Ye Lin

An Experimental Study on Exploring the Possibility of Applying Artificial Light as Radiation in Wind Tunnel

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1. Introduction

In recent years, the Urban Heat Islands (UHI) phenomenon has become a widespread problem and has attracted extensive attention all over the world. Many research activities focusing on different factors have been conducted to clarify how to mitigate UHI with both experimental and numerical methods.

For the experimental method, scale modeling is a very effective and economical way, which can be carried out both indoor and outdoor[1]. The advantage of outdoor scale modeling is the reality of the meteorological conditions[2]. But fewer outdoor experiments were conducted because it is difficult to control the needed conditions. Indoor experiments were mainly applied in the wind tunnel. Variables can be easily controlled. The main concerns include the investigation of flow regime[3], pollutant dispersion[4], transfer coefficients[5], and radiation and energy balances[6].

Because of the difficulty to control the radiation and thermal conditions, and scale thermal admittance, few experiments were focusing on the radiation and energy balances. Most of the previous studies used heating elements to generate buoyancy flow and investigate the heating influence of canopy wall. In this study, we conducted experiments to explore the possibility of using artificial light as radiation in wind tunnel. Using radiation appropriately in wind tunnel can help better representing the different solar angle and shading effects, and understanding the UHI phenomenon.

2. Methodology

The experiment was conducted in the wind tunnel of Meteorological Research Institute (MRI), Japan. As shown in Fig. 1, a model house made of real construction materials was used. Geometry scale is 1/15. Roof is made of asphalt shingle, wood model base, and with extruded polystyrene foam as thermal insulated materials under the roof. Albedo of used asphalt shingle is 2 % which was measured using CNR1 Net Radiometer (Kipp and Zonen Co. Ltd, spectral range: short wave (300 - 2800 nm), long wave (4500 - 42000 nm). Albedo is defined as

$$\alpha = S_{up}/S_{down}, \qquad \textit{Equation 1}$$

where S_{up} is the reflected solar radiation (upward shortwave radiation) and S_{down} is incoming radiation from the sky (downward shortwave radiation).

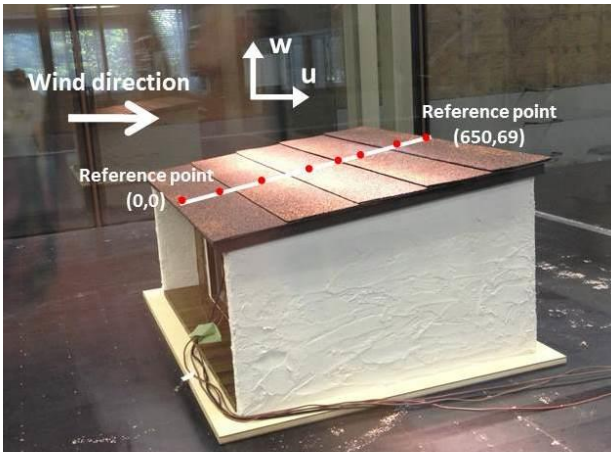

Fig.1 Experimental setup

In this experiment, we chose four layers above rooftop to detect the wind velocity, which are 1 cm, 2 cm, 3 cm and 5 cm. 8 points were selected along the centerline in each layer, as shown in Fig. 1. Table 1 shows the coordinate of all the testing points.

Table 1 Coordination of testing points (Unit: mm)

Layer distance above the rooftop	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
50 mm	(650,119)	(600,113.7)	(500,103.1)	(400,92.5)	(325,84.5)	(200,71.2)	(100,60.6)	(0,50)
30 mm	(650,99)	(600,93.7)	(500,83.1)	(400,72.5)	(325,64.5)	(200,51.2)	(100,40.6)	(0,30)
20 mm	(650,89)	(600,83.7)	(500,73.1)	(400,62.5)	(325,54.5)	(200,41.2)	(100,30.6)	(0,20)
10 mm	(650,79)	(600,73.7)	(500,63.1)	(400,52.5)	(325,44.5)	(200,31.2)	(100,20.6)	(0,10)

The inflow wind velocities of 0.5 m/s and 1 m/s were studied. Wind speed was measured using LDV continuously for five minutes to get the average wind speed. Roof surface temperature, indoor temperature and background temperature were measured by thermocouples. For heating the roof, we used four halogen lamps of 500 W each, which were fixed 60 cm above from the roof (Fig. 2). Air temperature of inlet flow was 25.13 ºC. At this condition, the surface temperature of asphalt could reach 65 ºC when wind velocity was 0.5 m/s, which is similar to the real condition. When we increased the velocity to 1 m/s, the surface temperature of asphalt decreased to 57 ºC.

