ANNUAL PERFORMANCE PREDICTION OF COOL AND HEAT TRENCH IN THE MEDICAL FACILITY

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Abstract - In this paper, an annual prediction method of pre-cooling and pre-heating performance for an earth-to-air heat exchanger (EAHE) by the unsteady CFD analysis which does not analyze flow fields to reduce the calculation load, are proposed, and the validity are verified of this analysis in comparison with by long-term measurements. We predict the annual thermal performance of an EAHE in a medical facility by long-term measurement results. Moreover, the prediction accuracy of this CFD analysis is verified by comparing the results of annual survey.

Keywords - Earth-to-Air heat exchanger, Long-term Measurements, CFD analysis, Calculation load reduction, Annual prediction method.

I. INTRODUCTION

In recent years, passive cooling and heating systems have been added to existing buildings, thus bringing them to the public's attention. Passive cooling and heating systems, which control or utilize natural energy sources, can contribute to the cooling and heating of a building without mechanical equipment. Cool and heat trenches, which are a type of earth-to-air heat exchanger, have often been adopted in relatively large buildings. In order to simulate the pre-cooling and pre-heating effects of outdoor air through cool and heat trench, it is necessary to conduct three-dimensional unsteady analysis of computational fluid dynamics (CFD) over long periods. However, because of the limitations of the calculation load of flow fields, annual calculation of unsteady CFD analysis is difficult by conventional computers.

In this study, we evaluate the annual thermal performance of a cool and heat trench in a medical facility by long-term measurements. Moreover, an annual prediction method of pre-cooling and pre-heating performance of a cool and heat trench by unsteady CFD analysis, which did not analyze flow fields to reduce the calculation load, was proposed [1)], and its validity was verified in comparison with long-term measurements.

II. BILDING SPECIFICATION

The target medical facility of this investigation (Table.1) is located in Kyushu, Japan. This building introduces EAHE (cool and heat trench) in order to reduce the fresh air load. In this system, outdoor air is always supplied to an outdoor air-conditioning unit through the ventilation channel (colored in black in the figure), and is then distributed to the shared area of management and logistics department. The outdoor air is usually introduced under conditions of low flow rate, but the ventilation air volume can be switched to high or low flow rate by operation of staff. As shown in Fig. 1, since the heat storage tank is located near the outlet this trench, thus introduced outdoor air is also affected by the heat loss of this storage tank.

Site	Kyushu
Construction	RC
Floor	B1-4F
Completion year	Oct.2013
Width × Height of Trench	0.95m × 3.5-4.8m
Floor space of Trench	135.8m^2
Length of Trench	113 m

Table.1 Site Overview

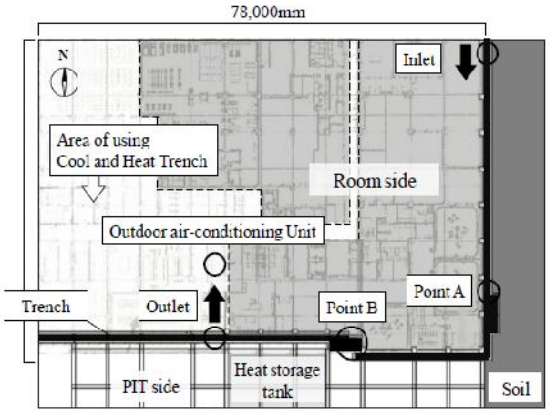

Fig. 1 Plan of Cool / Heat Trench (Black : Trench)

III. MEASUREMENT

3.1. Overview of Measurements

The measurement period was 12 months from March 1, 2015 to February 29, 2016. During this period, the outdoor air temperature and relative humidity at the inlet and outlet of this trench and an outdoor air-conditioning unit, and the surface temperature of point A and point B (Fig.1) were measured every 1hour. The flow rate of outdoor air and the water temperature in the heat storage tank were measured by BEMS (Building Energy Management System) [2)].

