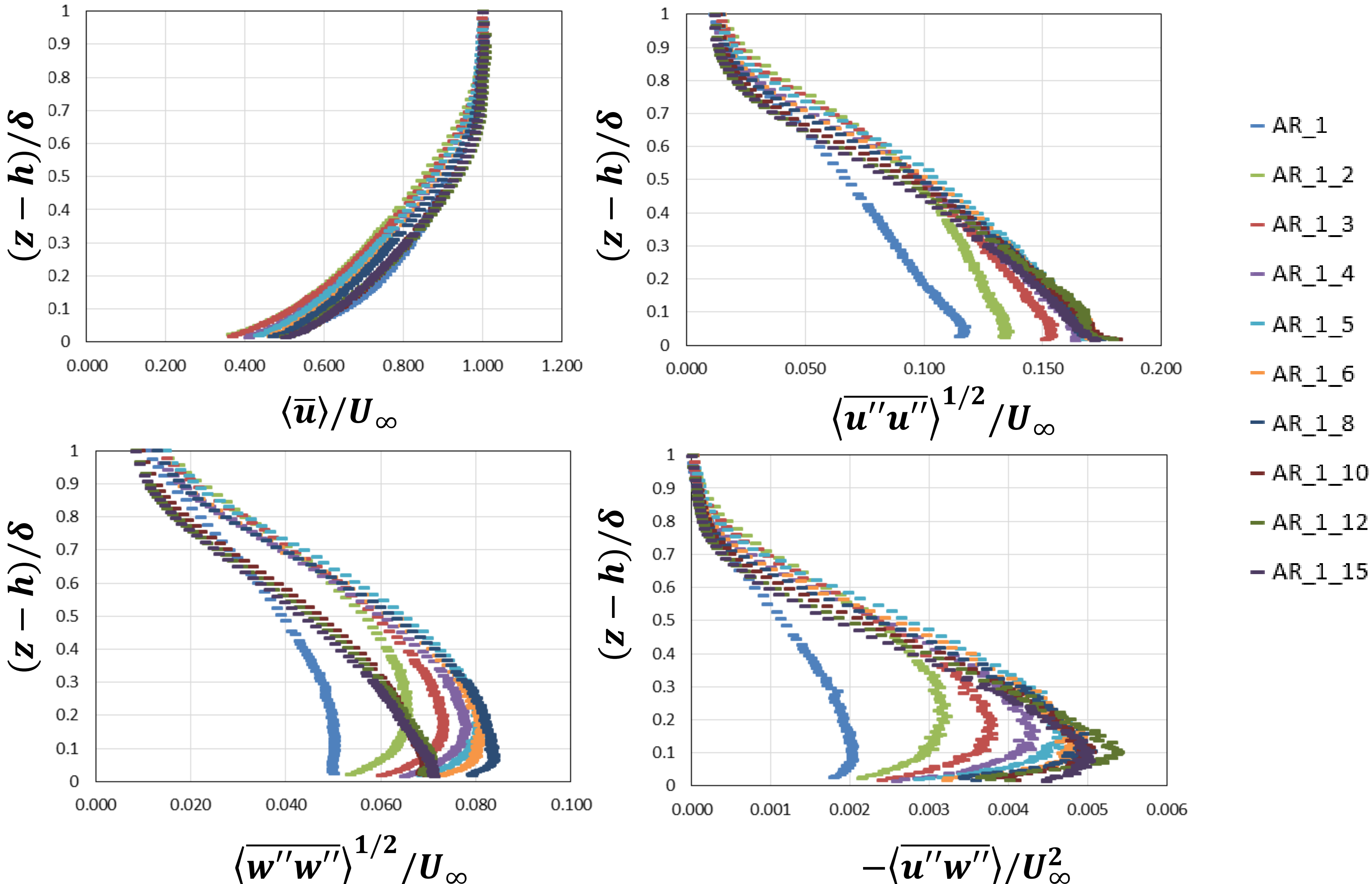
