Measurement of temperature distribution and CO_2 concentration in a space-heated classroom

Shuzhao Liu[1], Hiroshi Yoshino[1], Akashi Mochida[1]

[1] Tohoku University, School of Engineering, Sendai, Japan 980-8579

Abstract

The winter thermal environment and indoor air quality in classrooms has been reported to be very poor in Japan. In this study, an air-conditioned, mechanically ventilated classroom was surveyed. Air temperature, globe temperature and the concentration of CO_2 were monitored before, during and after the three-hour occupancy by 35 adults. Airtightness and airflow rates of the ventilation system were also measured. With the outdoor air of about 0℃ and the thermostat temperature setting of 30℃, the vertical difference in air temperature exceeded 10℃, while the horizontal difference was under 2.5℃. After half an hour of occupancy, CO_2 concentration exceeded 1500 ppm in the respiration zone, and it reached 2500 ppm from the respiration zone to the middle of the room height for a consecutive 1.5-hour. The concentration decay showed that the air change rate was 0.82 ach. It was far from the national criterion of 2.2 ach.

Keywords: classroom, temperature, CO_2

1. Introduction

Due to the poor performance of airtightness and heat insulation, the vertical temperature distribution in classrooms in the heating season is usually large, which often causes very

serious problems related to thermal comfort [1]. It has also been reported that the CO_2 concentration in classrooms often exceeded the criterion of 1500 ppm during lessons due to low ventilation rates [1][2]. In university classrooms, occupants have complained of large temperature distribution and poor indoor air quality.

With the objective aimed at improving the thermal environment and performance of ventilation in classrooms, the actual condition of the indoor environment of a space-heated classroom with ceiling-concealed air conditioners and ventilation fans was investigated. This paper reports the measurement results of the distributions of air temperature, globe temperature and CO_2 concentration during the occupancy.

2. Investigated classroom and measured items

Investigated classroom

The classroom investigated was situated among the middle rooms of a one-storey building at Tohoku University in Sendai, Japan. It was 7.9 m wide, 9.1m long and 3.0 m high and had 60 seats. Two air conditioning units (AC) with the maximum heating capacity of 5.91 kW each were concealed in the ceiling. Two ventilation fans with heat exchangers were equipped in the north façade. *Figure 1* shows the floor plan. *Table 1* shows the materials of the building components.

Measured items

The survey included a measurement of the airtightness of the whole room and building components, the inflow and outflow rates of the ventilation fans, the thermal profile of the airflow from the AC, the indoor and outdoor air temperatures, the indoor globe temperatures, and the CO_2 concentrations of indoor and outdoor air.

3. Methods of measurements

The airtightness of the whole room and building components

The airtightness of the classroom was measured by an airtightness meter (KNS-4000II), under the depressurization method. The leakage area for each building component was estimated by the difference of the total leakage area before and after the component was sealed with vinyl films.

The supply/exhaust flow rates of the ventilation fans

With the diffuser removed, the supply and exhaust flow rates of the two ventilation fans in the north façade were measured by an airflow meter (Swema Flow 65). The measurements were conducted under the high and low operation modes of the fans when the doors were open and closed.

The thermal profile of the airflow from the air conditioners

To obtain the thermal profile of the airflow from the AC, an infrared camera (Avio TVS-610) was used. Below the symmetrical center line of the AC's diffusers, a piece of vinyl film was tensioned between two poles, which were held and pulled by two people. After 10 minutes in

this state, an infrared image of the surface temperature was taken. Since the film is thin, the surface temperature could be regarded as the same as the air temperature around it.

The air temperature and globe temperature

As shown in *Figure 2*, thermometers with loggers (TR-72 in set) were used to monitor the indoor and outdoor air temperatures. The vertical air temperature distributions were monitored at the middle and rear of the center aisle with the room height. At 1.0 m above the floor, the horizontal distribution was monitored near the south doors, the north window, the front fan, and at the front of the middle aisle. As a reference, the outdoor air temperature was also monitored at the north balcony by a thermometer in a hand-made aluminum duct that sheltered it from solar radiation and snow/rain. At the places where the horizontal distribution of indoor air temperatures were monitored, globes including T-type thermocouples were also set up. The log rate was every five minutes.

The indoor and outdoor CO_2 concentration

In the middle of the center aisle, CO_2 meters with loggers (JMS-301 in set) were set up with the height of the room. The outdoor concentration was monitored at the north balcony. The log rate was every one minute.

