MULTIPOINT MEASUREMENT ON THE TURBULENT CHARACTERISTICS WITHIN URBAN-LIKE CANOPY USING NUMEROUS FINE WIRE THERMOCOUPLES

Aya Hagishima*, Ken-ichi Narita**, Jun Tanimoto*, and Tomohito Kimura **
*Kyushu University, Fukuoka, Japan, **Nippon Institute of Technology, Saitama, Japan

Abstract

The authors performed a field measurement on the turbulent characteristics of an urban canopy layer over a square array of concrete cubes using numerous fine thermocouples and nine ultrasonic anemometers. Measured data using both thermocouples and anemometers is recorded simultaneously with a frequency of 10 Hz. The time and spatially fluctuations of air temperature based were discussed comparing the instantaneous velocity under the unstable condition. The result clearly showed that the passage of the microfront of temperature around the canopy, which are correlate the sweep and ejection motions measured above the canopy.

Key words: Outdoor experiment, urban canopy layer, temperature fluctuation, microfront

1. INTRODUCTION

The turbulent characteristic within urban canopy layer (UCL) is one of the subjects to be investigated from the standpoints of dispersion of pollutant, thermal comfort, and so on. It is well known that the airflow and temperature fields of UCL are highly heterogeneous due to the morphological effect which causes the three dimensional vortex, separation and inhomogeneous surface heating (e.g. Offerle et al. 2007), and such a heterogeneity is one of the reasons of the difficulty to grasp the spatially representative tendency experimentally in real urban areas. It is generally hard to perform multipoint measurement on three dimensional flow filed within UCL because of the various limitations, such as experimental cost and through traffic. Under these circumstances, we did the field measurement of turbulent characteristics over a regular cubical array of ‘COSMO’ (Comprehensive Outdoor Scale MODel experiment for urban climate) site, located in Saitama, Japan. To resolve the three dimensional time series tendency of UCL, we installed numerous fine wire thermocouples (hereafter TC), they are relatively inexpensive, and does not obstruct the airflow due to its small size, and fast response. Although air temperature does not provide the information of air velocity explicitly, there is some possibility to use the spatially fluctuation of air temperature as the tracer element of turbulence. In this paper, we present the measurement result under the unstable condition.

2. EXPERIMENTAL DETAILS

2.1. Site and Instrumentation

The experiment was done over the cubical array consists of 512 concrete blocks with a size of 1.5m (hereafter 1H). The detail of this measurement site is mentioned in Kanda et al. 2004. The layout of array is lattice type square, and the plan area index was 0.25.

Figures 1 indicate the plan view and side view of the measured area. We installed E type TCs with a diameter of 0.025 mm at eight elevations, from 14 cm (z/H=0.09) to 300 cm (z/H=2) around a cube near the center of the site, and obtained the spatially distribution of air temperature based on the data measured in 223 points. Moreover we installed 3D ultrasonic anemometers (KAIJO, DA600, TR90-AH) at 9 points in a vertical plane near the center of the cavity. The measured data using both TCs and ultrasonic anemometers was recorded automatically every 0.1 second using a data logger (Chino, KE3000), simultaneously. Meanwhile, we previously measured the air temperature using both TCs with several diameters and ultrasonic anemometer in a frequency of 10Hz in this site, and confirmed that the measured value of TC with a diameter of 0.025mm shows good agreement with that of the ultrasonic anemometer. In addition, we measured the global solar radiation, longwave radiation, and surface temperature distribution of a cube and the floor. The experiment was from November 1, to December 12, 2008. The predominant wind direction during winter is from the northwest and parallel to the street. Hence we define the mean wind direction, spanwise direction and vertical direction as x, y and z-axis, respectively. The velocity components u, v, and w are defined by these coordinates axes, x, y and z.

2.2. Selected data for analysis

Firstly we calculated the time average, variance, and skewness every 30 minutes and picked up 389 samples of period with 30 minutes based on the following criteria; the mean wind from northwest within the range of ±15 degrees, the number of missing value for all TCs less than five, and no daily precipitation. In this paper, we present the result for a period from 13:30 to 14:00 on December 11, 2008, when the stability parameter z/L...
showed the negative maximum value –0.82, because such a strong unstable condition of weak wind and strong surface heating will be suitable for the challenge to grasp the instantaneous times of temperature field. The measured surface temperature of the cube and floor indicated the strong heterogeneity of the surface heating as follows. The two south-facing walls (SE wall and SW wall, shown in Fig.1) and the roof is warmer about 5 to 8 °C than the both remaining surfaces and air temperature of UCL.