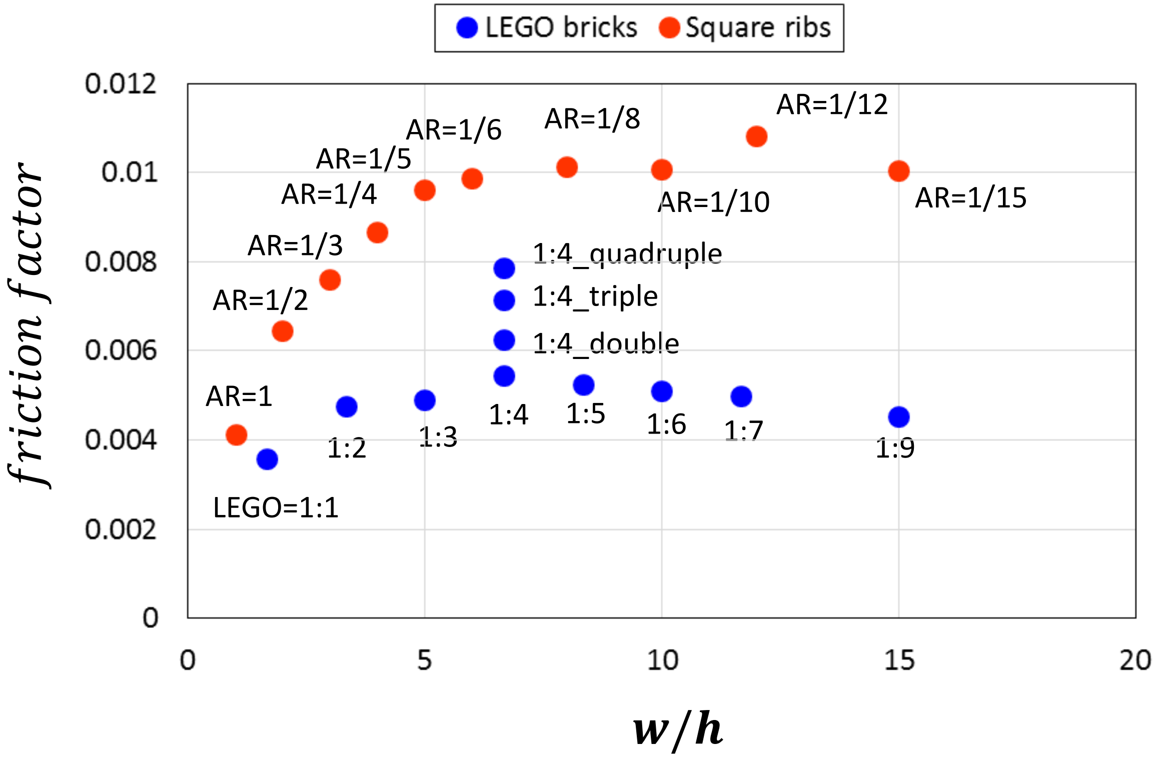


