School Eco-Renovation Method for Improvement of Thermal Environment in Large Workshop of High School without Air-Conditioning System

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Abstract

In recent years school buildings, containing the workshop in high school, are old in Japan. Therefore most of them need renovating. Any air-conditioning systems are not often installed in the workshops. Workshops without air-conditioning systems often have bad indoor thermal environments. Since bad thermal environment is exhausting and *likely to cause some accidents, eco-renovation method for improvement of thermal environment is required. In this paper, various kinds of eco-renovation methods are examined by CFD simulation. The examined methods are insulation of the PC roof and the walls to decrease the surface temperature, and utilization of more ventilation rate in summer.*

Keywords: Workshop, Thermal environment, CFD simulation, Eco-Renovation.

1. Introduction

In Japan many schools have old buildings because they were built during the 60's - 70's of high economic growth. In the old school buildings any ecological systems are not considered. To change this situation, Japanese government started a project named "School Eco-Renovation and Environmental Education Program" since 2005. This project helps the old school buildings to be renovated ecologically, and it is expected that through the renovation students come to know well about “Energy and Environment Matter.” More than twenty schools have been renovated as models of this policy since 2005 in Japan [1].

In addition, most of the workshops of school have bad thermal environments because they are not equipped with any air-conditioning systems. Since bad thermal environment is exhausting and likely to cause some accidents, improvement of the thermal environment is required.

In this study eco-renovation method of a large workshop in a high school is proposed in order to improve the indoor thermal environment. The target workshop is in a building which school, as a model of the “School Eco-Renovation and Environment Education”, has. Therefore the method is based on passive control without air-conditioning system. This paper shows that comparison between measurement and simulation by Computational Fluid Dynamics (CFD), and the effect of the insulation of the Prestressed Concrete (PC) roof and walls and the increase of ventilation rate will be examined.

2. Measurement

A measurement research of the thermal environment in large workshop was carried out to compare with simulation results. The large workshop to be investigated is a workshop of a technical high school in Osaka. The plan and sections of the workshop are shown in Figure 1.

The top height of the workshop is 6.6 m. The roof is made of PC (Pre-Stressed Concrete) and covered with waterproof sheets with silver coating. Three ventilation fans are installed on the east and west walls respectively. No air-conditioning system is installed in this workshop. In summer, the workshop is used with all windows open to introduce natural wind. In the workshop there are some turning machines and milling machines.

Measurements of the thermal environment were conducted between on the 6^{th} to the 19^{th} September 2009. Measurement points are shown in Figure 1. The measurement points are located in the center of workshop. Measurement points of air temperature are 10 points and that of surface temperature are 3 points (floor: 1 point, ceiling: 2 points). Air temperature and surface temperature were measured with thermocouples.

To determine the boundary conditions of CFD analysis a measurement the ventilation rate of mechanical fans was measured by tracer gas method on the 19^{th} September 2009. During the measurement only two windows on the west wall were opened (see Fig. 2 CFD analysis domain). The airflow rate was calculated from the concentration of tracer gas. SF_6 was used as tracer gas and emitted at four points near the floor.

3. CFD Analysis

3.1 Model and Cases

The calculation domain for CFD simulation is shown in Figure 2. However in the real workshop the top height of the center is higher than that near the wall (see Fig. 1(b)), in CFD analysis all the ceiling height is assumed to be the same throughout the workshop. Outdoor air is supplied from 20 windows on the east and the west walls and exhausted from six ventilation fans. In this analysis, only convective heat transfer is considered and radiative heat transfer is not calculated. The temperatures and convective heat transfers of the ceiling, floor and east and west walls are set at constant values. All the surfaces in this model, except for ceiling, floor and east and west walls, are assumed to be adiabatic. In this model 37 heat generation panels are at floor, on the small rooms and on the north wall (see Fig. 2). They are caused by the solar radiation from the top lights. All heat generation in the room is exhausted only through six ventilation fans. The conditions of CFD analysis conditions are shown in Table 1.