4. Results of the measurements

Airtightness of the room and building components

Table 2 shows the equivalent leakage areas of building components. The total leakage area of the room is 570 cm^2, which is 8 cm^2 per square meter of floor area. The leakage area of the walls, ceiling and floor occupied nearly 2/3 of the total.

The supply/exhaust flow rates of ventilation fans

Table 3 shows the measured supply and exhaust flow rates of the ventilation fans under the conditions of high/low running modes when the doors were open and closed, with the specification flow rates under high running mode as a reference.

Despite the same specification value for both supply and exhaust flow rates, measurements showed that the outflow rate was much larger than the specified value while the inflow rate was smaller, resulting in a large difference in the flow rates between supply and exhaust. The difference in the airflow was caused by the infiltration through the cracks of the room.

The thermal profile of the airflow from the air conditioners

With the set point temperature of 30℃ and downward direction of airflow supplied from AC, infrared images of the airflow from the AC running at high, medium and low wind speed modes were shown in *a*, *b* and *c* of *Figure 3*, respectively.

In medium wind speed mode, due to the relatively low speed and large buoyancy, the airflow went up to the ceiling immediately after it was jetted out, resulting in a large temperature difference. In this case, the occupied zone was not heated and the zone around foot level was

left cold. This problem became more serious in low mode. This phenomenon is due to the poor thermal performance of the building

Variation of indoor air temperature due to occupancy

The indoor thermal environment was measured under conditions with the set point temperature of 30℃, downwards blowing at high speed, and the ventilation fans operated in high mode. The indoor air temperature changes in the periods before, during and after the three-hour of occupancy by 35 adults is shown in *Figure 4*.

At the center and the rear of the room, the vertical temperature difference was over 10℃, between the lowest near the floor and the highest near the ceiling. The temperature at the center of foot level was under 20℃. As for the heat released from the occupants, the temperature rose during the occupancy in the zone under 1.5 m. At all heights under 1.5 m, the temperature changed following the outdoor air, which means that the temperature control of the AC of the occupied zone was limited.

No large horizontal distribution in the air temperature was seen throughout the room at the height of 1.0 m.

Difference of air temperature and globe temperature

Figure 5 shows the difference between the globe temperature and air temperatures, at the height 1.0 m over the floor.

The globe temperature was about 2℃ higher than the air temperature in the middle of the room. It was about 1.5℃ lower than the air temperature near the door. These are respectively due to the radiation from the air conditioners and the ceiling around them, and the cold inside surfaces of the doors.

Variation of CO_2 concentrations

Figure 6 shows the variation of CO_2 concentrations in the middle of the classroom.

It was found that, after about half an hour of occupancy, CO_2 concentration at the respiration zone (1.0 m over the floor) exceeded the nation's criterion [3] of 1500 ppm for classrooms. The value increased and it reached 2500 ppm after a consecutive 1.5 hours of occupancy.

Distributions of temperature and CO_2 concentration along room height

Figure 7 gives the vertical distributions of air temperature and the concentration of CO_2, based on the averaged values between 11:00 am – 12:00 am.

The air temperature increased with the height. The lowest and highest temperatures appeared near the floor and the ceiling respectively. This phenomenon can be easily understood when thinking of the fact that the main source of heat was the AC in the ceiling. Because the thermal performance of the building was poor, due to the buoyancy effect, warm air tended to rise up. On the other hand, the concentration of CO_2 showed a different pattern of distribution. The peak was not seen near the ceiling. It seems reasonable to think that after CO_2 was

respired by occupants at higher temperature than the ambient air, it was transported upwards due to the buoyancy effect, and tended to be accumulated on the way up. At the same time, in the areas under the ceiling, where the fans were installed, the indoor air was diluted by the fresh air from the ventilation fans. Eventually, the peak was reached at about 1.5 m above the floor.

Air change rate estimated by the decay of CO_2 concentration

Figure 8 shows the normalized concentration decay with the elapsed time. It is estimated that the air change rate of the room was 0.82 ach, which is very close to the value obtained by the exhaust flow rate measurement of the ventilation fans.

5. Conclusions

The following conclusions were obtained by the detailed measurement of temperatures, CO_2 concentration, airtightness etc in a space-heated classroom with ceiling AC.

