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Energy consumption for a real ETC based on Energyplus simulation with experimental verification

Yukun Xu, Xin Wang, Fei Wang, Shuren Shen and Zhuo Zhu

School of Environment and Architecture, University of Shanghai for Science and Technology, Shanghai 200093, China

usstwangxinshiyun@163.com

Abstract. Energy consumption simulation is widely used to analyse dynamic energy consumption in large spaces. In this paper, a real Engineering Training Centre (ETC) in Shanghai was taken as the research object, and its energy simulation models were established by EnergyPlus. The zone division was combined with Room Air to investigate the rational forms of the ETC models. The results showed that the simulated values of the hourly air temperature and the hourly cooling (heating) load using Room Air were more close to the measured values, and the different zone division had different simulation advantages for summer and winter cases. Therefore, the modelling ideas for dealing with energy simulation in large spaces in different seasons were provided.

1. Introduction

With the development of computer electronics technology, various energy simulation software emerged as the times require, and it has matured over the years. The widely used energy simulation software in the market includes: DOE-2, EnergyPlus, TRNSYS and DeST [1].

In recent years, in the field of energy consumption analysis for large spaces, dynamic energy consumption analysis method is widely used. Mambo [2] established the energy simulation model of airport terminal building and used occupancy-driven supervisory control strategies to minimize energy consumption. Zhai [3] briefly outlined a coupled energy simulation and computational fluid dynamics program with different coupling methods, and then used this program to calculate the cooling load of a large-scale indoor auto-racing complex. Pan [4] combined CFD with EnergyPlus to propose appropriate methods of simulating different types of atrium buildings. Peter [5] verified the rationality of EnergyPlus in predicting light power and reheat coil power through experiments.



However, a question still remains how to accurately describe the vertical temperature distribution, which is essential and urgent for energy simulation. Therefore, this paper took a real Engineering Training Center as the research object, and its energy simulation models were established by EnergyPlus. The measured data of the typical cases in summer and winter were compared with the simulated data to illustrate the accuracy of the established models.

2. Building and experimental method

The main research object of this paper is the air-conditioned area, as shown in figure 1. The ETC covers an area of about 500 m². The maximum height is at the top of the double-slope roof, 12 m from the floor. The ETC uses a composite dual-source heat pump equipped an air source heat pump and a ground source heat pump, which can be operated separately or in combination. The specific unit type and detailed equipment parameters are shown in table 1. The positions of nozzle air supply are installed at 5.5 m with the same diameter of 373 mm. The side wall of the engine room is provided with a return air outlet with a size of 3 m × 2 m. The electric control system of the air-conditioning system adopts automatic variable frequency control, and combines with the touch screen display to realize convenient man-machine operation.

