Commissioning of a Coupled Earth Tube and Natural Ventilation System at the Acceptance Phase

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ABSTRACT

In this paper, the environment and energy performance of an actual coupled earth tube and natural ventilation system in a gymnasium was measured during the acceptance phase in two operation states: no ventilation and natural ventilation. From the measurement result, the authors found a design fault, which the airflow temperature from floor apertures on the north side was 3 degrees lower than from the floor apertures on the south side. By the use of the CFD (Computational Fluid Dynamics) coupled analysis with natural ventilation method, the natural ventilation air volume and the indoor temperature in three outdoor air conditions have been calculated to perform commissioning. Several findings were obtained and informed to the operator.

KEYWORDS

Earth tube, Natural ventilation, CFD coupled analysis with natural ventilation method

INTRODUCTION

Recently, even though coupled earth tubes and natural ventilation systems are often used in Japan, the amount of basic information based on actual measurements and simulations of such systems is limited. Furthermore, design methods and optimal operation policy have yet to be clarified. When the commissioning of a coupled earth tube and natural ventilation system is performed during the acceptance phase, as part of efforts to verify the design and prevent faults that might occur due to unclear information or lack of experience on the part of the designers during the planning and design phase, and in order to confirm the function and performance of the system under various outdoor air conditions and system utilization states, the following questions must be answered clearly:

- What commissioning items must be considered?
- What points should be measured for each commissioning item?
- What simulation tools should be adopted?
- What should be simulated?

The purpose of this paper is to clarify the commissioning method and processes for this type of system.

As part of that effort, the authors reviewed previous research efforts and existing simulation tools used for coupled earth tube and natural ventilation systems and then developed a natural ventilation simulation tool that considers vertical air temperature distribution and coupled the CFD analysis method with this simulation tool (Zheng, 2007; Pan, 2007b). Using this CFD coupled analysis method, the authors performed the commissioning of an actual system at the plan/design phase (Pan, 2007a; Pan, 2007b). The commissioning results of the following four items are reported:

- energy conservation performance
- air temperature of the occupied section
- natural ventilation air volume
- airflow velocity through the floor apertures

In this paper, we report the measurements and simulations of the actual system completed on February, 2008, during which commissioning at the acceptance phase was performed and several findings were obtained.

OUTLINE OF THE COUPLED EARTH TUBE WITH NATURAL VENTILATION SYSTEM

An outline of the building and the coupled earth tube with natural ventilation system is shown in Tables 1 and 2, respectively. The building is the indoor gymnasium of an elementary school. The ventilation system consists of rotary natural ventilation windows near the ceiling of the north and south walls, floor apertures, under-floor pits and the outdoor earth tube. Outside air is obtained from inlets and supplied to the room by means of seven south floor apertures and six north floor apertures, as shown in Figure 1, after the air flows through the outdoor earth tube, under-floor pits, indoor vertical shaft and outdoor vertical shaft. Furthermore, forced ventilation is performed by means of two supply fans installed at the inlet of the under-floor pits and the two exhaust fans installed near ceiling of the north outside wall. No-ventilation operation (natural room temperature state) can easily be achieved by closing all the floor apertures.

MEASUREMENT CASE, ITEM AND EQUIPMENT

The purpose of commissioning at the acceptance phase is to confirm the thermal environment of occupied sections as well as the natural ventilation air volume of each aperture in the gymnasium and the supply air temperature of floor apertures. For that reason, measurement of various sample cases for the three operation states were planned, as shown in Table 3. When commissioning is performed, it is very important to predetermine the commissioning items and the measurement points. For a general natural ventilation system, it is sufficient to measure indoor vertical temperatures and the distribution and natural ventilation air volume of each aperture in the room, but when a coupled earth tube with natural ventilation system is under consideration, it is also necessary to measure the air temperature and humidity at the inlet and outlet of earth tube, as well as the airflow volume from the floor apertures, because the air temperature of the floor apertures is higher in winter and lower in summer than the outdoor temperature. The measurement items and equipment are shown in Table 4. The position of each measurement point is shown in Figures 1 and 2 a).