Analysis cases are showed in Table 2. Case 0 is the case for comparison between measurement and simulation by CFD. The set temperatures in case 0 are based on the measurement results at 14:00 on the 19th September 2009. Case 1 is the case only for simulation at 14:00 on the hottest day of the year, the 15th July 2009. The set temperatures in case 1 are based on calculation of zonal model [2]. Case 2 and 3 are the cases of insulation of the ceiling to decrease the ceiling temperature. Case 4 is the case of increased ventilation rate. In the case 4, the airflow rate of ventilation fans is twice as much as that of real building. Case 5 is the case of insulation of the walls. In case 5, the east and west walls are heat insulation.

Case 6 is the case that all methods, insulation of the ceiling and the walls, and increased ventilation rate are applied. Only in case 0, outdoor air is supplied from two windows on the east wall (see Fig. 2) on the assumption of the condition at 14:00 on the 19th September 2009.

3.2 Boundary Conditions

Boundary conditions are shown in Table 3. The velocity boundary conditions are applied to the windows and ventilation fans. In case 0 – 3 and 5 the velocity at the ventilation fan is 1.67 m/s reflecting total exhaust airflow rate in the workshop is 9000m^3/h. In case 4, the velocity at the ventilation fan is 3.33 m/s reflecting total exhaust airflow rate in the workshop is 18000m^3/h. At the ceiling, floor, and east and west walls, heat transfer are assumed. Convective heat transfer coefficients of ceiling, floor and walls are 2.33 W/m^{2}K, 4.66 W/m^{2}K and 3.5 W/m^{2}K respectively [3]. The amount of heat emission of each panel on the assumption of solar radiation is 0.81 times as much as the horizontal solar irradiance, considering the transmission of the top light glazings of 0.9, and the solar absorption of the floor, of 0.9.

The mesh system is shown in Figure 3. The number of the mesh division is 953,120 (296x70x46). It has finer mesh near the walls and ceiling.

4. Results and Discussion

4.1 Comparison between measurement and CFD analysis

Vertical temperature distributions obtained by the measurement and CFD analysis are shown in Figure 4. Under the same boundary conditions, the temperatures of CFD analysis are calculated on the same position as the measurement. The vertical temperature distribution of the measurement is almost uniform from the floor to the ceiling. The temperature of calculation (case 0) is approximately lower than that of measurement by 2 deg C from the floor to 2000 mm height. This difference of temperatures between measurement and calculation is considered to result from the electric fans used at the measurement.

The contours of calculated temperatures (case 0) are shown in Figure 5. The electric fans are not considered on CFD analysis. As Figure 5 indicates, the temperature of measurement points is lower than that of the surroundings. On the other hand, during measurement on the 19^{th} September, several electric fans were used in order to stir up the indoor air for tracer gas method. Since the indoor air was mixed by the fans, the temperature distribution of measurement was supposed to be uniform.

Although there is a little difference between measurement and calculation at a low height of the room, temperature distributions in Figure 4 show almost good agreement.

4.2 Effect of improvement methods

The vertical temperature distributions of CFD calculations are shown in Figure 6. As the results of case 1, 2 and 3 indicate, the temperatures decrease at a high height of the room because of the insulation of ceiling. The temperature of case 3 at a low height of the room is approximately 1 deg C lower than that of case 1. Though the decrease of the temperature by the insulation of ceiling results in the decrease of the air temperature of the room, the difference between case 1 (no improvement method) and case3 (the insulation of ceiling) is not large.

In Figure 6, case 4 shows the effect of increased ventilation rate. The temperature of case 4 shows 1.5 deg C lower values than that of case 1 at all heights of the room. Increased ventilation rate results in the larger difference of the air temperature compared with that in the case of the insulation of ceiling.

In Figure 6, case 5 shows the effect of the insulation of walls. The temperature of case 5 at a high height of the room is approximately 1 deg C lower than that of case 1 although there is little difference of the air temperature at a low height of the room. Therefore, the insulation of walls can bring in the decrease of the air temperature at a high height of the room.

Case 6 shows the effect of all improvement methods, insulation of ceiling and walls and more ventilation rate. The temperature of case 6 is approximately 2 deg C lower than that of case 1. As the supply air temperature is 34 deg C, the air temperature at a low height of the room is 1 deg C higher than that of supply air.