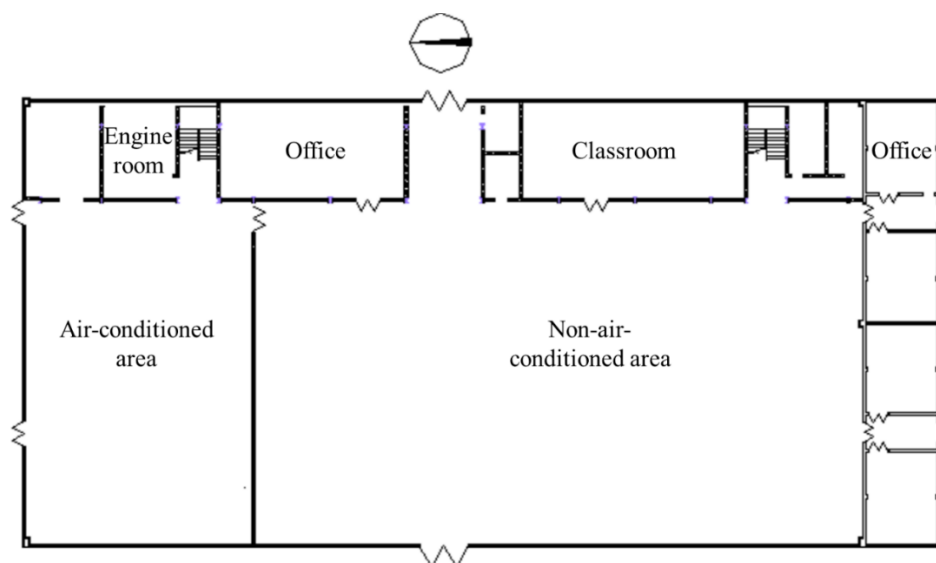


Figure 1. Plan view of engineering training center.

Table 1. Water system equipment list.

Name	Type	Parameters
Ground source heat pump	WGZ-030-BM-SR	Rated cooling / heating capacity: 103 kW / 118 kW
Air source heat pump	MAC-100-DR	Rated cooling / heating capacity: 29.8 kW / 30 kW
Chilled / cooling water pump	KQL 80/285-3/4	Head / flow volume: 20.6 m / 24.3 m ³ /h

This experiment focused on four typical cases (two-purpose and two-standby) in summer and winter. The main parameters are shown in table 2. Data collection time is from 10:00 to 16:30. Indoor environmental parameters and unit performance parameters are recorded every 30 minutes.

Table 2. Typical cases in summer and winter.

Case	Test date	Outdoor average temperature/ °C	Total air volume/ m ³ /h	Indoor heat source/ kW	Supply air temperature/ °C
1	2017/7/19	35.9	18356	12	16.5
2	2017/7/20	32.8	21543	12	17.7
3	2018/1/16	7.7	25204	0	30.1
4	2018/1/20	13.4	25324	0	30.6

3. EnergyPlus simulation

The specific settings of the EnergyPlus models are based on the geometric models. Since the research object of this paper was a large space, the building was divided into an air-conditioned area and a non-air-conditioned area according to the air supply height during load calculation. Therefore, for zone division, this paper took two forms, as shown in figure 2.

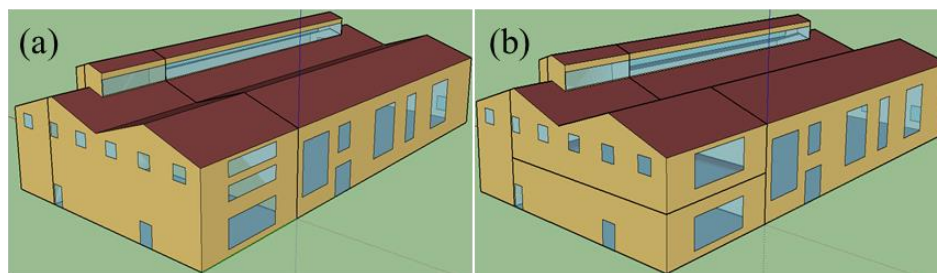


Figure 2. Different hot zone division: (a) Single Zone; (b) Double Zone.

The meteorological parameters and interior design parameters were obtained through experimental measurement. The envelope parameters were also obtained through experimental measurement, as shown in table 3. The heat dissipation of personnel activities, lighting, and equipment inside the building could be set separately through People, Light and Equipment modules in EnergyPlus.

Table 3. Envelope parameters in ETC.

Envelope	Roof	Exterior wall	Exterior window	Door	Interior wall
Heat transfer coefficient/ W/m ² ·°C	0.91	2.05	6.38	5.94	1.66

In conventional arithmetic processing, EnergyPlus follows the principle of using a single indoor air state to characterize the thermal environment in a single zone. However, for the unique features of large spaces, EnergyPlus provides Room Air (*Room Air: Temperature Pattern: Nondimensional height*) to describe the air temperature stratification. This mode describes the temperature distribution in the vertical direction of the building by setting the nondimensional height and the corresponding air temperature. The dimensional height is defined as equation (1):

$$z_i = (z_{i, cenrriod} - z_{floorAvg})(CeilingHeight)^{-1} \quad (1)$$

where z_i is the dimensional height of the location of the measurement point, $z_{i,centroid}$ is the actual height of the location of the measurement point, $z_{floor,Avg}$ is the average height of the floor, and $CeilingHeight$ is the net height of the roof from the floor.