Table 1: Outline of the building

Usage	Elementary school gymnasium
Location	Toyama Province, Japan
Construction	Reinforced Concrete, 4 floors above ground
Floor height	14 [m]
Floor area of gym	840 [m^2]

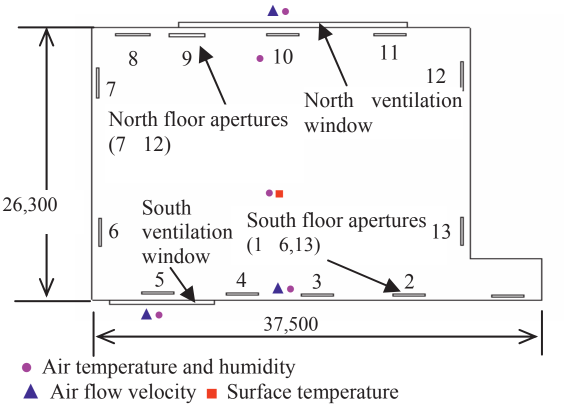


Figure 1: Floor aperture and measurement points

Table 3: Measurement Case

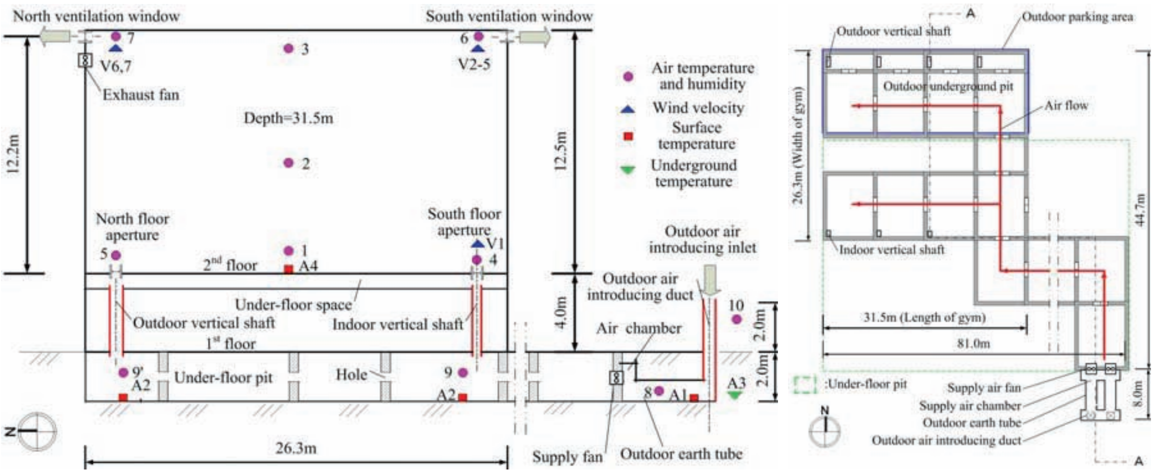
	Measurement date	Case	Floor aperture
Case1	11:00-15:00 on Feb. 3	No ventilation	Close
Case2	From 16:00 on Feb. 4 to 13:00 on Feb. 5	Natural ventilation	Open

Table 2: Outline of the coupled earth with natural ventilation system

Height and rotation angle of south and north ventilation windows [m]	12.2 45°
Area of south and north ventilation window [m^2]	6.76 12.79
Total effective area of the floor aperture [m^2]	1.43
Total length of the outdoor earth tube and the under-floor pits [m]	130.0
Cross-sectional area of outdoor earth tube and the under-floor pits [m^2]	2.25 14.4
Cross-sectional area [m^2] and height [m] of indoor south vertical shaft	1.47 4.0
Cross-sectional area [m^2] and height [m] of outdoor north vertical shaft	1.84 4.0
Height [m] and area of outdoor air introducing inlet [m^2]	4.0 2.25
Cross-sectional area of hole in the under-floor pits [m^2	0.28×3
Rated air volume [m^3] and power [W] of the supply fan	3,600 198
Rated air volume [m^3] and power [W] of the exhaust fan	5,800 390

Table 4: Measurement items and equipment

Measurement items	Measurement position	Measurement equipment
Vertical air temperature and humidity in the gymnasium	Center of indoor gymnasium (3 points)	Thermo recorder
Air temperature and humidity of the floor aperture	Number 3, 10 floor aperture (2 points)	Thermo recorder
Air temperature and humidity of south and north ventilation window	South and north ventilation windows (2 points)	Thermo recorder
Air temperature and humidity of outdoor earth tube or under-floor pits	Inlet of outdoor earth tube and outlet of under-floor pits (2 points)	Thermo recorder
Inside surface temperature outdoor earth tube or under-floor pits	Inlet of outdoor earth tube and outlet of under-floor pits (2 points)	Thermography
Outdoor air temperature and humidity	Outdoor Floor + 1.5 m (1 point)	Thermo recorder
Soil temperature	Outdoor underground 2.0 m (1 point)	Thermocouple
Floor surface temperature	Center in 2nd Floor of the gymnasium (1 point)	Thermo recorder
Airflow velocity of floor aperture	Number 3 floor aperture (1 point)	Climomaster (single channel)
Airflow velocity of south window	South ventilation window (4 points)	Anemometer (multi channel)
Airflow velocity of north window	North ventilation window (2 points)	Anemometer (multi channel)



a) Image figure of A-A section   b) Plane figure of under-floor pits

Figure 2: Imagine figures of the coupled earth tube and natural ventilation system and measurement points