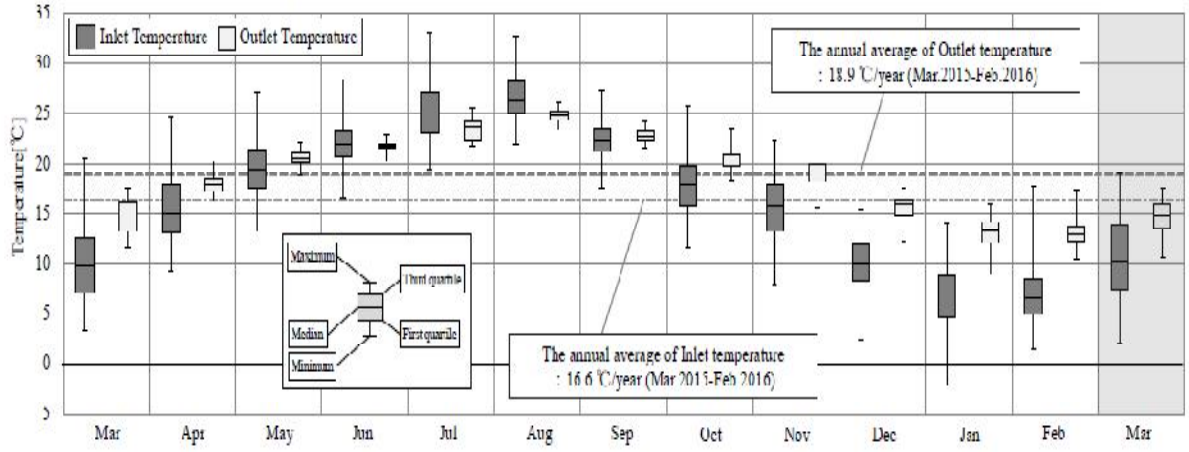

Fig.2 The inlet / outlet air temperature

3.2. Measurement Results

Fig. 2 shows box plots of the inlet / outlet air temperature of the trench in the measurement period. Compared with the inlet and outlet air temperatures, the width between first quartile and third quartile of the outlet air temperature in Fig.2 is small and the variation of the median value is also small. It was confirmed that characteristics of EAHE using ground heat storage. Moreover, compared with annual average of inlet air and outlet air temperatures, the outlet air temperature was 2.3℃ higher. Fig. 3 shows box plots of the inlet / outlet air humidity in spring and summer seasons. The first quartile of the outlet air humidity in July and August ware approximately 90%, thus it was likely that the high humidity environment frequently was occurred in a cool and heat trench. Fig. 4 shows the annual change of daily average temperature difference between the inlet and outlet air temperatures. The annual maximum pre-cooling and pre-heating effects were about 8 °C in winter and about 4 °C in summer respectively.

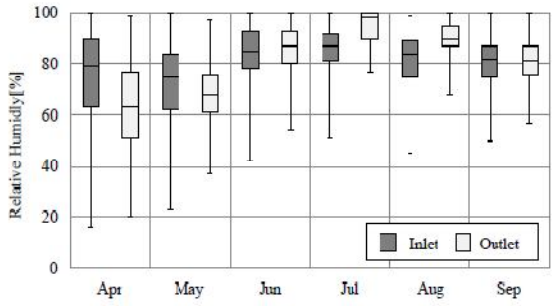

Fig.3 The inlet / outlet air humidity (spring / summer)

Also, the plots in spring season were below side of the approximate straight line due to the cooling and the plots in the autumn season were upper side of the approximate straight line due to the heating in summer. Fig. 5 shows monthly integrated heating/cooling effects. The introduction conditions of outdoor air have been changed since January 2016. Thus the monthly integrated in take amount of outdoor air (Jan.-Mar.2016) have nearly doubled, and the annual maximum values of monthly integrated heating and cooling quantity were 5.4GJ (August) and 21.8GJ (January). Moreover, the sensible heat load of outdoor air-conditioning units was reduced by 48.4% and 44.5% in summer and winter respectively, and the annual reduction ratio of sensible heat load was about 45.3% (Fig. 6).

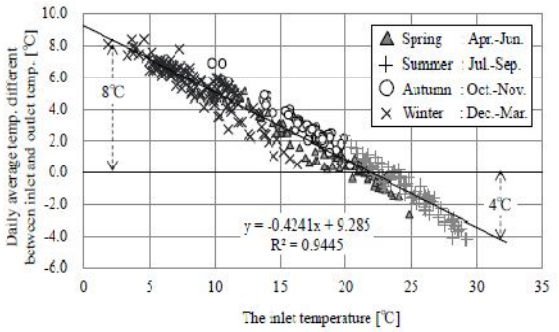

Fig.4 Annual change of daily average temp. difference between the inlet and outlet air temp