3. RESULTS AND DISCUSSIONS

3.1. In-plane temperature fluctuation around obstacles

We discuss the measured in-plane fluctuation of temperature for a period of 60 seconds from 13:31 to 13:32, in this section. The instantaneous velocity components measured at points C and D are shown in Fig.2, and temperature fluctuations measured in the lines parallel to mean wind are shown in Fig.3. The abscissa and ordinate of Fig.3 indicate time and distance of mean wind direction. Hence, the large value of ordinate indicates the leeward position. Therefore the diagonally right up streaks of contours shown in Fig.3 indicate that the temperature fronts measured in the windward position passed in the leeward position after a moment. Comparing the data measured in the line A-A’ located in the street parallel to mean wind (shown in Figures.3d, 3e and 3f), the diagonally right up streaks can be observed at nearly same time. The gradients of the streaks against abscissa become steeper for the higher position, in contrast the streaks become blur for the lower position. Moreover, we can hardly recognize the similar streak for the positions below 0.56H. These tendencies may be consistent with the following phenomena, so-called ‘channel flow’ can survive on the streets parallel to mean wind within the upper half of the canopy layer under strong unstable condition, but the airflow of the lower half of the canopy is strongly affected by the natural convection due to local surface heating and vortices generated by the cubes.

Regarding the time period between 23 seconds and 30 seconds, the keen negative peaks can be observed above 1H in the lines of both A-A’ and B-B’. It should be coherent fronts of the low speed upward motion, namely sweep

---

**Fig. 1** Schematic views of the measured area. The black square and yellow circle refer a measurement position of ultrasonic anemomter and thermocouple, respectively.

**Fig. 2** Instantaneous velocity components above the array.
The seventh International Conference on Urban Climate,
29 June - 3 July 2009, Yokohama, Japan

Fig. 3  Temperature fluctuation measured in the lines A-A’ and B-B’ shown in Fig. 1. The horizontal and vertical axes refer the time and position coordinate of mean direction scaled by the cube height $x/H$, respectively. The fluctuation of temperature shown on colour bar is subtracted from time-averaged values of each measurement points for a period of 60 seconds.
event, clearly detected at the height of 2H shown in Fig.2a. Since the coherent microfront was observed in the all x-z planes from $y=0.5H$ to $y=1.78H$, the size of this turbulent structure near the canopy height should be at least larger than H. The ejection event is subsequently observed for eight seconds.

The temperature fluctuations shown in Fig.3g and 3h ($z=1.01H$ and 1.17H) in the line of B-B’, small positive peaks are observed after 15 seconds. In addition, the instantaneous vertical velocity at the point D shows the instant positive peak. Considering the following facts that 1) the size of positive streak for $z = 1.01H$ takes place more early with more keen peak compared with that for $z = 1.17H$, 2) there is no similar streak in the line of A-A’ at the same moment, the instant increase of temperature may be caused by a relatively small thermal generated by the hot roof surface.

The strong positive streaks for Fig.2g (line B-B’, $z/H=1.01$) observed after 35 seconds are located above the cavity. The warm air above the cavity may be caused by the complex separations near the leeward corner which involves the thermal generated by the three heating surfaces, namely the roof, SW wall and SE wall.

Lastly, we make a scrutiny on the temperature fluctuation measured in the vertical line of E-E’ in the cavity as shown in Fig.4. The temperature distribution within and above the canopy height is clearly separated all through the period. The warm air exists within the cavity in contrast the air temperature above canopy is clearly low for the first half period, and the opposite temperature field is observed for the latter half. In addition, it is shown that the passage of the cold air mass clearly observed above the roof level for the period from 23 seconds to 28 seconds is not so effective to change the temperature within the cavity. Besides, the intermittent positive peaks take place at the height of 1H after 45 seconds, those are consistent with the peaks shown in Figure 3g and 3h.

3.1. Two-points correlation of temperature around obstacles

We calculated the two-points correlation of temperature (e.g. Christen et al. 2007) using the time series data for all measurement point for the period of 30 minutes we selected. Figure 5 indicates the vertical distribution of two-points correlation between the data of reference point F and those measured in a y-z plane adjacent to the leeward heated wall. The area with relatively high correlation widely spreads toward the bottom of the cavity, in contrast the intervals of the isograms are narrower above the canopy height. It is consistent with the statement based on the previous works. In short, strong shear stress and large turbulent kinetic energy are generated at near the roof level thus dispersion rate and turbulent length scale above the roof is much larger than that below the roof.

5. CONCLUSIONS

We performed the outdoor measurement using numerous TCs within the UCL of the square cubical array, and presented the time-spatially fluctuation of air temperature under the unstable condition. The measured data resolved the microfront of temperature around the canopy, which are correlate the sweep and ejection motion measured above UCL, and small thermals generated from the heating surface are also detected.

References