EnergyPlus offers Zone Mixing to streamline the process of air exchange between adjacent zones, balancing the energy of the pool zone but not the source zone. EnergyPlus provides a basic solution to infrared radiation heat exchange between the surfaces of different temperatures by Infrared Radiation Transfer (IRT) materials. It should be noted that the IRT surface does not participate in heat exchange between adjacent zones, so the convective heat transfer coefficient of these surfaces needs to be specially set to minimize this effect.

4. Results

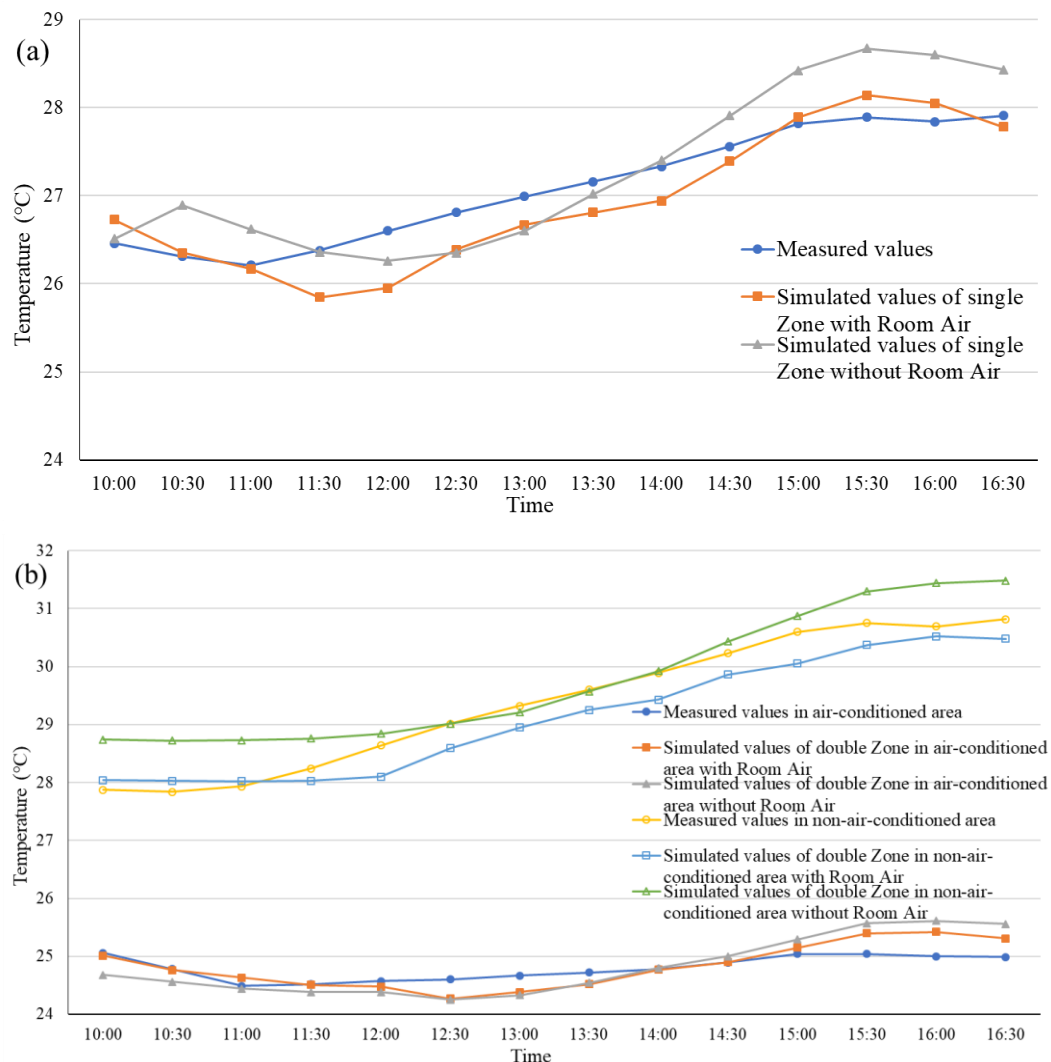


Figure 3. The effect of Room Air on hourly air temperature in typical summer cases for: (a) Single Zone; (b) Double Zone.