MEASUREMENT RESULTS AND ANALYSIS

Weather at the measurement period

Measurement results of the outdoor air temperature and humidity as well as the meteorological observatory data (Anonymous) of the wind velocity and direction during the measurement period are shown in Figures 3-5. The outdoor air temperature and relative humidity changed within the range of 1.5 -4.2 degrees and 80 - 90% respectively. The primary wind direction of each day was east-northeast, south, and west respectively.

Indoor vertical air temperature distribution and residential air temperature

The measurement result of the indoor vertical air temperature distribution in each case is shown in Figures 6-9 respectively. From these figures, the following findings were obtained:

1) The indoor vertical air temperature distribution of each day shows strong stratification distribution whereby the air temperature measured at 11.0 m above the 2nd floor rises rapidly. The high air temperature measured at a point 11.0 m above the 2nd floor originates in lighting heat and has the effect of increasing the driving force of buoyancy ventilation.

2) The air temperature of the occupied section rises during the no ventilation state.

3) The air temperature of the occupied section decreased from 6.3 degrees at 16:30 to 5.8 degrees at 17:30 on February 4. According to Figure 4, the wind velocity changed in the range of 3.8 - 2.2 m/s and the outdoor air temperature gradually decreased from 3.8 to 2.2 degrees. If the open/close state of natural ventilation windows could be controlled by the outdoor air conditions, it would be inadvisable to adopt natural ventilation when the wind velocity is higher than 2.2 m/s and the outdoor air temperature is lower than 3.8 degrees.

4) Until 9:40 on February 5, even though the outdoor air temperature was about 2.5 degrees, and lower than the previous day, the air temperature of the occupied section descended from 5.1 to 4.5 degrees because the wind velocity was about 1.8 m/s, which is lower than that of the previous day. Afterwards, even though the outdoor air temperature descended to 1.5 degrees, the air temperature of the occupied section rose to 5.1 degrees because the wind velocity decreased gradually to 1.0 m/s at 13:00. In other words, if the open/close state of natural ventilation windows could be controlled by the outdoor air conditions, it would be advisable to adopt the natural ventilation state when the wind velocity is lower than 1.8 m/s, even if the outdoor air temperature decreases to 1.5 degree.

Natural ventilation air volume and direction at each aperture

The measurement results of the natural ventilation air volume of each aperture in the room, and the air temperature of the south/north ventilation windows on February 4 and 5 are shown in Figures 10-13. From these figures, the following findings were obtained:

1) Air flowed in from the south ventilation windows and flowed out through the north ventilation windows because the south ventilation windows were in the windward side on February 4, and after 10:35 on February 5. Therefore, the air temperature in the south ventilation windows is lower than that in the north ventilation window. For the same reason, the airflow direction of the south/north ventilation windows changed to the opposite direction during the period before 10:35 on February 5.

2) The air volume flowing into the room after 16:30 on February 4 was larger than that measured after 10:35 on February 5. According to Figure 4 and Figure 5, the following three finding were obtained: a) The outdoor air temperature on February 4 was about 1 degree higher than the one recorded after 10:35 on February 5; b) The main wind direction at about 17:00 on February 4 was northerly. There was no wind blowing to the south ventilation windows

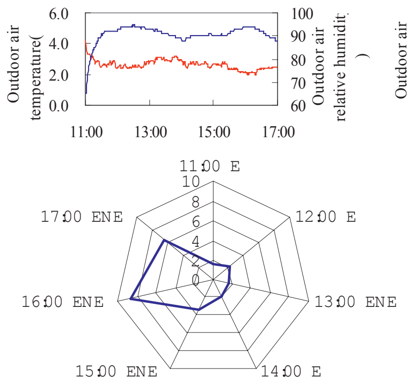


Figure 3: Outdoor air temperature/humidity and wind velocity/direction(Feb. 3)