1. The airtightness of the classroom was 8cm^2 per square meter of floor area. Equivalent area of cracks in walls, ceilings and floors are dominantly larger than in the doors and windows.

2. The air temperature near the floor was over 10℃ lower than that near the ceiling. It was under 20℃ at foot level. The poor performances of the building insulation and airtightness accounted for the large temperature difference.

3. The peak concentration of CO_2 appeared at about the middle of the room height. In the respiration zone, the concentration exceeded the national criterion of 1500 ppm after about half an hour of occupancy.

4. It was estimated from the CO_2 decay that the air change rate was 0.82 ach, which was far below the national criterion of 2.2 ach for classrooms.

References

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2. Iwashita Go, Hanada Y., Yoshino H., Discussion on the Indoor Air Quality in Classroom of the Elementary Schools without Heating Equipments During Winter Season based on the Window Opening and the CO_2 Concentrations (in Japanese), AIJ Journal, No.618, pp61-67, 2007

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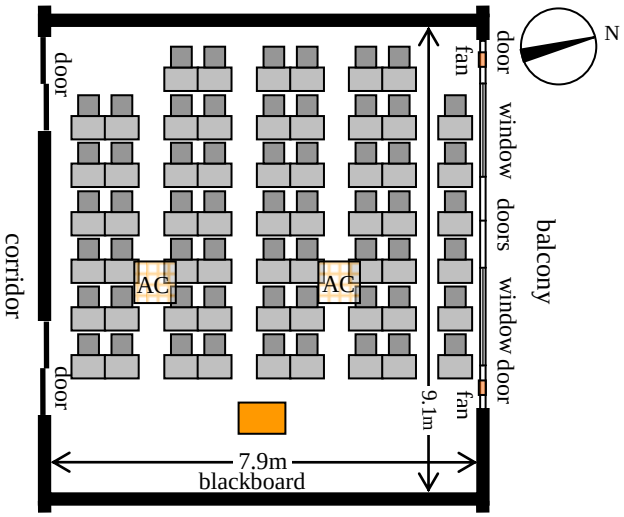


Figure 1 Plan of the surveyed classroom investigated

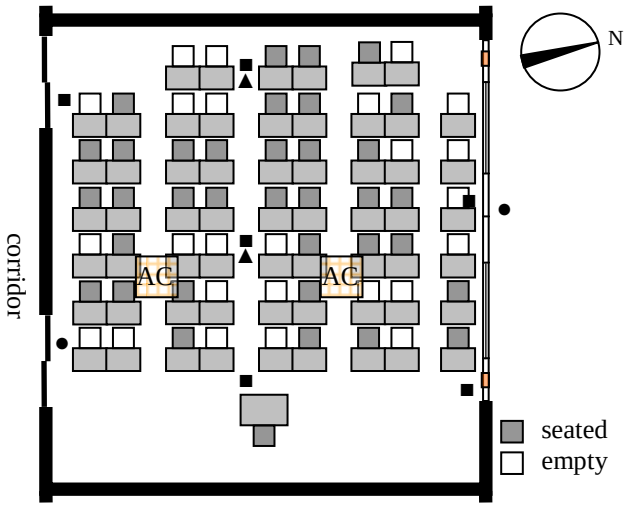
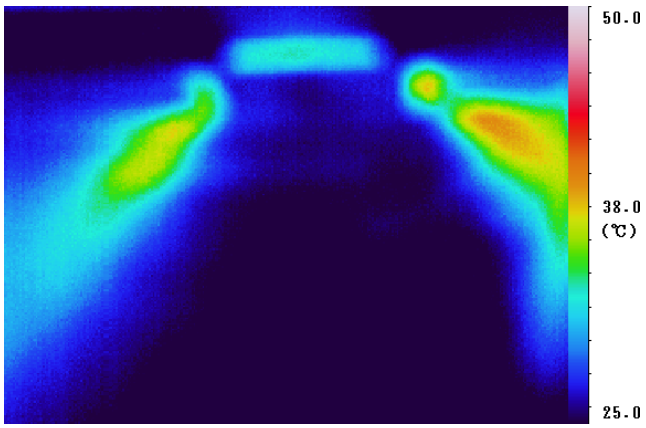
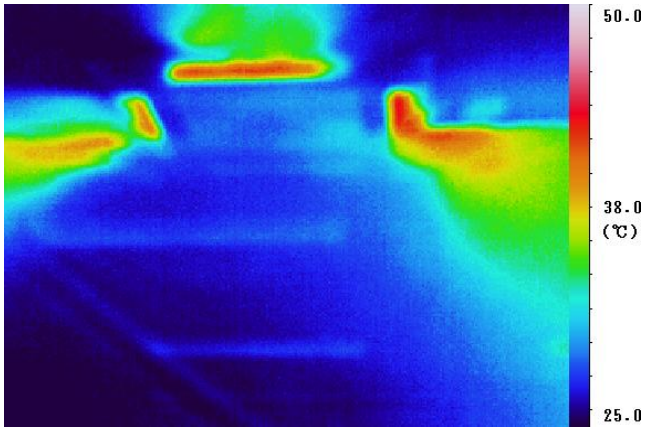