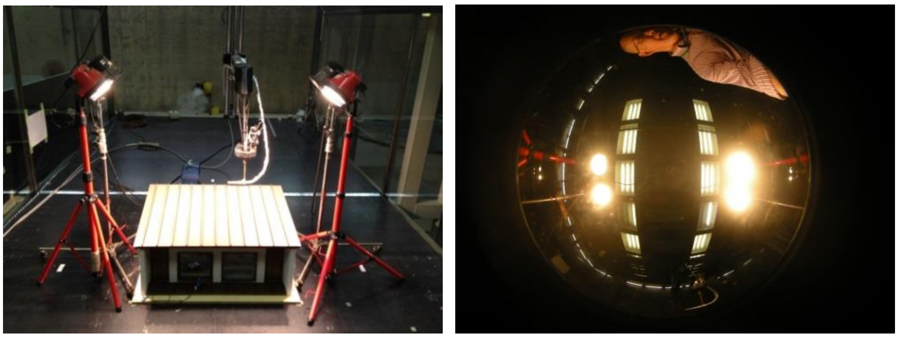

Fig. 2 Configuration of halogen lamps

Wind velocity is calculated as below,

$$u = \sqrt{u_{ave}^2 + w_{ave}^2 + v_{ave}^2} \qquad \text{Equation 2}$$

Turbulent intensity is defined as,

$$I = u'/u \qquad \text{Equation 3}$$

u is the mean velocity, u' is the root-mean-square of turbulent velocity fluctuations

No roughness was set at the upwind area. It is considered to be neutral condition, which the wind profile power law is approximately 1/7. But the height of the model house is 380 mm, which has exceeded the thickness of boundary layer in neutral condition. Therefore, the wind speed of inlet flow was considered to be vertically constant around the roof. The blockage effect is 5 %.

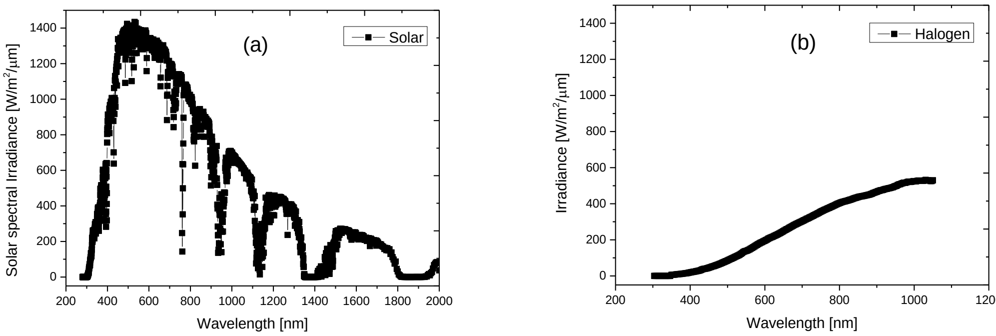

Fig. 3 Comparison is irradiance between (a) solar and (b) halogen radiation

Due to the limitation of equipment, the spectral irradiance can only be measured to around 1050 nm wavelength (Fig. 3). It can be seen that the halogen lamp cannot fully reproduce the solar radiation. Downward radiation of halogen lamp is 734 W/m^2 (shortwave) and 513 W/m^2 (longwave), which was measured at the center of the roof top using CNR1 Net Radiometer, Kipp and Zonen Co. Ltd.

3. Discussion

3.1 Applying Artificial light with different inflow velocities

As shown in Fig. 4, the wind velocity of each layer generally increased upon heating the roof, which enhanced the transport of pollutants. At a velocity of 0.5 m/s, the velocity increase was more significant than that of 1 m/s. The difference of velocity between heating and neutral condition could hardly be observed at the 5 cm level when inflow was 1 m/s. After heating the roof, the wind velocity under 0.5 m/s and 1 m/s inflow conditions increased by 12 % and 4 % respectively. It was thus concluded that, under low velocity condition, the impact of buoyancy is more sensitive. At the condition of relatively high velocity, the wind flow through the roof before getting influenced by the buoyancy generated by the heated roof.