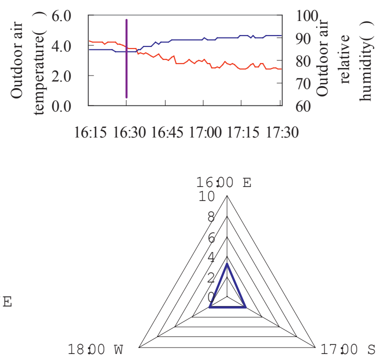


Figure 4: Outdoor air temperature/humidity and wind velocity/direction(Feb. 4)

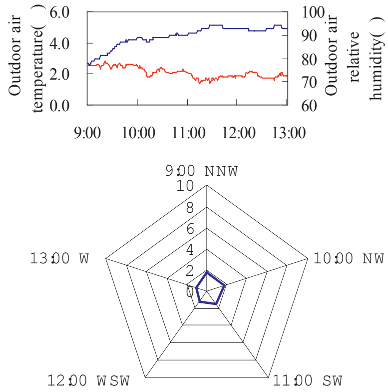


Figure 5: Outdoor air temperature/humidity and wind velocity/direction(Feb. 5)

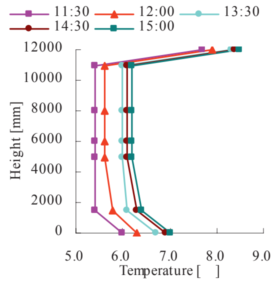


Figure 6: No ventilation

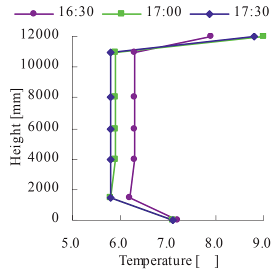


Figure 7:Natural ventilation(wind velocity 2.5m/s)

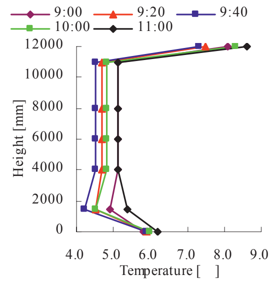


Figure 8:Natural ventilation(wind velocity 1.2m/s)

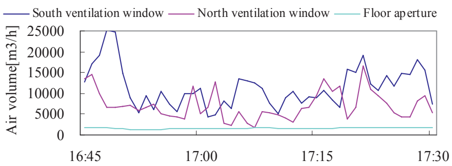


Figure 9: Airflow volume of each aperture (Feb. 4)

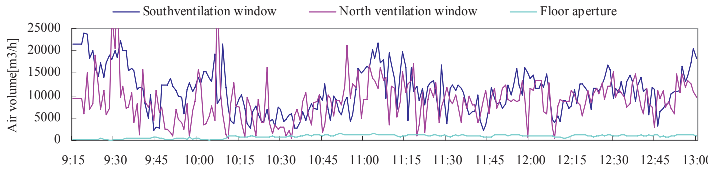


Figure 10: Airflow volume of each aperture (Feb. 5)

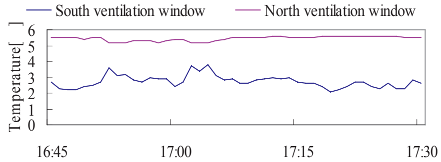


Figure 11: Air temperature in ventilation window (Feb. 4)

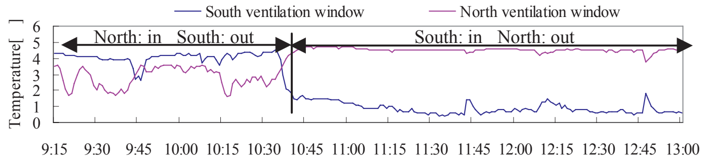


Figure 12: Air temperature of ventilation window (Feb. 5)

directly after 10:35 on February 5, because the primary wind direction changed from southwest to west; c) The wind velocity on February 4 changed in the range of 2.2 - 3.8 m/s and was about twice as high as the one recorded on February 5. In other words, the wind force ventilation on February 4 was higher than the one measured after 10:35 on February 5, while the buoyancy force ventilation on February 4 was smaller. Due to the multiplying effect of the two types of natural ventilation driving force, the driving force measured on February 4 was bigger than the one measured after 10:35 on February 5 and, as a result, the natural ventilation air volume on February 4 was larger.

3) The airflow volume from floor aperture at the two period mentioned above was only about 14% and 12% of the airflow volume from the south ventilation window. Therefore, the influence of the quantity of heat gain from earth tube on the indoor thermal environment was small.