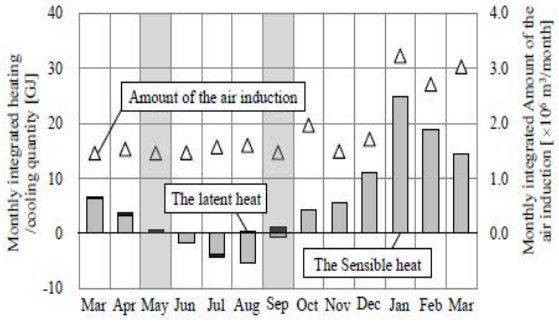

Fig.5 Monthly integrated heating/cooling effects

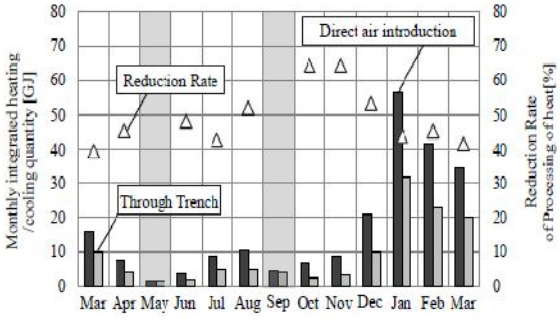

Fig.6 The reduction ratio of sensible heat load

IV. PROPOSED METHOD

Proposed method is obtained flow fields simulated in advance, and loading these flow fields according to the analysis procedure shown in Fig. 8 (a) (uncoupled simulation). Thus, this method linearizing the energy transport equation, and reduces the calculation load for CFD analysis. The following effects are expected by using the proposed uncoupled simulation:

1. The conventional method (full coupled simulation) solves equations for continuity, momentum, energy, turbulence energy (TE), and dissipation of TE rate for every time step (Fig. 7 (b)). However, uncoupled simulation solves only energy equation by using flow fields simulated in advance.
2. Wind velocity (U, V, W), TE, and dissipation rate of TE were treated as constant in the uncoupled simulation. Thus, the energy equation is linearized, and this linearization improves the convergence and enables expansion of time intervals comparison with the full coupled simulation.

V. OUTLINE AND RESULTS OF ONE－DIMENSIONAL HEAT CONDUCTON ANALYSIS

Underground temperature distributions were calculated using STREAM, which is structured grid CFD software. The results are not shown here, but at about 8 m or deeper, the temperature converges to about 16.6 °C, agreeing with annual average value of outdoor temperature in this area.