Aerodynamic resistance —— Friction factor

$$f = \frac{\tau_w}{\rho U_\infty^2/2} = \frac{2u_*^2}{U_\infty^2}$$

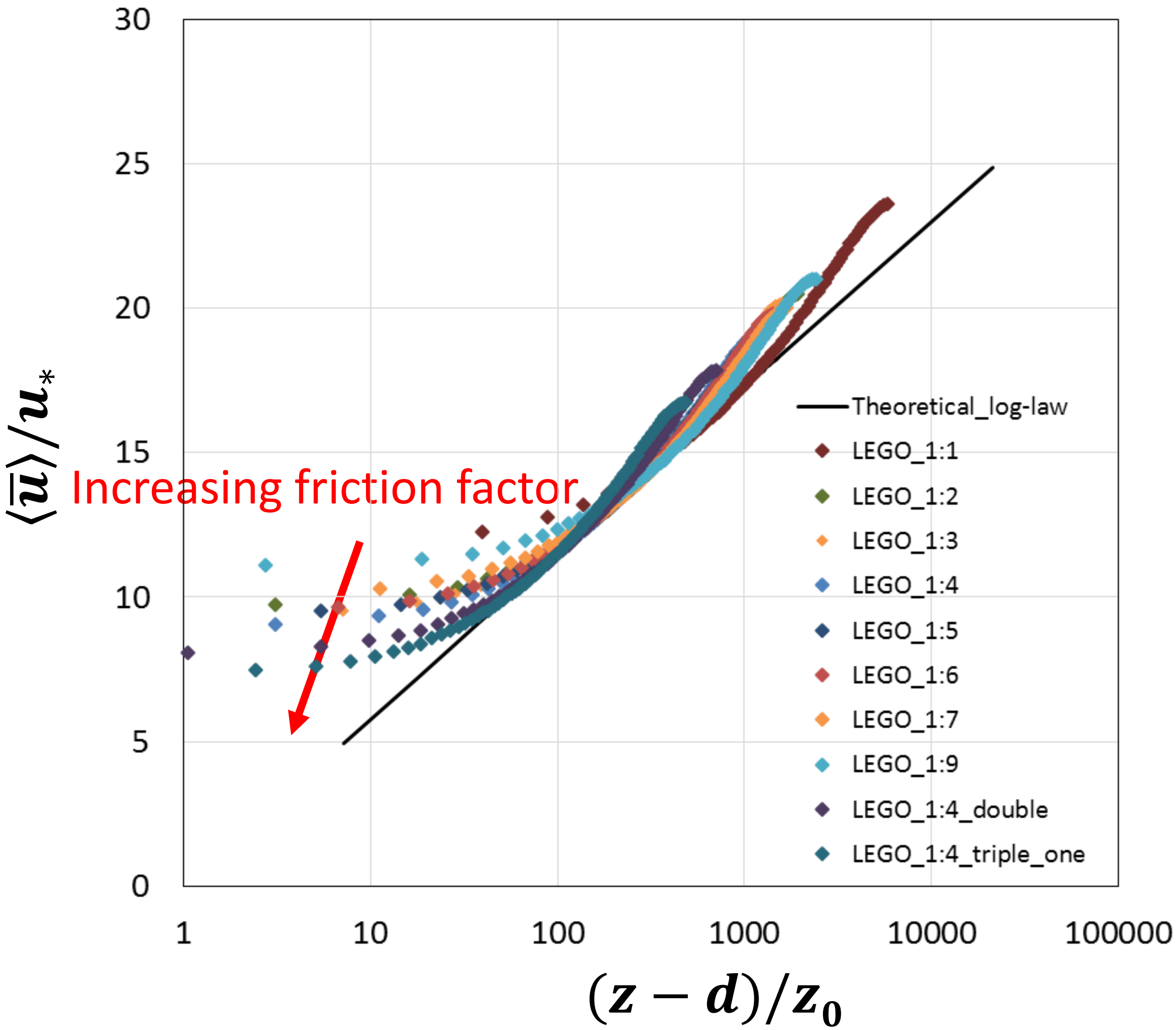
where τ_w is the shear stress induced by the bottom rough surface, ρ is the fluid density, U is the free-stream velocity (Wong and Liu, 2013; Ho et al., 2015), u_* is the friction velocity, estimated using Reynolds stress (Cheng and Castro, 2002; Ploss et al., 2000).