Supply air temperature and volume of south and north floor aperture

The measurement result of the air temperature, airflow volume of south/north floor apertures and outdoor air temperature during the natural ventilation state (16:15 and 16:59 on February 4) is shown in Table 4. From this information, the following findings are obtained:

1) The natural ventilation airflow volume of floor apertures in 16:15 is about 2 times in 16:59. The reason is considered as the following. a) Because the outdoor air temperature of the former is higher than that of the latter, the driving force of buoyancy ventilation of the former resulting from the air temperature difference between outside and inside of the room is smaller than that of the latter. b)

Although the wind velocity of the former is bigger than that of the latter, wind of the latter flows straight to the natural ventilation windows. In other words, the driving force of wind ventilation of the former is smaller than that of the latter.

2) The average air temperature from the north floor apertures was 3.0 degrees lower than one of south floor apertures. The reason for that is because the airflow from the north aperture passed through the pits under an outdoor parking area and an outdoor vertical shaft which are not insulated. In other words, after being warmed by the under-floor pits in the building, the airflow from the north apertures were then cooled by the outdoor underground pits and the outdoor vertical shafts.

COMMISSIONING OF SYSTEM USING CFD COUPLED ANALYSIS METHOD

Case Analysis

To perform commissioning using simulation, it is necessary to verify the reproducibility of the CFD calculation model and the CFD coupled analysis method. Two cases (Case 1: no ventilation state. Case 2: natural ventilation state.) were calculated. Through a comparison of the calculation value and measurement data of the indoor vertical air temperature distribution and the airflow volume of each aperture in the room, the reproducibility of the coupled CFD analysis model was verified. By the use of the verified CFD analysis model, Case 2-2 and Case 2-3 were analyzed to verify the effectiveness of the two solution methods for the fault pertaining to lower air temperature from the north side floor apertures in winter, while Case 3 - Case 5 were performed to predict the indoor thermal environment and natural ventilation air volume of peak load period in winter, summer and for an intermediate season during no-wind conditions.

Calculation conditions

Internal heat generation rates, the overall heat transfer coefficients and the outer surface temperature of each wall are shown in Table 7. The CFD model of each aperture in the room and that of the exhaust fans is shown in Table 8. Effects of solar radiation were disregarded since the weather consisted of clouds, rain, and snow during the measurement period. As there were only 2 or 3 persons in the room, illumination heat, which was 21 kW, was set as the internal heat generation rate. A three-dimensional computational fluid analysis program based on the standard k-ε model was used for the CFD, with which the solution with a comparatively coarse grid could be obtained (Kato, 1997, 1998). The main analysis conditions related to the convergence of the CFD were set as the following: mesh number was 57 (x) × 30 (y) × 20 (z) in an unequal interval, the convergence criterion for the simultaneous linear equations was 0.01, and the convergence criterion for the pressure correction was 1.0E-4.

Repeatability of the CFD coupled analysis with natural ventilation method

The comparison of the measurement and calculation value of the indoor vertical air temperature distribution in Case 1-2 is shown in Table 8 and Figure 13-14. The comparison of the measurement and calculation values of the natural ventilation air volume for each aperture in the room is shown in Table 9. From these tables and figures, it was determined that the biggest air temperature error occurring between the measurement and calculation value was lower than 0.7 degrees, except for the data collected at 12.0 m above the 2nd Floor. From Table 9, it was determined that the error between the measurement and calculation value of the airflow volume in the south /north ventilation windows and south/north floor apertures was as small as 9.9%, 7.8%, -6.5%, and -6.4% respectively. In other words, the repeatability of the CFD coupled analysis method was sufficiently high that it can be used to predict the indoor vertical air temperature distribution and airflow volume of each aperture in the room.

Effectiveness of the two solution methods

To verify the effectiveness of the two solution methods used for the design fault mentioned above, the reason why the air temperature from the north floor apertures was lower than one from south floor aperture, based on CFD model of Case 3, Case 3-2 and Case 3-3 were calculated. In Case3-2, the air temperature of the north and south sides were both set at 8.2 degrees. In Case 3-3, only the seven apertures of south side were open and the air temperature for those was set at 8.2 degrees. The calculation conditions and results are shown in Table 11-12 and Figure 17. From these figures and tables, it was determined that the air temperature in the occupied section would only increase by 0.1-0.2 degree using the two solution methods. After taking into consideration the cost of insulation of the outdoor underground pits and the outdoor vertical shaft, it was determined that it would be more advisable to operate the system as it currently exists.

