Wind Engineering Joint Usage/Research Center
FY2018 Research Result Report

Research Field: Indoor Environment
Research Year: FY2018
Research Number: 182005
Research Theme: Study on energy-saving indoor climate control with improving occupants' arousal and productivity

Representative Researcher:
1. HeeChang Lim (Pusan National University·School of Mechanical Engineering·Professor)
2. Kunio Mizutani (Tokyo Polytechinic University)
3. Yingli Xuan (Tokyo Institute of technology)
4. YoungWoo Lee (Pusan National University·School of Mechanical Engineering·PhD Student)
5. KwonHo Park (Pusan National University·School of Mechanical Engineering·Msc Student)

Budget [FY2018]: 100,000 Yen

1. Research Aim

In order to build an energy-saving structure aiming to minimize energy consumption, we'll analyze the thermal buffering phenomena between the ventilation flow inside and the unsteady wind flow outside the building, and suggest an optimized design criteria. Therefore, this proposal aims to (i) obtain comprehensive mean and fluctuating thermo-fluid properties in order to delineate more clearly the link between unsteady motions of the wind flow and the shape of the obstacles, (ii) analyze the mechanism of natural/forced ventilation similarity (e.g. Grashof & Rayleigh number) in the modelling of turbulent flows inside generic three-dimensional obstacles of a wide variety of heights and aspect ratios, (iii) make a flow modelling between the unsteady flow outside of the obstacles and the natural/forced ventilation inside and herein analyze the thermal buffering, and (iv)thus secure the core technologies of the structural design criteria.

2. Research Method

First, the wind tunnel tests were conducted in the turbulent boundary layer wind tunnel (Fig. 1) of the Wind Engineering Research Center at Tokyo Polytechnic University (TPU) in Japan. This wind tunnel is an open-circuit, low-speed wind tunnel designed for wind environmental assessment and ventilation studies. Most of the experiments were conducted in the end-part test section of the tunnel, where the sectional dimensions were 1.2 m width, 1.0 m height, and 14 m length, with a maximum wind speed of approximately 30 m/s. Table 1 gives the dimensions of the group of surface roughness blocks used in the wind tunnel to generate the simulated turbulent boundary layer. The details of the generated turbulent boundary layer are illustrated in the Fig. 2.

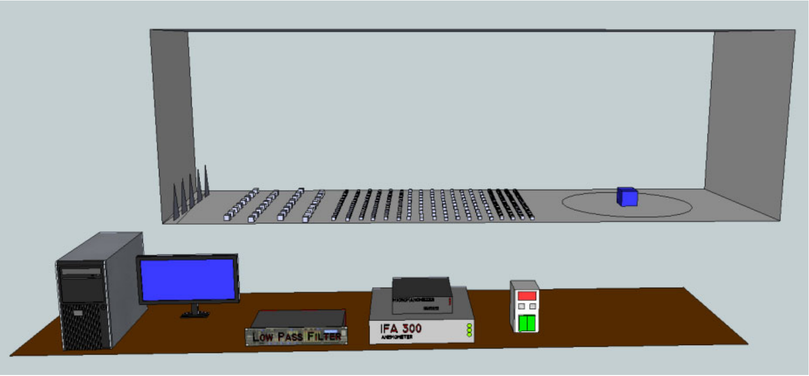

Figure 1 Wind tunnel measurement and test apparatus

	A	B	C	D	E	F
Size [WxH] [mm^2]	30x30	50x50	50x50	50x50	98x98	70x700
No. Elements	60	60	128	108	36	3
Length [mm]	240	525	1,780	1,435	2,450	450