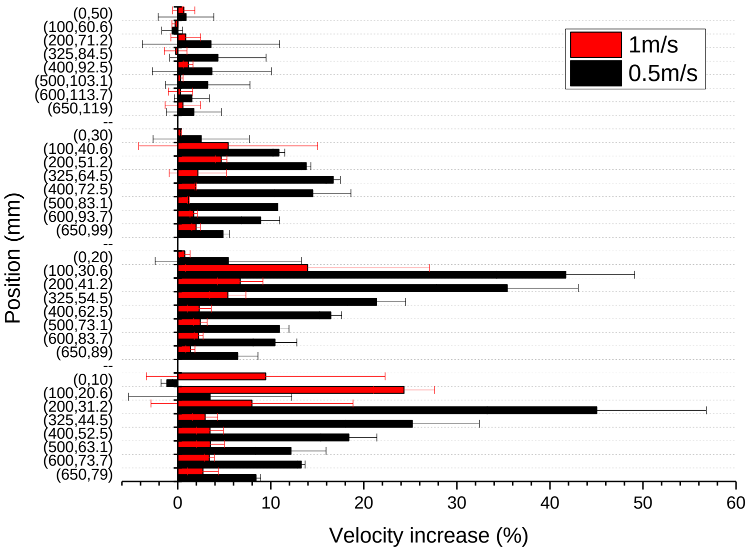

Fig. 4 Velocity increase at each layer after heating the rooftop

In addition, a vortex was formed near the windward edge, mainly because of the slightly inclined roof. The energy maintaining the vortex came from the turbulent kinetic energy of windward edge. The turbulent intensity decreased after heating, which is clearly shown in Fig. 5, especially at the vortex area, which inhibited the pollutant mixing. This decrease by heating is because of the effect of upward buoyancy flow generate for roof surface, which reduced viscosity, weakened the vortex and speeded up the wind (Fig. 6).

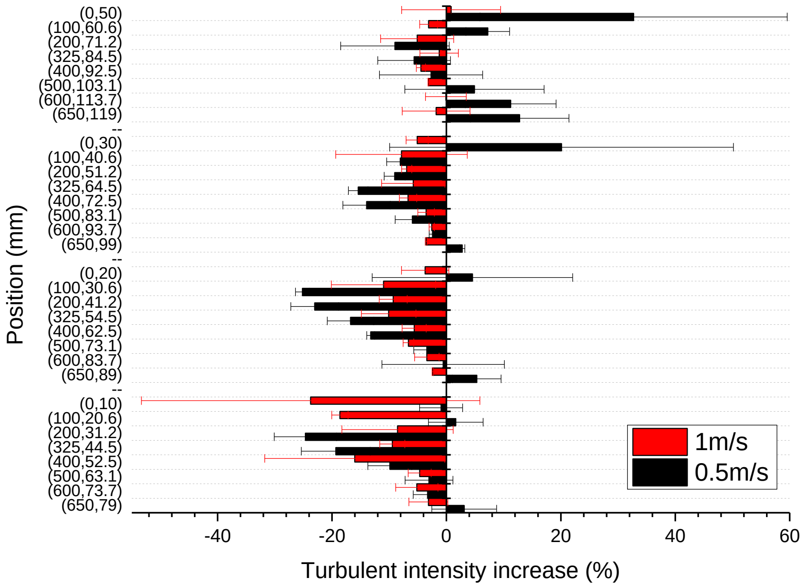

Fig. 5 Turbulent intensity increase at each layer after heating the rooftop

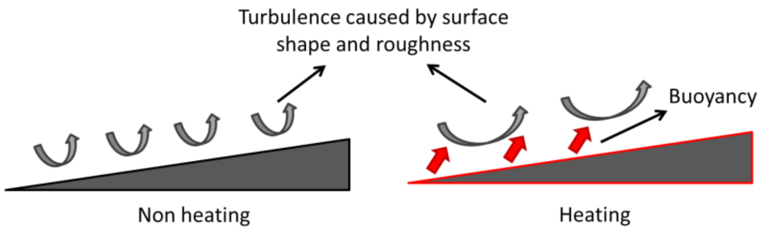

Fig. 6 Turbulence difference above the rooftop between heating and no heating conditions

3.2 Applying insulated coating on rooftop

Insulated coating[7] (composed of micro-size hollow silica particles with mesoporous shell wall) was applied on the roof top. In this part of the experiment, air temperature of inlet flow was 23.16 ºC. After applying the insulated coating, although the roof surface temperature did not show significant change, the indoor temperature decreased by nearly 1 ºC, as shown in Table 2. This is because the insulating coating is composed of hollow microsphere with mesoporous shell wall which can delay/lower the heat conduction. These micro-size particles generate more surface reflectance, and maintain more heat in the hollow part. The increased reflection and decreased conduction nearly kept balance, and the heat storage in the hollow particle increased, which made the surface temperature slightly higher.