Prediction of thermal environment and natural ventilation air volume during three outdoor air conditions

The comparison of the indoor vertical air temperature distribution of Case 2 (outdoor air temperature is 2.9 degrees, wind velocity is 2.1 m/s, natural ventilation state) and Case 3 (outdoor air temperature is -1.2 degrees, no-wind, natural ventilation state) is shown in Figure 18. A comparison of the indoor vertical air temperature distribution of Case 4(outdoor air temperature is 34.9 degrees, no-wind, natural ventilation state) and Case 5 (outdoor air temperature is 27.8 degrees, no-wind, natural ventilation) is shown in Figure 19.The natural ventilation air volume and air temperature of each aperture in the room of the four cases are shown in Table 12. From these tables and figures, the following findings were obtained.

Table 5: supply air temperature and volume of each floor aperture during natural ventilation

	16:15 on Feb. 4 (Outdoor air temperature =4.4 C, East wind, 3.0m/s)		16:59 on Feb. 4 (Outdoor air temperature =2.9 C, North wind, 2.1m/s)	
	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]
South floor aperture	8.2	290	8.2	496
North floor aperture	5.1	603	4.6	1,033
	6.78(Average)	893(Total)	6.40(Average)	1,529(Total)

Table 6: Heat transfer coefficient and outside surface temperature of each wall

		Outside wall	Inside wall	Window	Floor	Roof
Heat transfer coefficient [W/m^2 K]		0.13	3.8	1.7	3.0	0.4
Outer surface temperature [C]	No ventilation (Winter)	2.5	4.3	2.5	7.8	2.5
	Natural ventilation (Winter, South wind)	2.9	4.4	2.9	8.2	2.9
	Natural ventilation (Winter, peak load)	-1.2	2.4	-1.2	8.2	-1.2
	Natural ventilation (Summer, peak load)	34.9	31.5	34.9	31.5	45.0
	Natural ventilation (Intermediate season)	27.8	27.8	27.8	25.8	35.0

Table 7: CFD simulation model of each aperture in the coupled earth tube and natural ventilation system

	Effective area [mm×mm]	Number	Position	Air flow direction
Floor aperture	1,960 × 56	13	2nd Floor	Up (out)
South ventilation window	10,906 × 43.8	1	11.9 m above the 2nd floor	Horizontal (out/in)
North ventilation window	6,875 × 43.8	3	11.9 m above the 2nd floor	Horizontal (out/in)

Table 8: Comparison of vertical air temperature [C] of measurement and simulation value of each case

	2nd floor	2nd floor +1.5 m	2nd floor +4.9 m	2nd floor +6.0 m	2nd floor +8.0 m	2nd floor +10.0 m	2nd floor +12.0 m
No ventilation (measurement)	7.0	6.3	5.8				
No ventilation (calculation)		5.6	5.7	5.8	5.9	6.4	23.1
Natural ventilation (measurement)	7.1	5.8		5.8			8.8
Natural ventilation (calculation)		6.1	6.2	6.2	6.3	6.4	6.7

Table 9: Comparison of the measurement and simulation value of case 2

	South ventilation window		North ventilation window		South floor aperture		North floor aperture		Infiltration	
	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]
Case2 (measurement)	2.9	9,894	5.3	-11,743	8.20	496	4.60	1,033	2.9	320
Case2 (calculation)	2.9	11,227	6.6	-12,659	8.20	464	4.60	968		
Error		9.9%note)		7.8%		-6.5%		-6.4%		

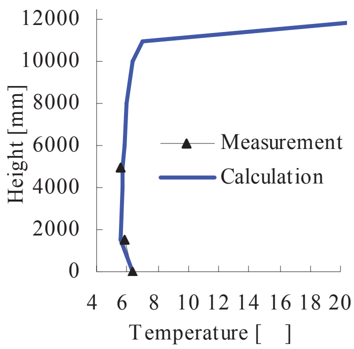
Note: Error = (measured inflow air volume of south ventilation window + predicted infiltration air volume) / calculated inflow air volume of south ventilation window*100%. [-] mean the air flowing out of the room.

Table 10: Comparison of vertical air temperature [C]of the calculated value for each case

Case	2nd floor	2nd floor +1.5 m	2nd floor +4.0 m	2nd floor +6.0 m	2nd floor +8.0 m	2nd floor +10.0 m	2nd floor +12.0 m	2nd floor +12.5 m
Case 2	7.1	6.1	6.2	6.2	6.3	6.4	6.7	9.5
Case 2-2	7.1	6.3	6.3	6.3	6.4	6.6	6.9	9.7
Case 2-3	7.1	6.2	6.3	6.3	6.4	6.5	6.8	9.5