Table 1 Group of surface roughness blocks used in the tunnel

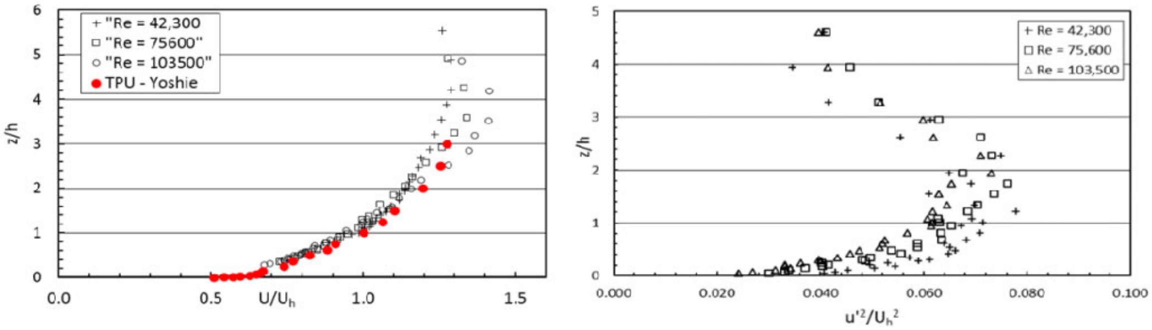

Figure 2 Mean velocity and axial stress profiles

The work involved covers a combination of microclimate measurements, numerical microclimate simulations and studies of the urban planning process. If possible, field measurements would be conducted in areas with significantly differing characteristics, including variations in urban geometry and distance to the sea, to map variations in microclimate and outdoor thermal comfort within each city. To cover a wider range of urban design, to test the impact of different design parameters on outdoor thermal comfort and to achieve optimum design solutions, microclimate simulations using Computational Fluid Dynamics (CFD) software will be conducted in the near future. The results obtained will be studied and examined as well as analyzed carefully for preparing criteria of urban ventilation and thermal comfort criteria for outdoor environment.

Two different rough surfaces

There are two different rough surfaces in this study, one of them is staggered pattern and the other is aligned pattern that is a 90 degree turn from staggered pattern. Then, each pattern uses roughness block that size is 50 x 50 x 50 mm^3, having three different types of area density (11%, 16%, and 25%), which is defined as the total roughness area divided by total floor area. Therefore, wind tunnel test has been made at six different type of rough surfaces as illustrated in the Fig. 3.

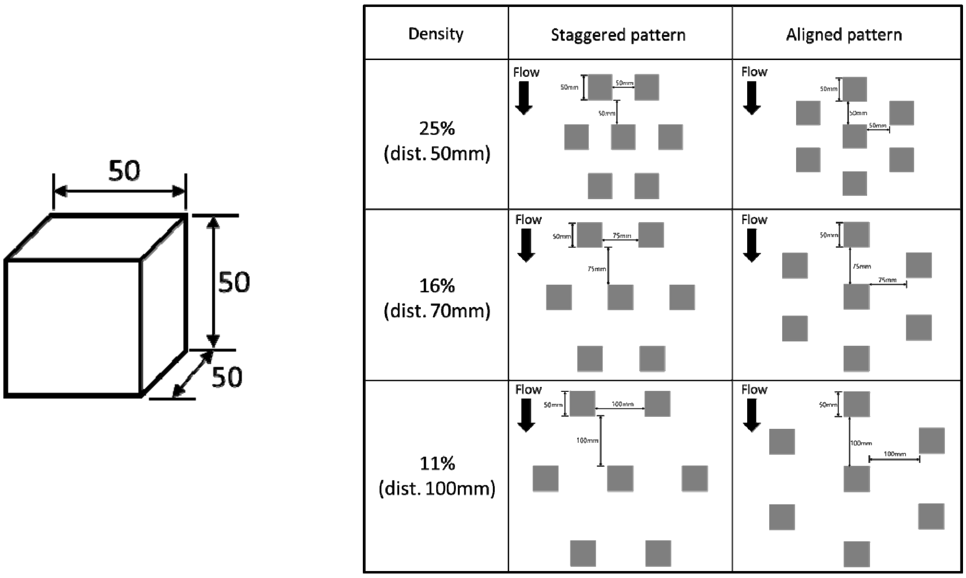

Figure 3 a roughness block (left) and six different rough surfaces (right)

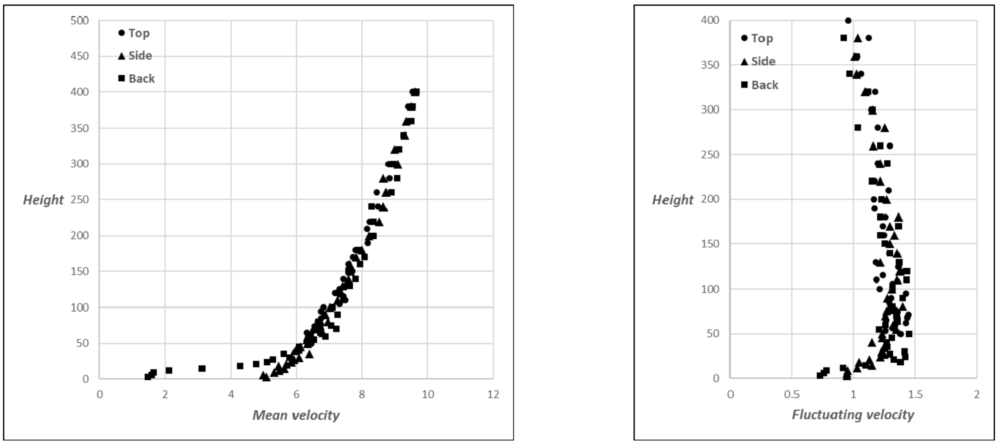

Figure 4 Mean and fluctuating velocity (25% density staggered pattern)