VI. ESTIMATION OF THE ANNUAL COOLING/HEATING EFFECTS

6.1. Overview of CFD Analysis

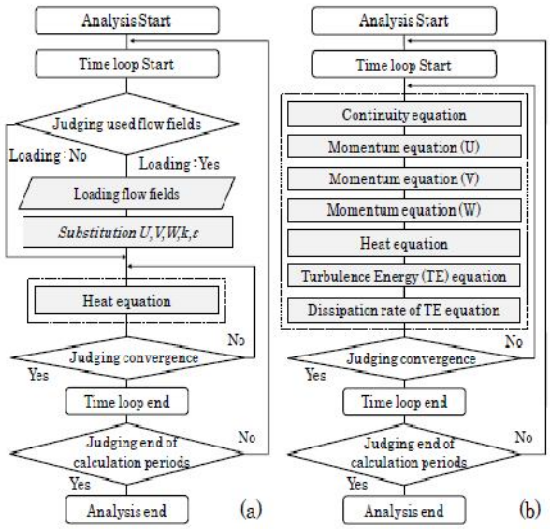

Fig.7 Analysis flow
(a) Uncoupled simulation, (b) Full coupled simulation

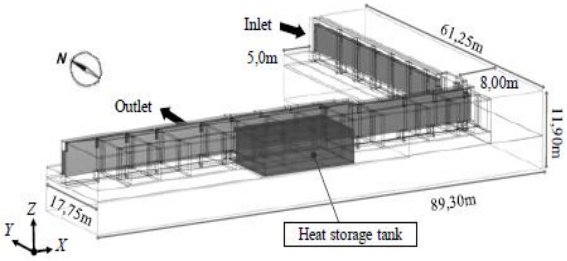

Fig.8 Analysis model of the system

		The pre CFD analysis	The uncoupled CFD analysis (unsteady state)
Calculation period		Analysis Steady state	Annual Analysis : March 1, 2015 to February 28, 2016
Time interval		Analysis Steady state	3,600 s (When switching flow field: 10 s ~)
Domain		89.30m（X）×61.25m（Y）× 11.90m（Z）	
Mesh		288（X）× 228（Y）× 81（Z）= 5,318,784	
Turbulence model		Low Re-type k-ε model (Abe-Nagano-Kondo model)	
Scheme for advection term		Temperature: QUICK	
Initial temperature of underground and air tunnel and		Results of the one-dimensional heat conduction analysis	
Boundary conditions	Inlet of air tunnel	*Tin*: Measurement results [°C], *Uin* :BEMS[m^3/h], $k_{in}=3/2(U_{in}\times0.05)^2$, $\varepsilon_{in}=C\mu^{3/4}\cdot k_{in}^{3/2}/l_{in}$	
	Outlet of air tunnel	Free slip	
	Wall in air tunnel	Velocity and Temperature : Analytical wall function (AWF)	
	Ground surface	Temperature : Sol air temperature[3], Convective heat transfer coefficient : 17.9W/(m^2·K)	
	Heat storage tank boundary	Temperature : BEMS, Convective heat transfer coefficient : 100W/m^2K	
	Room side boundary	Temperature : BEMS, Overall heat transfer coefficient : 9 W/m^2K	
	Upper side of air tunnel	Adiabatic	
Convergence condition		Temperature transport equation and Pressure correction equation: 1×10^{-4} Momentum, k and ε transport equation: 1×10^{-6}	

U_{in}: Inlet wind speed (m/s), ℓ_{in}: Length scale (=1.2) [m], k_{in} : Inlet turbulence energy (m^2/s^2), ε_{in} : Dissipation rate of k_{in} (m^2/s^3), C_μ : Model constant (=0.09) [-]

Table.2 Analysis conditions for CFD Analysis

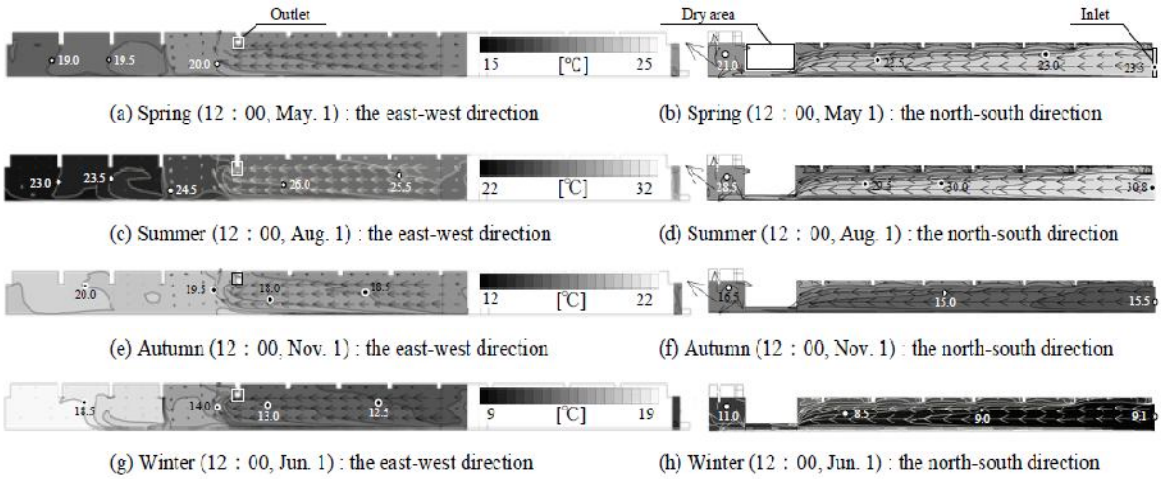

Fig. 9 Air temperature and flow fields of the vertical surface

The pre CFD analysis and uncoupled CFD analysis conditions are listed in Table 2, and the analysis model of the cool and heat trench is shown in Fig. 8. Total of 23 types of flow rate of outdoor air (300 to 8,400 m3 / h) were selected by the measured data (Fig.10), and corresponding flow fields were obtained acquired by the pre CFD analysis. This analysis was conducted as isothermal steady state. The approaching period of CFD analysis was 1 year (from March 1, 2015 to February 28, 2016). The initial temperature distribution of underground and cool and heat trench elements were set based on the results of the one-dimensional heat conduction analysis at 0:00 on March 1. Interval time of this analysis was 3,600s. The flow rate of outdoor air and the inlet air temperature were scheduled based on BEMS and measured data.