Table 11: Calculation condition and results for each case

Case	Case 2		Case 2-2		Case 2-3	
	Temp. [C]	Vol. [m^3/h]	Temp. [C]	Vol. [m^3/h]	Temp. [C]	Vol. [m^3/h]
South ventilation window	2.9	11,227	2.9	11,227	2.9	11,228
North ventilation window	6.6	-12,659	6.7	-12,659	6.5	-12,630
South floor aperture	8.2	464	8.2	464	8.2	1,402
North floor aperture	4.6	968	8.2	968		



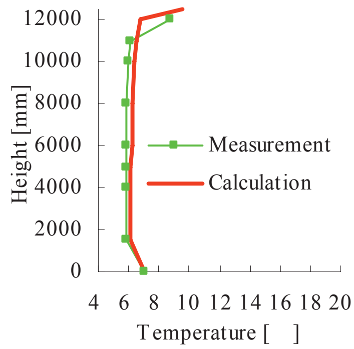


Figure 13: Repeatability of vertical air temperature(no ventilation) Figure 14: Repeatability of vertical air temperature(natural ventilation)

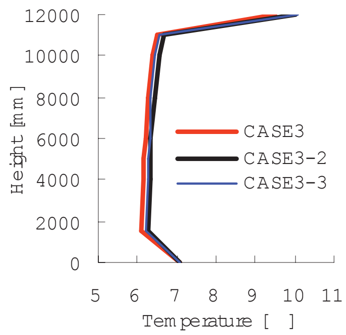


Figure 15:Vertical air temperature of three operation states in winter

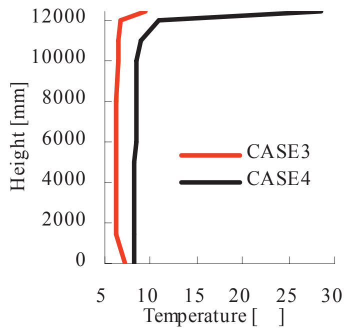


Figure 16: Vertical air temperature of two outdoor air conditions in winter

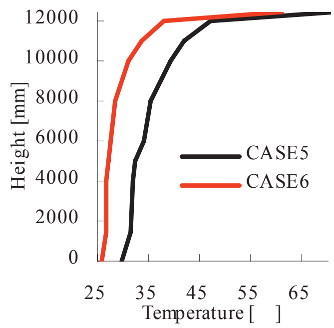


Figure 17: Vertical air temperature in summer (peak load) and intermediate season

Table 12: Comparison of air temperature and natural ventilation air volume of each aperture for several cases

	South ventilation window		North ventilation window		South floor aperture		North floor aperture	
	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]	Tem. [C]	Vol. [m^3/h]
Winter (measurement, 2.9 C, south wind)	2.9	11,227	6.6	-12,659	8.2	464	4.6	968
Winter (peak load, -1.2 C, no-wind)	17.4	-151	17.0	-1,216	8.2	443	4.6	884
Intermediate (27.8 C, no-wind)	47.8	-53	48.2	-433	25.8	158	26.8	329
Summer (peak load, 34.9 C, no-wind)	58.9	-16	59.2	-131	29.6	48	33.2	99

Note: [-] means the air flows out the room.

1) During peak load and no-wind conditions in winter, the airflow volume from the floor apertures is 1.367 m^3/h, while the air volume flowing out the room from the south and north ventilation windows is 151, 1,216 m^3/h respectively. Because the necessary air ventilation volume for sick-house measures and people in room is 1,024 m^3/h and 12,400 m^3/h (20m^3/h×620person)respectively, it is better to adopt forced ventilation at no-wind state in winter for the latter.
2) From the simulation result of Case3 (no-wind, outdoor air temperature is -1.2 C) and Case4 (south wind, wind velocity is 2.1 m/s, outdoor air temperature is 2.9 C), it is known that the natural ventilation air volume from the floor aperture of case3 in the former is only 65 m^3/h smaller than the one of case4. In other words, natural ventilation in winter is mainly driven by the indoor vertical air temperature distribution and the difference between the air temperature of outdoor and one of indoor.
3) During the no-wind condition measured in the intermediate season, the airflow volume from the floor apertures was 487 m^3/h, while the air volume flowing out from the south and north ventilation window was 53, 433 m^3/h respectively. The natural ventilation air volume is smaller than the necessary air volume for sick-house measures. Furthermore, the air temperature in the occupied portion was about 27C and 0.8C lower than the outdoor air temperature. This indicates that it is more advisable to open the north side door for ventilation than to use the earth tube.
4) During the peak load and no wind conditions in summer, the airflow volume from the floor apertures was only 147 m^3/h, while the air

volumes from the south and north ventilation windows was 16 and 131 m^3/h, respectively. The natural ventilation air volume is very smaller than the necessary air volume for people in room (12,400m^3/h). Furthermore, the air temperature is the occupied portion was about 31 C, which was 3.9 C lower than the outdoor air temperature. This indicates that it advisable to use forced ventilation to maintain the necessary ventilation air volume and the indoor thermal environment during summer weather.