SET* distribution at a 1,100 mm height of the room in all cases are shown in Figure 7. The assumption of amount of clothing, metabolic rate and relative humidity are 0.6 clo, 1 met and 50% respectively. MRT for the calculation of SET* of case 1, 2, 3 and 4 is the average temperature of ceiling, east and west walls and floor, while that of case 5 and 6 (insulation of walls) is the average of temperature of ceiling and floor. SET* of case 1 (no improvement method) indicates more than 40.0 deg C in the room. SET* of case 5 (insulation of walls) is higher than that of case 1 (no improvement method). This is because MRT of case 5 (the average temperature of ceiling and floor) is higher than that of case 1 (the average temperature of ceiling, floor and east and west walls) since the temperature of ceiling is much higher than that of floor and east and west walls. SET* of case 2 and 3 (insulation of ceiling) are lower than that of case 4 (increased ventilation rate) and 5 (insulation of walls). This result shows that insulation of ceiling is more effective in decreasing sensory temperature in the occupancy area than the insulation of walls or increased ventilation rate.

5. Conclusions

The effects of some of the improvement methods on the indoor thermal environment were examined in this paper. It was turned out that the insulation of ceiling is the most effective improvement method and the essential method to decrease the sensory temperature in the occupancy area. In addition to the insulation of ceiling, the increase of velocities in the room is a good way to decrease sensory temperature, too. Although the improvement of thermal environment is achieved by increasing ventilation rate of mechanical fans in this paper, it can be achieved by natural ventilation as the effective way of energy saving.

Although it is not easy to do the time-series analysis of the indoor thermal environment by CFD, CFD is quite useful for the analysis of the distributions in the room, for example, of temperature, velocity and SET*. It is also proved that the method to combine CFD analysis with calculation of zonal model is so effective and successful.

Acknowledgments

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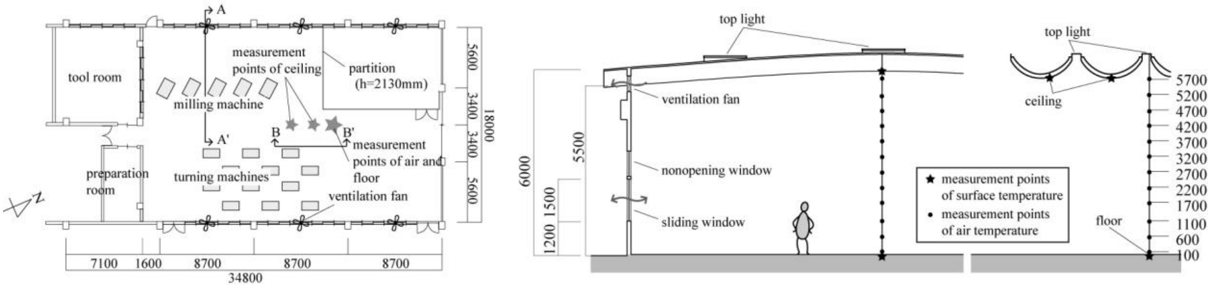
References

1. Web Pages and On-line Material: "eco-flow / School Eco-Renovation and Environmental Education Program." http://www.ecoflow.go.jp/en/ (July 25, 2010)

2. Yasui S., Yamanaka T., Sagara K., Kotani H., Momoi Y., Yamada J., *"Indoor Thermal Environment and Vertical Temperature Gradient in Large Workshop of School without air-conditioning,"* Submitted to *the 31st AIVC Conference,* Seoul, Korea, 2010

3. Togari S., Arai Y., Miura K., "*A Simplified Model for Predicting Vertical Temperature Distribution in a Large Space,*" *ASHRAE Transactions*, 1993, Part 1, pp.84-99