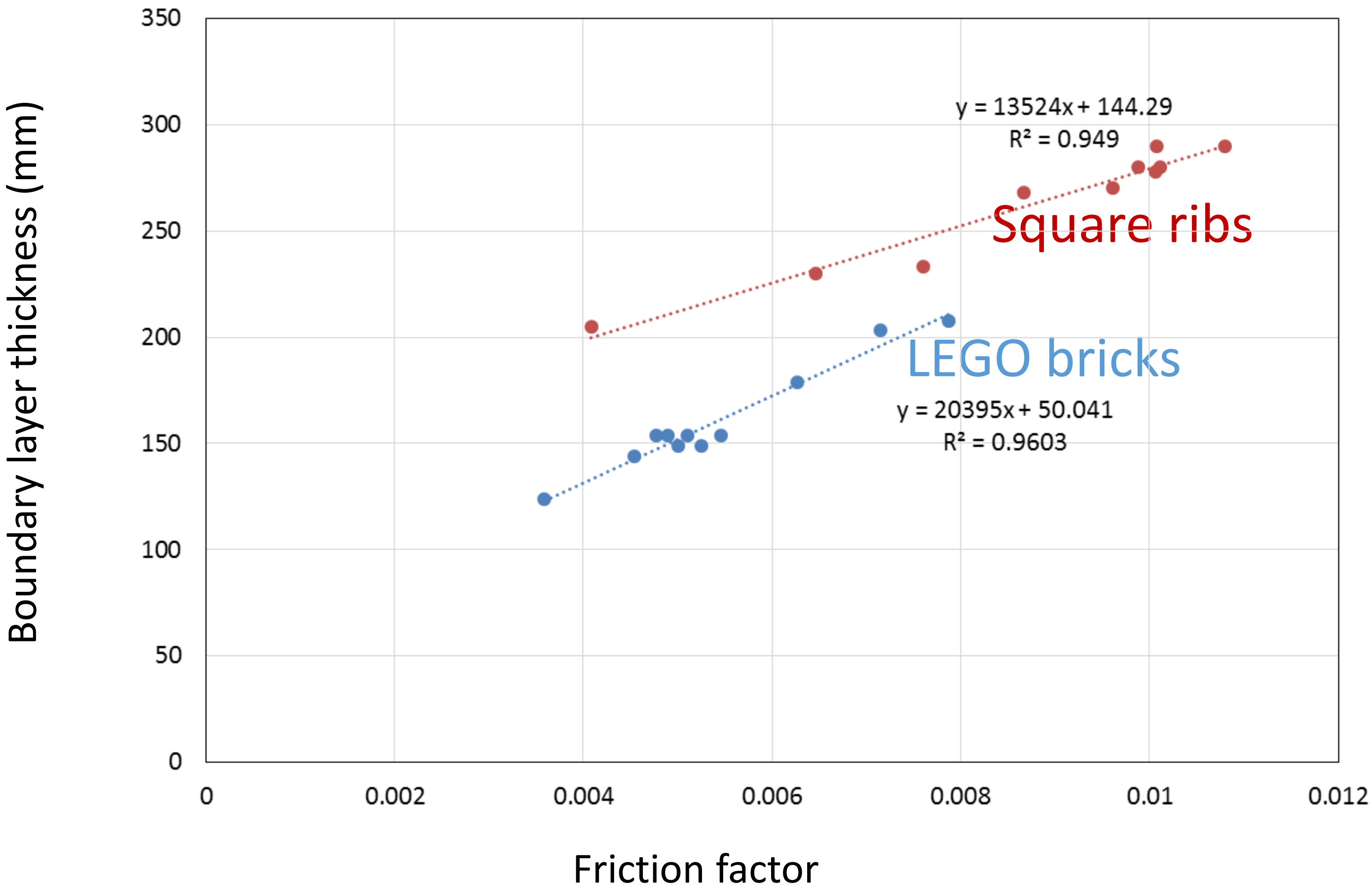
Logarithmic law (Pope, 2009):