Figure 3 depicts the effect of Room Air on hourly air temperature in single Zone and double Zone models in Case 1 (in summer). In general, the simulated values of hourly air temperature in both modeling modes showed the same trend as the measured values. Figure 3(a) showed the case of single

Zone with an average measured hourly air temperature of 27.1 °C. In the simulation model using Room Air, the maximum error between the simulated and the measured values was 0.6 °C, while without Room Air the maximum error was 0.8 °C. Figure 3(b) showed the case of double Zone. The average measured air temperature in the air-conditioned area and non-air-conditioned area was 24.8 °C and 29.4 °C, respectively. In the simulation model using Room Air, the maximum errors between the simulated and the measured values in the air-conditioned area and non-air-conditioned area were 0.4 °C and 0.5 °C, respectively, while without Room Air the maximum errors were 0.6 °C and 0.8 °C, respectively.

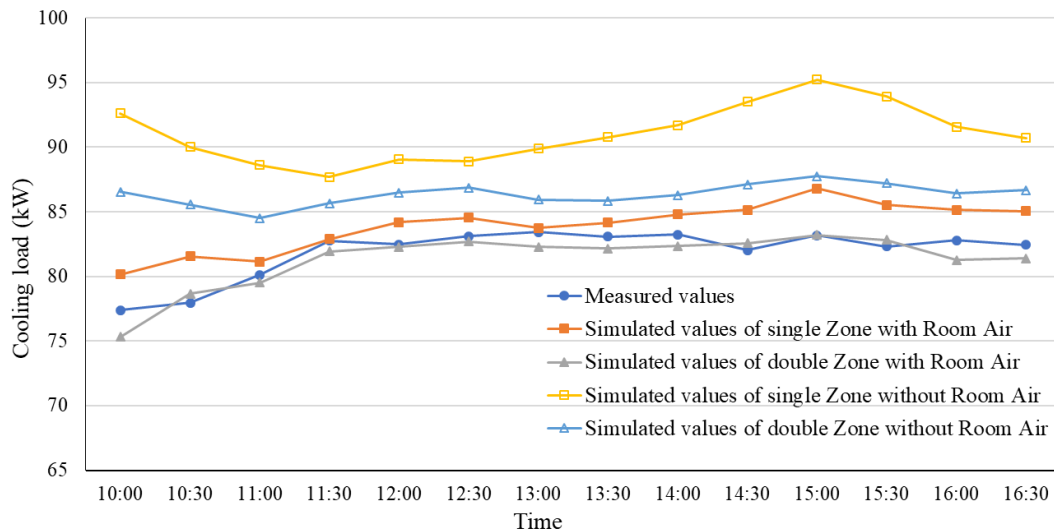


Figure 4. The effect of Room Air on indoor cooling load in typical summer cases.

Figure 4 depicts the effect of Room Air on cooling load in single Zone and double Zone models in Case 1 (in summer). The measured indoor cooling load peak value was 83.17 kW. In the simulation model using Room Air, the maximum errors between the simulated and the measured values in single Zone and double Zone were 4.35% and -2.67%, respectively, while without Room Air the maximum errors were 14.47% and 6.2%, respectively.

According to the simulation of the summer cases, the simulated value for cooling load using Room Air was closer to the measured value. Considering the model without Room Air, the cooling load simulation results in the double Zone model were superior to that in the single Zone model which was not considering temperature stratification.