(a) Plan (b) A-A’ section (c) B-B’ section

Figure 1 Plan and Sections of the workshop and Measurement Points

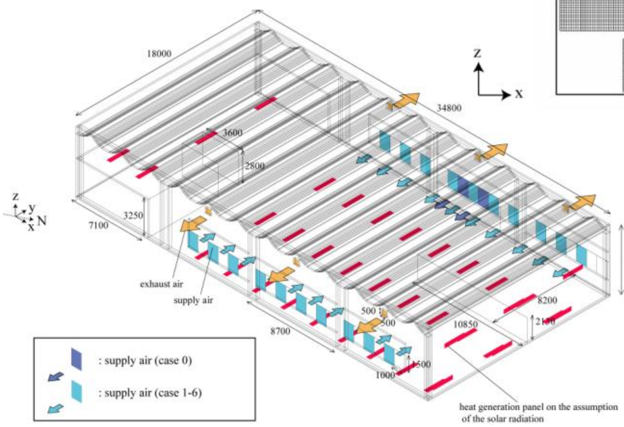
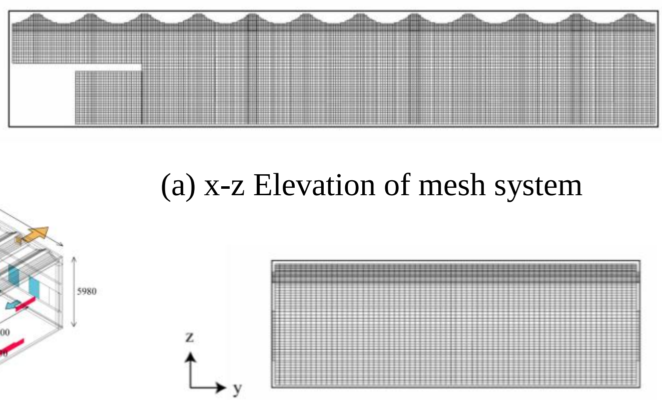


Figure 2 CFD analysis domain



(a) x-z Elevation of mesh system

(b) y-z Elevation of mesh system

Figure 3 Mesh System

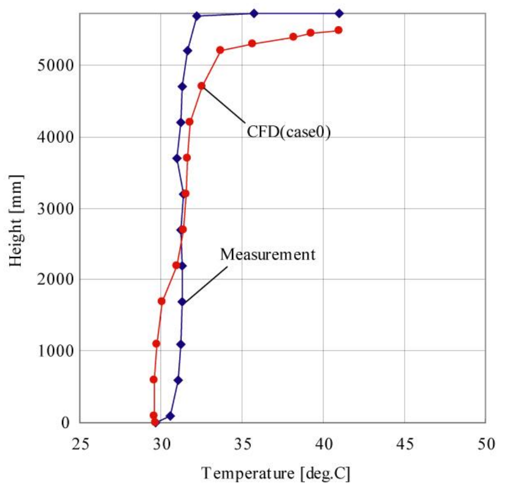


Figure 4 Vertical temperature distributions

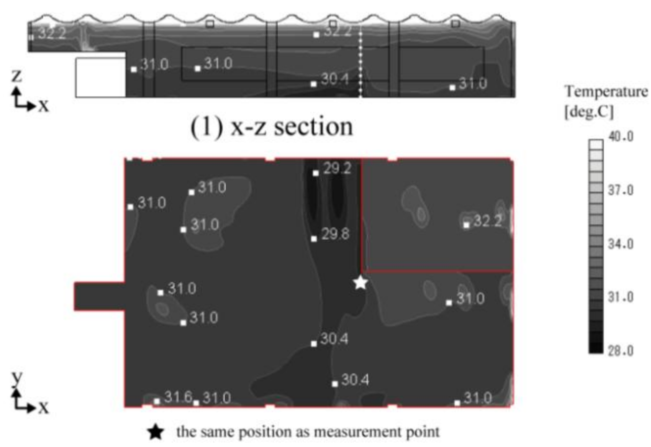


Figure 5 Counters of temperature obtained by CFD (case 0)