Table 2: Surface temperature increase with and without insulated coating

	Temperature increase (ºC)	
	No coating	coating
Roof	44.47	44.48
Indoor	6.38	5.63

With insulated coating, although the surface temperatures were the same, the wind velocities under the heating and coated condition were generally 3% lower than that under only the heating condition, and 5% higher than the neutral condition, as shown in Fig 7. At the downwind part of the roof, this influence was particularly more significant. As shown in Fig 8, turbulent intensity increased compared with the velocity under the heating and non-insulated condition. This might be caused by the changes in the surface properties generated by the insulating coating. This change influenced the absorption and reflectance of radiation, which means the impact of radiation on wind flow might be observed when applying artificial light as radiation.

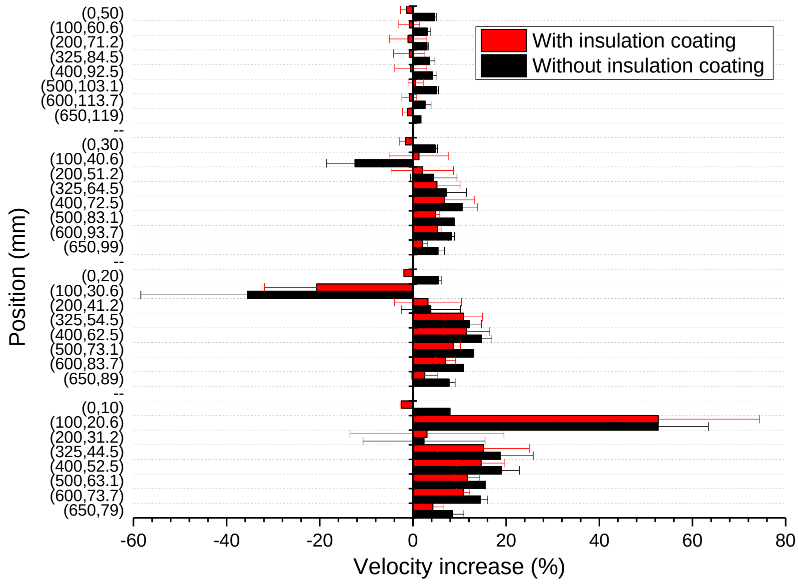

Fig. 7 Velocity increase at each layer after heating the rooftop, with and without insulation coating

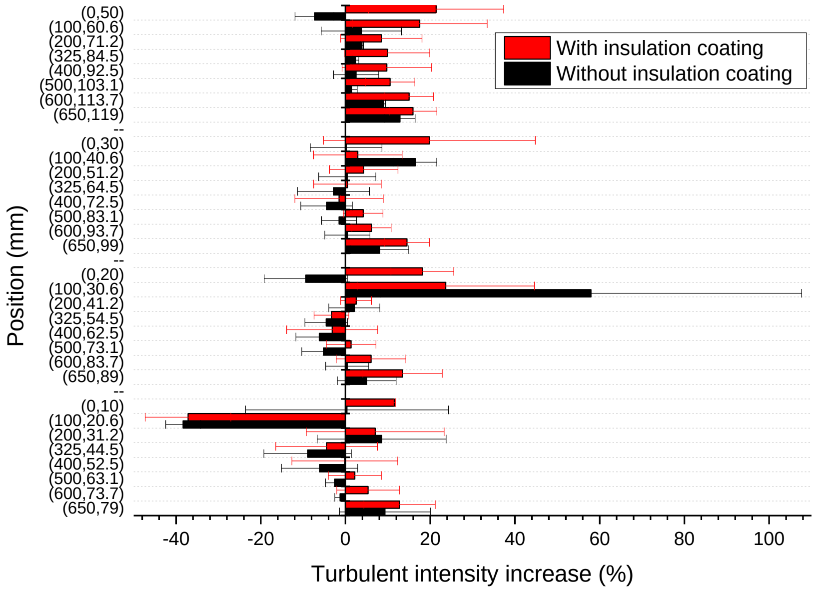

Fig. 8 Turbulent intensity increase at each layer after heating the rooftop, with and without insulation coating

4. Conclusion

A wind tunnel experiment using a scaled model made of real construction materials was conducted to explore the possibility of applying artificial light as solar radiation. Under the low inflow condition, the wind velocity was easily influenced by the shape of building and buoyancy flow. After heating the roof top, the velocity increased while turbulent intensity decreased. This might make pollutant transporting faster but inhibited pollutants from mixing. After applying the insulated coatings on the roof top, the velocity decreased while turbulent intensity increased. We assume this might indicate the influence of radiation on wind flow, and thus feasible to introduce radiation in wind tunnel. Using radiation appropriately in wind tunnel can help better representing the different solar angle and shading effects, and understanding the UHI phenomenon.

However there are still many difficulties to overcome. For example, it’s difficult to measure the air temperature precisely, due to the effect of radiation on thermocouple. Also we should take consideration on the effect of the lamp body, and conduct a better simulation technique for solar radiation study.

Acknowledgment

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