6.2. Results of the Annual Cooling/Heating Effects

Fig. 9 shows Air temperature and flow fields of the vertical surface in the east-west direction and the north-south direction (center of the passageway respectively) at the representative date (12:00) for each season. The introduced of outdoor air was gradually pre-cooled or pre-heated, and then sucked into the outlet.

6.3. Prediction accuracy verification of proposed method

Fig.11 shows the outlet air temperature of analysis and measurements. The prediction accuracy of the proposed method was verified by comparing the results with long-term measurements. RMSE (Root Mean Square Error) was 0.84□ in the measured period, thus it was confirmed that the proposed method had high prediction accuracy. Fig. 12 shows monthly integrated heating / cooling effects of analysis and measurements (Sensible heat). The error of annual integrated heating / cooling effects was about 1%, thus it was confirmed that the proposed method had high prediction accuracy. The required time for the annual prediction by full coupled simulation was estimated to be about 3 years and 6 months. However, the calculation time of the uncoupled simulation was 48 h 7 min. Thus, proposed method that reduces the calculation load for CFD analysis had high prediction accuracy and the calculation time was greatly reduced.

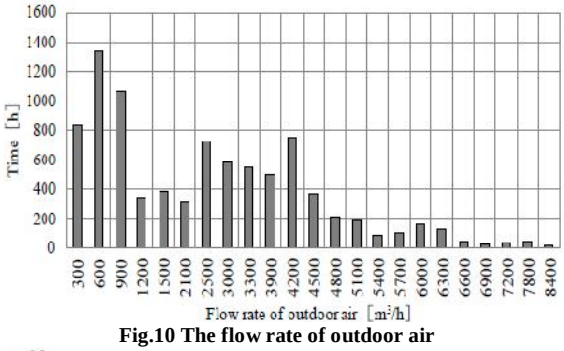

Fig.10 The flow rate of outdoor air

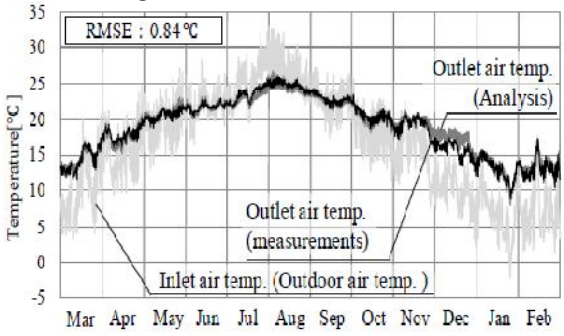

Fig.11 The outlet air temperature of analysis and measurements

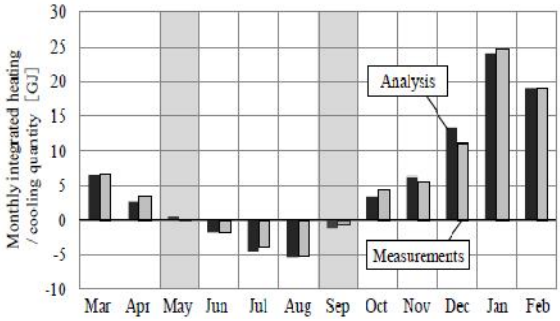

Fig.12 Monthly integrated heating / cooling effects of analysis and measurements (Sensible heat)

CONCLUSIONS

The following results were obtained:

1. It was likely that the high humidity environment frequently was occurred in a cool and heat trench.
2. The annual maximum values of monthly integrated heating and cooling quantity were 5.4GJ (August) and 21.8GJ (January).
3. The sensible heat load of outdoor air-conditioning units was reduced by 48.4% and 44.5% in summer and winter respectively, and the annual reduction ratio of sensible heat load was about 45.3%.
4. The prediction accuracy of the proposed method was verified by comparing the results with the long-term measurements. RMSE (Root Mean Square Error) was 0.84℃ in the measured period, thus it was confirmed that the proposed method had high prediction accuracy.
5. The required time for the annual prediction by full coupled simulation was estimated to be about 3 years and 6 months. However, the calculation time of the uncoupled simulation was 48 h 7 min.

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