$$\langle \bar{u} \rangle = \frac{u_*}{\kappa} \ln\left(\frac{z-d}{z_0}\right)$$

LEGO bricks

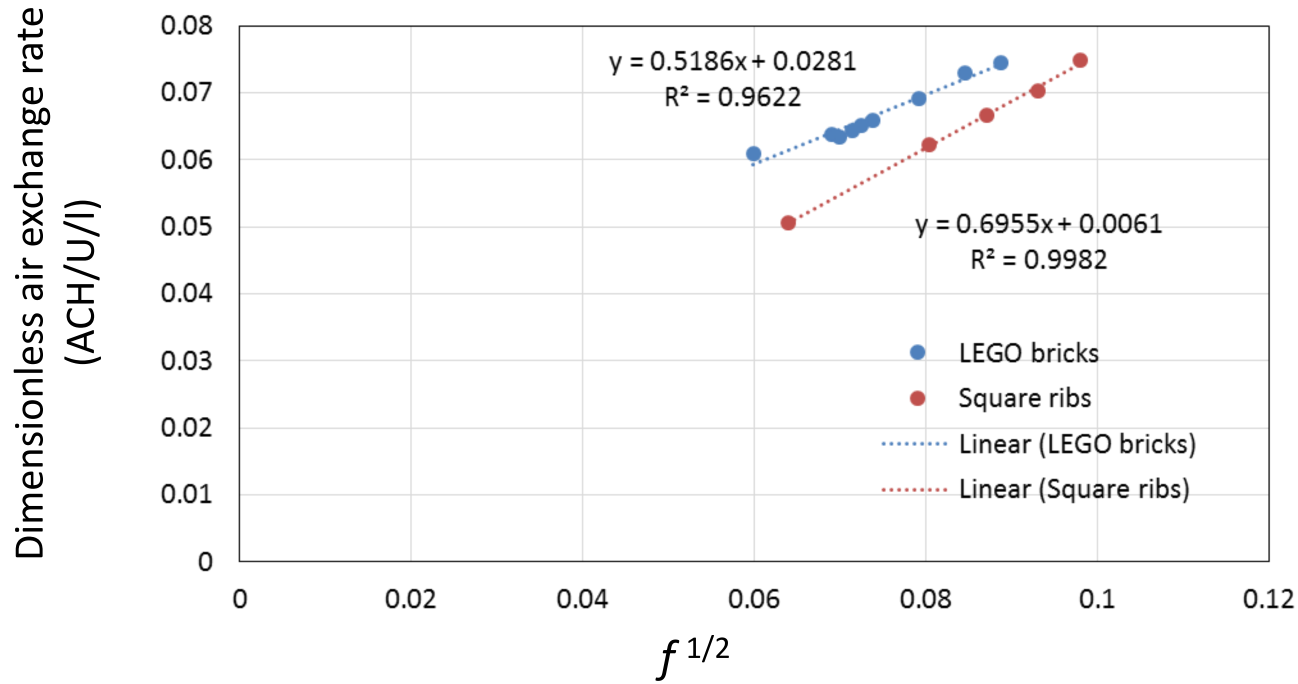


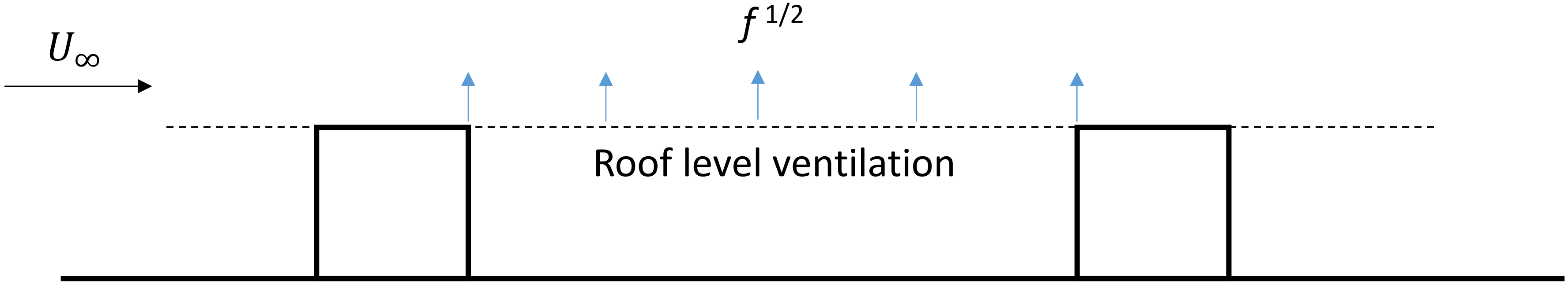
Boundary layer thickness vs friction factor