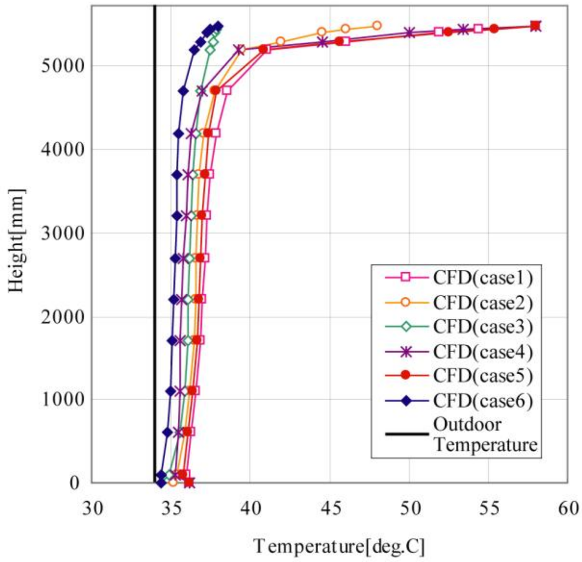


Figure 6 Vertical temperature distributions obtained by CFD analysis

Table 1 CFD analysis conditions

code	STREAM for Windows Version8
Turbulence Model	Standard k-ε Model
Algorithm	SIMPLEC
Scheme for Convective Term	1st order upwind scheme

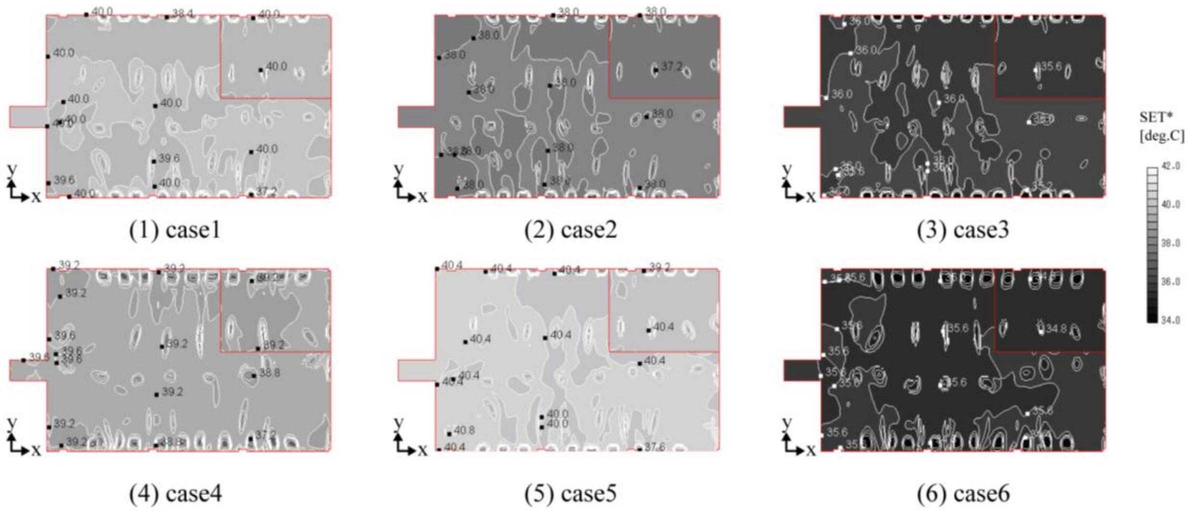


Figure 7 SET* distribution (at 1,100mm height)

Table 2 Cases for CFD simulation

	assumption case	improvement method	surface temperature [deg.C]			supply air temperature [deg.C]	ventilation rate [m^3/h]
			ceiling	floor	the east and west walls		
case 0	simulation at 14:00 on the 19th September 2009	X	41	29.7	32	28.6	9000
case 1	simulation at 14:00 on the hottest day of the year, the 15th July 2009	X	58	36.2	40.6	34	9000
case 2		insulation of ceiling	48	35.2	37.8	34	9000
case 3			38	34.4	35.1	34	9000
case 4		increased ventilation rate	58	36.2	40.6	34	18000
case 5		insulation of walls	58	36.2	X	34	9000
case 6		all the methods	38	34.4	X	34	18000

Table 3 Boundary conditions

flow	supply air	velocity boundary condition
	exhaust air	velocity boundary condition
walls		Standard Log-low
thrmal	ceiling	heat transfer coefficient: 2.33[W/m^{2}K]
	floor	heat transfer coefficient: 4.66[W/m^{2}K]
	east and west walls	heat transfer coefficient: 3.5[W/m^{2}K]
heat generation		37 panels: 15247.7 [W] (in total)