CONCLUSION

In recent years, even though coupled earth tube and natural ventilation systems are often installed, there is no method and support tool reported to perform the commissioning for design and operation policy. In this paper, through measurements of the performance of an actual system in winter and the simulations based on the coupled CFD analysis method with natural ventilation calculations, the commissioning at acceptance phase was performed and the following findings were obtained.

1) To perform the commissioning of this system at acceptance phase, it was necessary to measure several items such as outdoor air temperature and humidity, wind direction and velocity of wind, soil temperature, air temperature and humidity in the earth tube, the inner surface temperature of earth tube, air temperature and airflow volume from the floor apertures and ventilation windows, floor surface temperature, as well as the indoor vertical air temperature and humidity. Because the number of apertures is large, only the most typical floor apertures were measured to decrease measurement costs. Moreover, when the area of the ventilation window is large, it is necessary to measure the surface airflow velocity using the multi-channel airflow velocity equipment in order to decrease measurement errors to the minimum level.
2) Based on the obtained measurement data, a design fault originating in the information and experience shortage during the planning and design phase could be verified. In this paper, the design fault which caused the air temperature from the north side floor apertures to be lower than those from the south side floor apertures was found.
3) By the use of the coupled CFD analysis method with natural ventilation calculation, the effectiveness of two solution methods (a. thermal insulation of the pits under outdoor parking area and the outdoor vertical shaft. b. close the north floor apertures) for the design fault was verified. From the results, it was determined that the air temperature in the occupied section would only increase by 0.1-0.2 degree. After taking into consideration the cost of insulation of the outdoor underground pits and the outdoor vertical shaft, it was determined that it would be more advisable to operate the system as it currently exists.
4) Through predicting the environmental and energy performance of the system at the outdoor conditions different with the measurement, the coupled CFD analysis method with natural ventilation calculation which is developed by authors is considered to be a useful commissioning support method.

In the future, the authors plan to measure the system performance during summer weather and then to again verify the repeatability of their new simulation model that utilizes the coupled CFD analysis method with natural ventilation calculation. This will be done to ensure that natural ventilation air volumes and indoor thermal environments can be predicted more accurately. Furthermore, to eliminate design faults caused by information and experience shortages, it is expected that the coupled CFD analysis method with natural ventilation calculation proposed by the authors will become widely used during the commissioning of coupled earth tube and natural ventilation system during the planning and design phases.

REFERENCES

Anonymous http://www.data.kishou.go.jp/etrn/index.html

Kato, S. 1997, 1998. Application to indoor atmosphere of CFD (1-7). *SHASE* 71(6-11), 72(1) (In Japanese)

Mingjie Zheng, Song Pan and Harunori Yoshida 2007. Commissioning of Annexation System of Cool Tube and Natural Ventilation (Part 1) Natural Ventilation Analytic Method Coupled with CFD. *Technical Papers of Annual Meeting, SHASE* (2007): 1909-1912 (In Japanese)

Song Pan, Mingjie Zheng and Harunori Yoshida 2007a. Commissioning of Annexation System of Cool Tube and Natural Ventilation (Part 2) Commissioning for an Actual System at the Plan/Design Phase. *Technical Papers of Annual Meeting, SHASE* (2007): 1913-1916 (In Japanese)

Song Pan, Mingjie Zheng and Harunori Yoshida 2007b. Commissioning of a Coupled Earth Tube and Natural Ventilation System at the Design Phase. *Proceeding of ICEBO'2007, San Francisco US, November 1-2*

Song Pan, Mingjie Zheng and Harunori Yoshida 2008. Commissioning of a Coupled Earth Tube and Natural Ventilation System (Part 3) Confirmation of System Performance by measurement in winter. *Technical Papers of Annual Meeting, SHASE* (2008): 1445-1448 (In Japanese)

Mingjie Zheng, Song Pan and Harunori Yoshida 2008. Commissioning of a Coupled Earth Tube and Natural Ventilation System (Part 4) Commissioning at the acceptance phase using a coupled analytical tool with natural ventilation and CFD. *Technical Papers of Annual Meeting, SHASE* (2008): 1449-1452 (In Japanese)