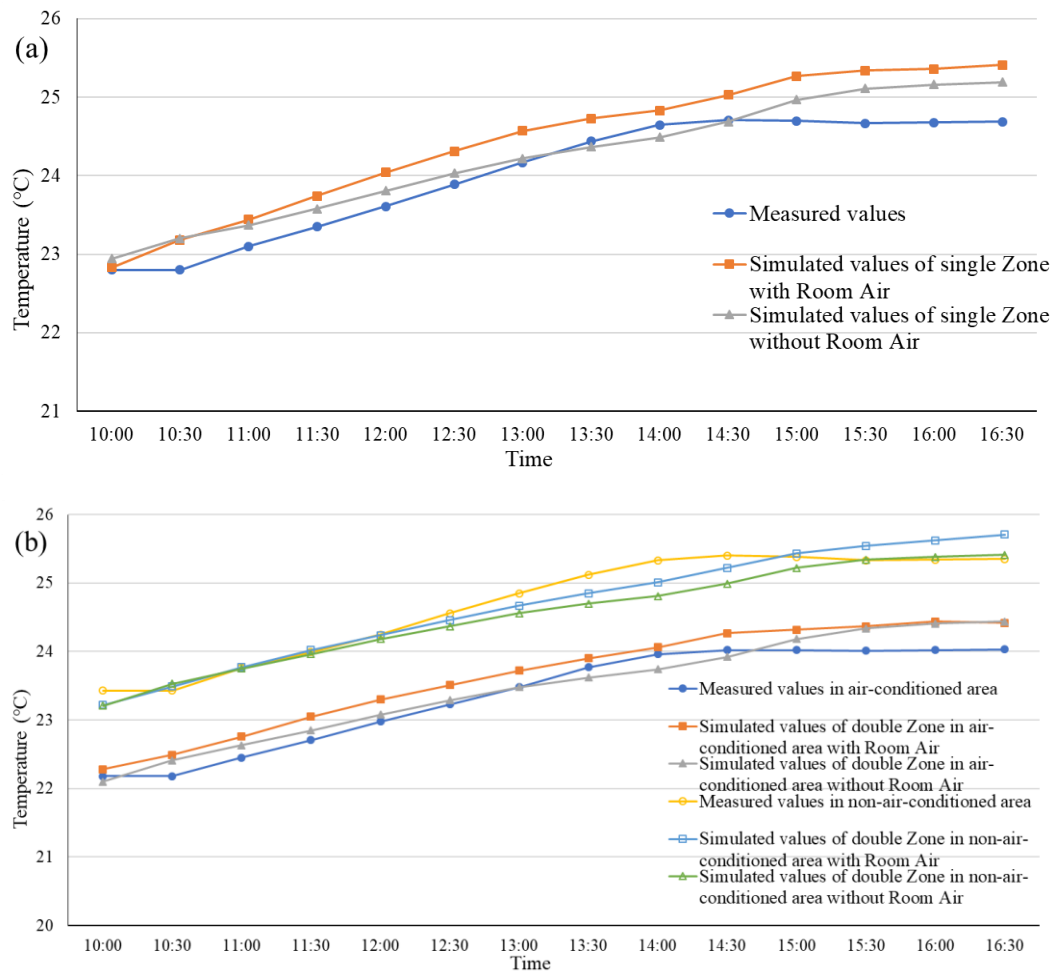


Figure 5. The effect of Room Air on hourly air temperature in typical winter cases for: (a) Single Zone; (b) Double Zone.

Figure 5 depicts the effect of Room Air on hourly air temperature in single Zone and double Zone models in Case 3 (in winter). Similar to the summer cases, the simulated values in both modeling modes showed the same trend as the measured values. Figure 5(a) showed the case of single Zone with an average measured air temperature of 24 °C. In the simulation model using Room Air, the maximum error between the simulated and the measured values was 0.7 °C, while without Room Air the maximum error was 0.5 °C. Figure 5(b) showed the case of double Zone. The average measured air temperature in the air-conditioned area and non-air-conditioned area was 22.8 °C and 24.4 °C, respectively. In the simulation model using Room Air, the maximum errors between the simulated and the measured values in the air-conditioned area and non-air-conditioned area were 0.4 °C and 0.4 °C, respectively, while without Room Air module the maximum errors were 0.4 °C and 0.5 °C, respectively.