Roof level ventilation - Air exchange rate (ACH) vs friction factor

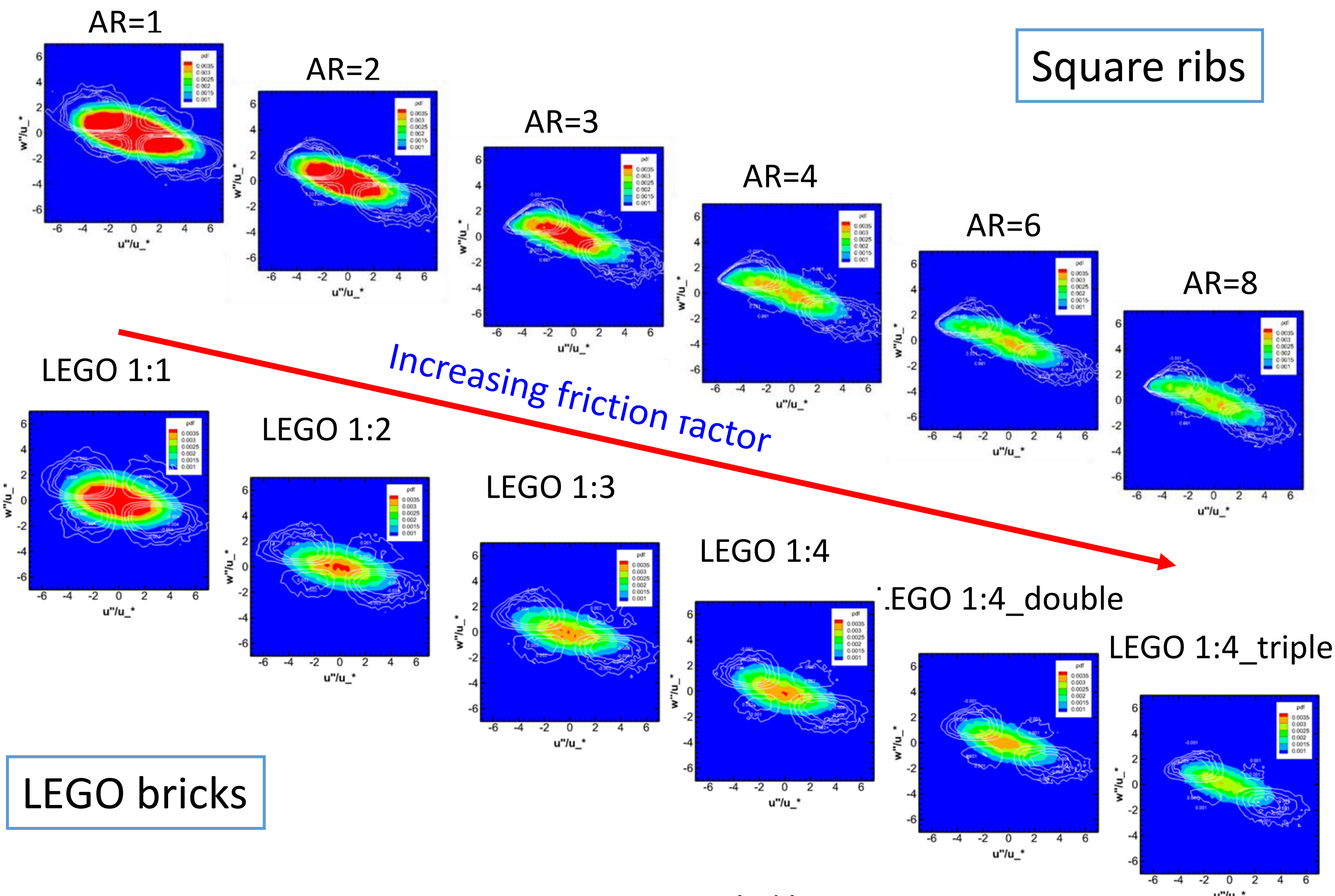
$$\mathrm{ACH} = \mathrm{ACH} + \mathrm{ACH}'' = \int_{\Gamma_{roof}} \left\langle \overline{w}_{+} \right\rangle \Big|_{\Gamma_{roof}} dx + \int_{\Gamma_{roof}} \left\langle w''w'' \right\rangle^{1/2} \Big|_{\Gamma_{roof}} dx$$





Note: The data point of roughness arrangements with too wide separation are eliminated.

Quadrant characteristics vs friction factor



Canyon top----scaled by u_*

Summary

- Flow structure are characterized in the turbulent boundary layer over two different types of surface elements: square ribs and LEGO bricks.
- Strong Relations are revealed between friction factor and the RSL, boundary layer thickness, roof level ventilation, etc.
- Next step research - using friction factor to parameterize dispersion coefficient over LEGO bricks.