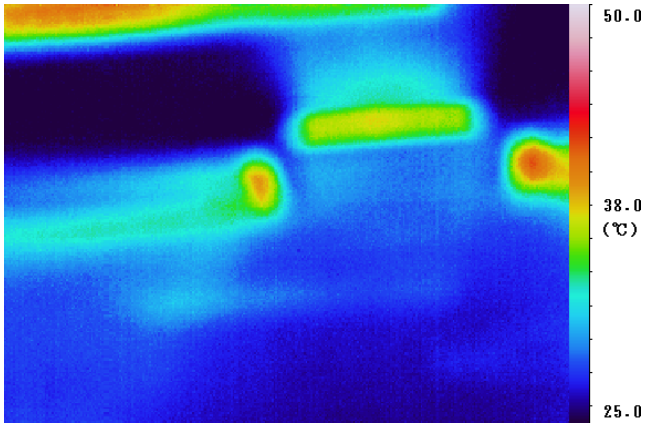
Figure 2 Location of measuring points



a) Wind speed: High

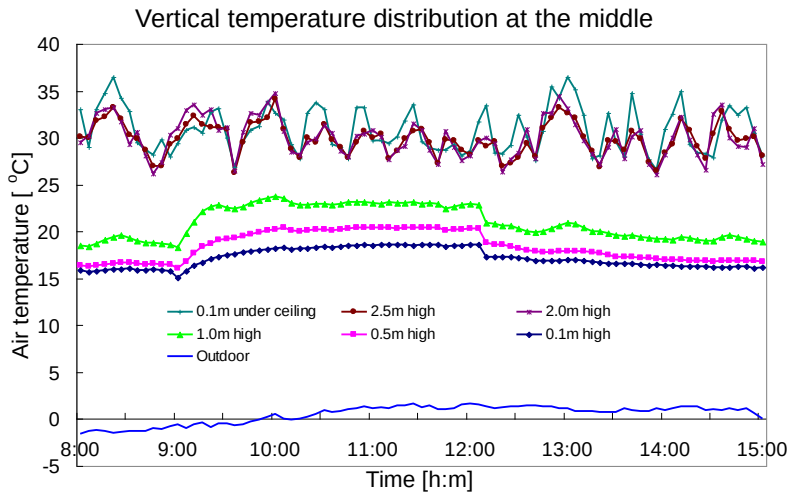


b) Wind speed: Medium



c) Wind speed: Low

Figure 3 Infrared images of airflows from air conditioners



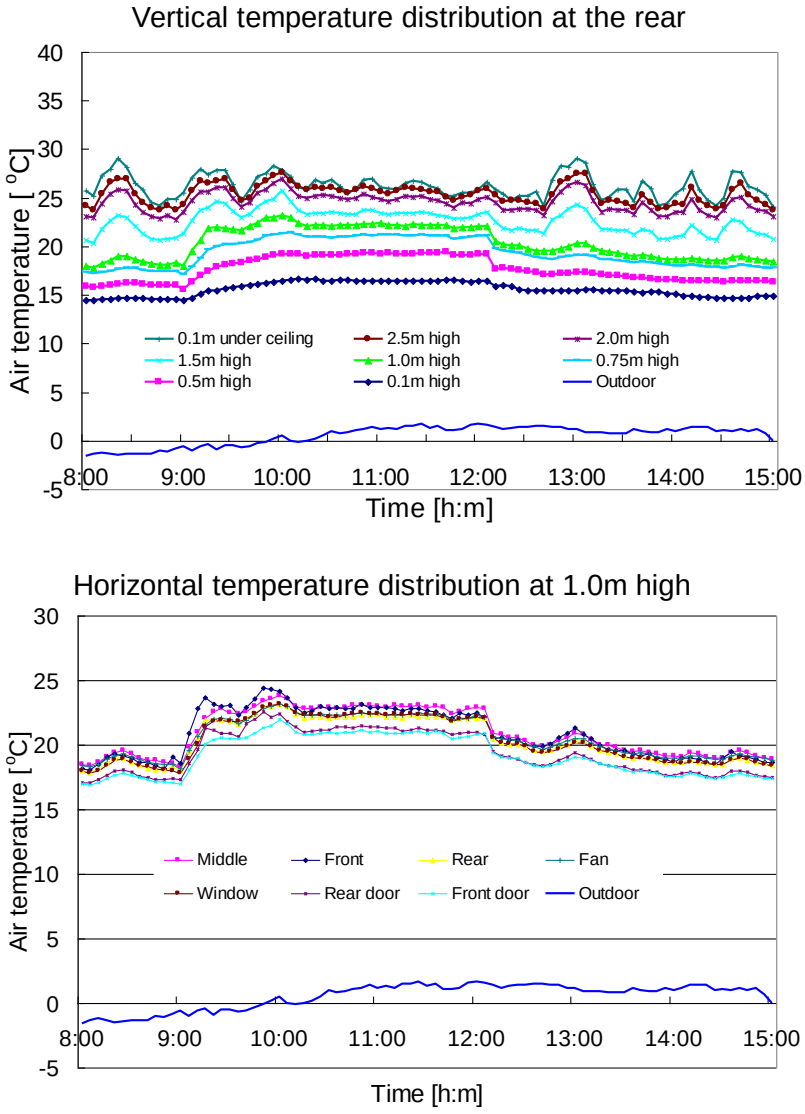


Figure 4 Vertical and horizontal distributions of air temperature

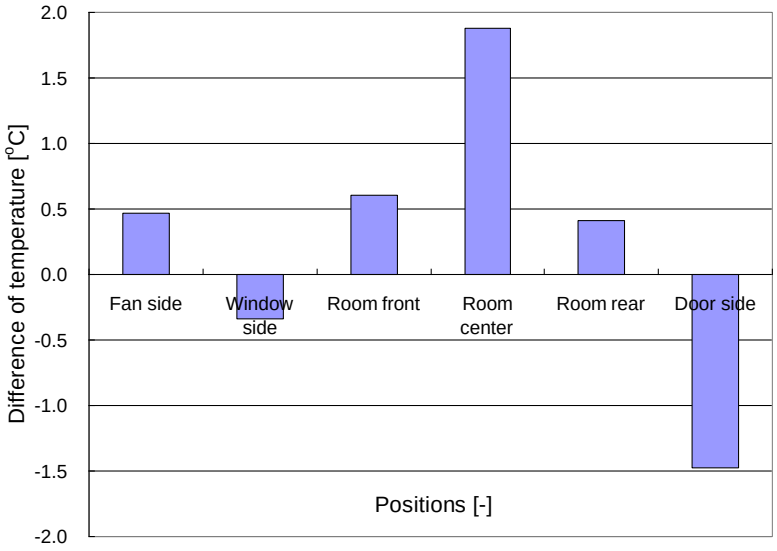


Figure 5 Difference between globe temperature and air temperature

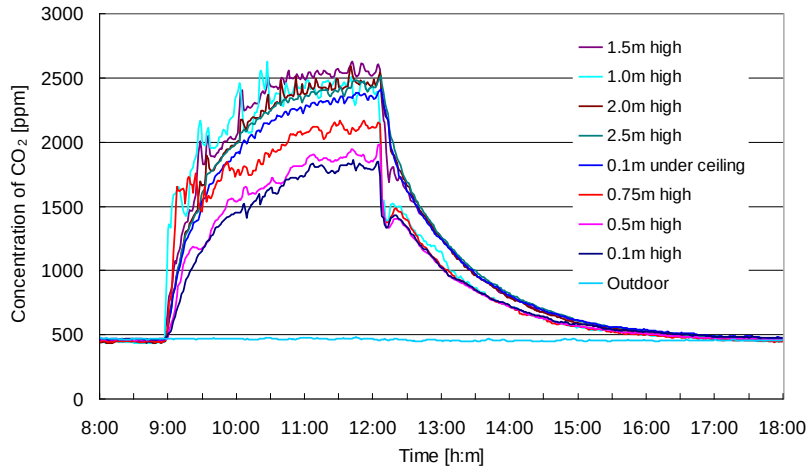


Figure 6 Variation of CO_2 concentration