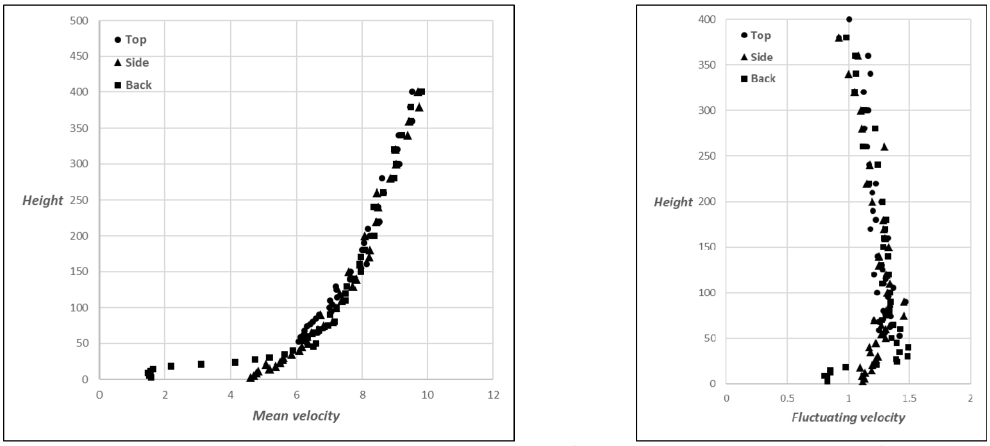

Figure 5 Mean and fluctuating velocity (25% density aligned pattern)

Figures 4 and 5 show mean and fluctuating velocity profiles over the top and between roughnesses (sides and front-backs) in staggered and aligned pattern. In mean velocity profile, all profiles in the inertial sublayer tend to make a good agreement, which seems that the profiles have all the same density over different patterns. However, the velocity profiles at the canopy layer area have totally different, in particular, in the measurement between front and back roughnesses, which seems similar tendency of velocity profiles over 25% roughness area density by Cheng & Castro (2002). On the other hand, the fluctuating velocity profiles are also similar in two different patterns, but the fluctuating velocity between front and back roughnesses is more scatter than those from sides.

3. Research Result

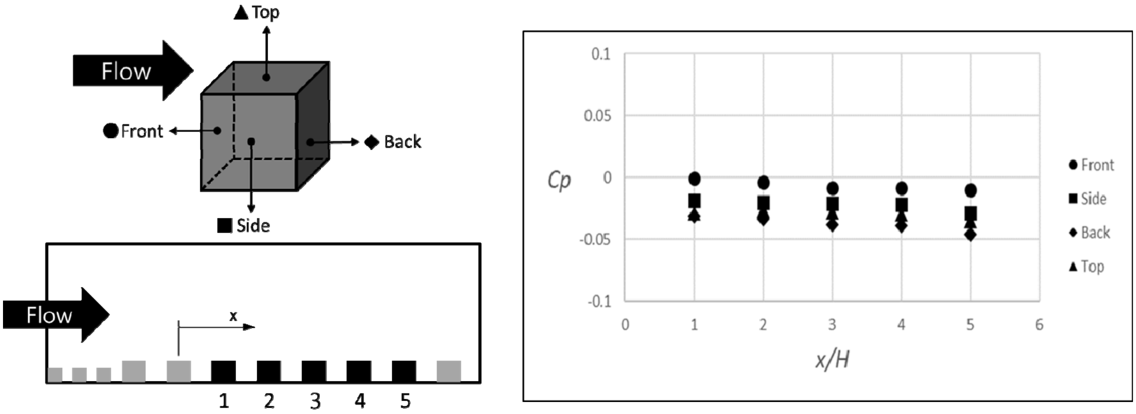

Figure 6 Pressure variation around longitudinal roughness (aligned pattern)

Figure 6 shows that the surface pressure around roughness, which tends to decrease as goes downstream. On-coming turbulent boundary layer firstly does hit the first square roughness blocks, and it produces slightly higher surface pressure on the front face of the block (see a blue solid circle at x/H=1 in Fig.6) making the surrounding pressures negative (i.e., side, back and top) around the front block due to the flow separation. Finally, the surface pressure gradually decreases as goes downstream. The pressure distribution around blocks helps providing basic information to understand the flow characteristics around blocks and inside tunnel.