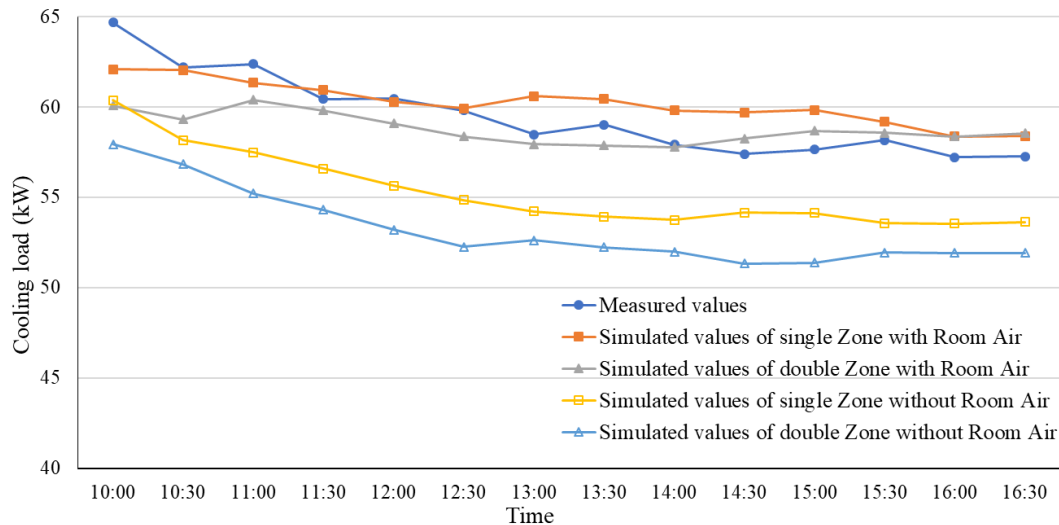


Figure 6. The effect of Room Air on indoor cooling load in typical winter cases.

Figure 6 depicts the effect of Room Air on cooling load in single Zone and double Zone models in Case 3 (in winter). The measured indoor heating load peak value was 64.67 kW. In the simulation model using Room Air, the maximum errors between the simulated and the measured values in single Zone and double Zone were 4% and -7%, respectively, while without Room Air the maximum errors were -8.27% and -12.46%, respectively.

The above results still showed the superiority of Room Air in energy consumption simulation in winter. However, considering the models without Room Air, the error of single Zone model was smaller. The reason was that, in the winter heating cases, the rising hot air made it different for the air-conditioned area to meet the design temperature. Therefore, the single Zone model considering that the internal air was in a fully mixed state had a smaller temperature gradient, the simulated values of heating load were also smaller.

5. Discussion

Room Air provides a feasible method for air temperature stratification in the energy consumption simulation models. Zone Mixing achieves air exchange between two adjacent zones. In the newly released EnergyPlus, users can combine Room Air Network and Airflow Network to achieve natural air flow in adjacent zones within a large space through the related settings of natural ventilation. The related content still needs further study. In addition, this paper has little discussion on the factors affecting the energy consumption of large spaces. In the future, by studying the main influencing factors, these factors can be classified according to the impacts.

6. Conclusions

In this paper, a real Engineering Training Centre in Shanghai was took as the research object, and its energy simulation models were established by EnergyPlus. The zone division was combined with Room Air to investigate the effects of different models on the hourly air temperature and the hourly cooling (heating) load values under typical cases in summer and winter. The results showed the superiority of

Room Air in energy consumption simulation. The double Zone model was more accurate for energy simulation in summer, while the single Zone model was more advantageous for winter cases.

Acknowledgements

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