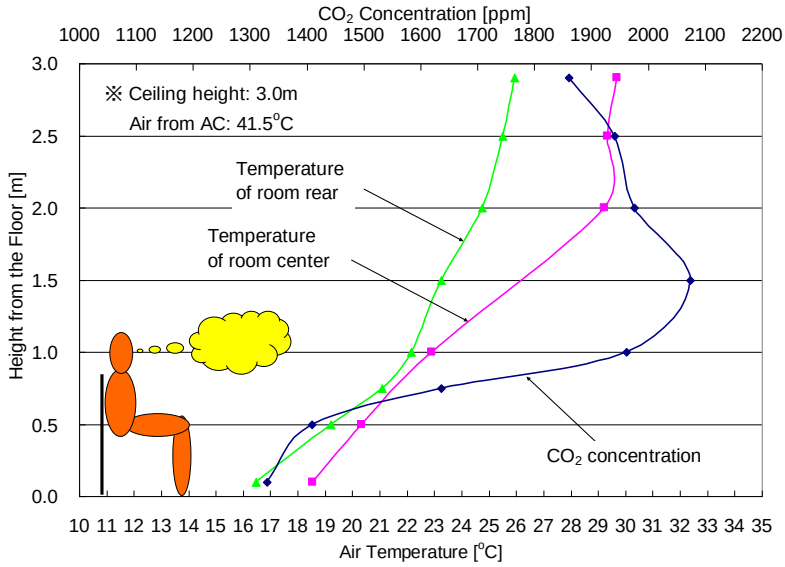


Figure 7 Vertical distributions of temperature and CO_2 concentration

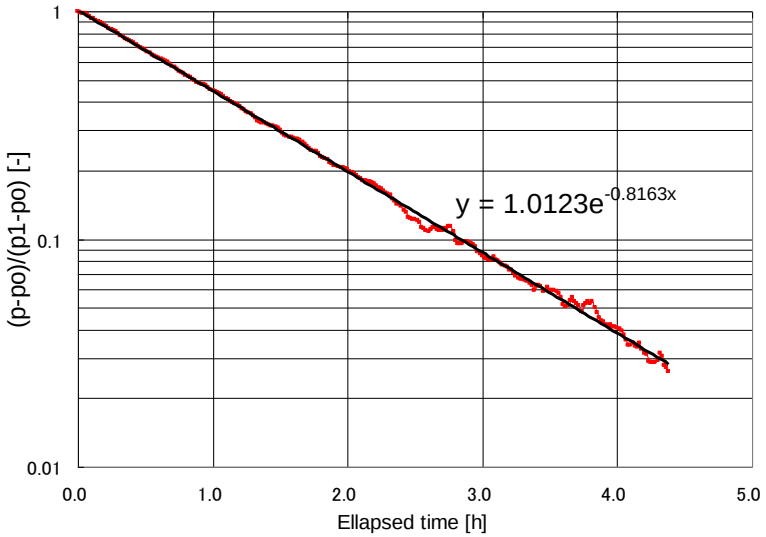


Figure 8 Normalized CO_2 concentration decay

Table 1 Components of the room envelope

Components	Materials
Window glasses	Double glazed: 5mm+6mm+5mm
Doors	Sliding doors with insulation material sandwiched by steel plates
Partition walls	Glass wool with 50mm thickness sandwiched by plaster boards 15mm thickness
Outer walls	North wall: insulation board with 120mm thickness South wall: insulation board with 120mm thickness
Floor	Tile carpet upon 80mm of concrete
Ceiling	Lowered ceiling with noise-absorption decoration board δ=12mm

Table 2 Equivalent areas of cracks [cm^2]

Components	Equivalent area		Total
South door	82	192	570
South window	14		
North door	82		
North window	14		
Others: walls, floor, ceiling	378		

Table 3 Flow rates of ventilation fans [m^3/h]

Measured articles	Status of doors	High mode		Low mode	
		Exhaust	Supply	Exhaust	Supply
Front fan	closed	93.1	53.7	19.0	15.8
	open	95.6	53.6	19.1	13.6

Rear fan	closed	93.0	51.7	18.6	16.9
	open	95.7	51.6	20.3	13.9
Specification	–	65		–	–