Figures 7 and 8 show mean surface pressure distribution around roughness with the changing area density. In staggered pattern, Cp decreases in front face as the density increases whereas it increases at the top and side surface. In addition, the pressure in the back of a roughness block becomes gradually constant as area density increases. In aligned pattern, the surface pressure has also the same tendency as the staggered, but the magnitude of pressure is smaller about 30%.

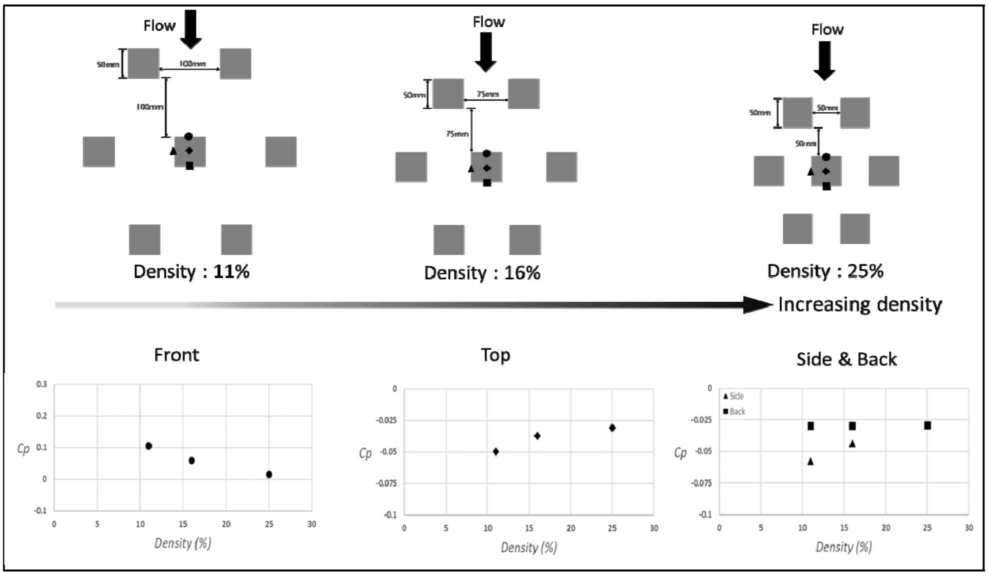

Figure 7 Mean surface pressure around roughness (Staggered pattern)

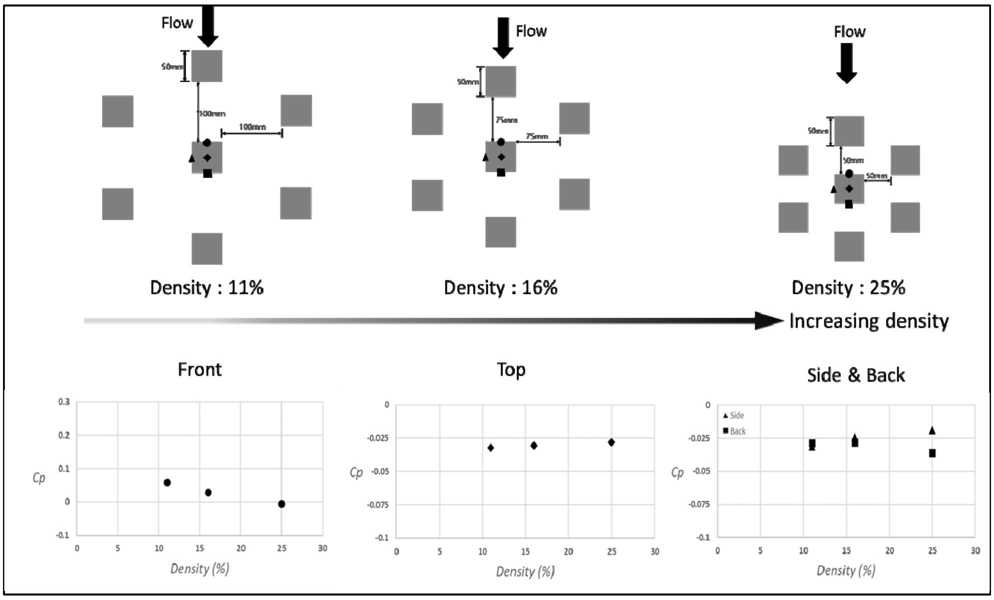

Figure 7 Mean surface pressure around roughness (Aligned pattern)

4. Published paper etc.

- K.H.Park, S.Y.Lee, and H.C. Lim, 2018, Effect of surface roughness pattern on flow and skewness of turbulent boundary layer, Wind Engineering Institute of Korea, Vol.22(3), pp.119-126.

5. Research Group

1. Representative Researcher
Name: HeeChang LIM
Organization: School of Mechanical Engineering, Pusan National University
Contact address: 2, Busandaehak-ro 63beon-gil, Geumjeong-gu, Busan, 46241, Rep. of KOREA
Tel: +82-(0)51-510-2302, Fax: +82-(0)51-512-5236, E-mail: hclim@pusan.ac.kr
2. Collaborate Researchers
Name: Kunio Mizutani
Organization: Tokyo Polytechnic University
Tel: +81-90)46-242-9923, Fax: +81-90)46-242-9923, E-mail: mizutani@arch.t-kougei.ac.jp
Name: Yingli Xuan
Organization: Tokyo Institute of technology
Name: YoungWoo Lee
Organization: School of Mechanical Engineering, Pusan National University
Tel: +82-(0)51-510-3085, Fax: +82-(0)51-512-5236, E-mail: nightmare999@naver.com
Name: KwonHo Park
Organization: School of Mechanical Engineering, Pusan National University
Tel: +82-(0)51-510-3085, Fax: +82-(0)51-512-5236, E-mail: stillity@naver.com

6. Abstract

Research Theme: Study on energy-saving indoor climate control with improving occupants' arousal and productivity
Representative Researcher (Affiliation): HeeChang Lim (Pusan National University)

The 'yellow dust' is known to be very harmful to the public health. Recently, fine and ultrafine dust are becoming an important issue in high-populated cities. Unlike yellow dust, however, fine dust is mainly caused by automobile smoke, house heating and dust from many industrial sectors. In particular, the fine dust should be controlled by each well-developing countries. Based on this circumstances, it is most important to keep indoor air quality fresh because people spend most of the day indoors. Some have used the mechanical ventilation with filters to remove dusts floating in the air. However, the natural ventilation would be the best policy to maintain the air quality better than using the mechanical instrument. Therefore, the current work is to visit a well-known research institute in Japan (Tokyo Polytechnic University) to acquire technical skill and understand the detailed mechanism of indoor air quality in low- and high-rise building.

Generally, fine dust is called airborne particles which are large size and can be released mostly from cotton or bronchus, which has no effect on the human body. However, if its size is under 10 ㎛, it becomes very harmful because it is deposited deep into the lungs without being filtered from nose, mouth and bronchus. In particular, ultrafine dust of less than 2.5 ㎛ tends to accumulate easily in the lungs and spread through the alveoli to the entire body through blood, which may cause cardiovascular problems. Accordingly, the study of fine dust and indoor air quality improvement will be done at this visit of TPU, this research aims to acquire worldwide research on fine dust and technology for improving indoor air quality. Recently, a number of research and technology development are conducted on (ultra-)fine dust. There have not been much work in the past, but it is expected to be done in the near future. Therefore, it still will be a task to conduct research on improving indoor air quality and fine dust. The Korean government also ask to prepare an appropriate criteria set for climate change by 2020. Therefore, in the future, local authorities are expected to use the structure design related to ventilation and reduce fine dust.

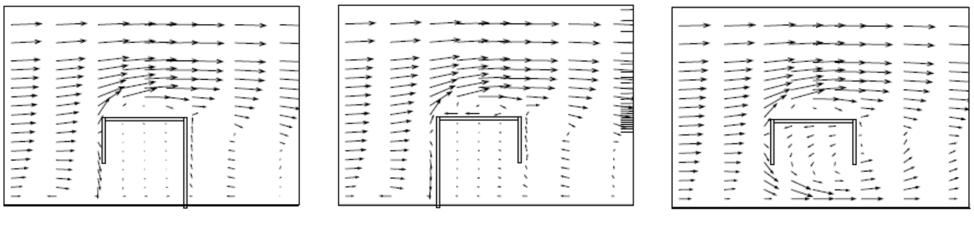

Figure. Flow interaction between a low-rise building and boundary layer flow