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Prediction and Simulation Research on Temperature Field of Computer Room Based on Proper Orthogonal Decomposition

Ha Xinnan
Information and Communication Company
State Grid Ningxia Electric Power Co., Ltd.
Yinchuan, China
haxinnan@126.com

Zhang Lizhong
Information and Communication Company
State Grid Ningxia Electric Power Co., Ltd.
Yinchuan, China
bh3932770@sina.com

Wang Ye
Information and Communication Company
State Grid Ningxia Electric Power Co., Ltd.
Yinchuan, China
12139259@qq.com

Wang Jianlei
Information and Communication Company
State Grid Ningxia Electric Power Co., Ltd.
Yinchuan, China
basket-wjl-16@163.com

Hu Feihu
School of Electrical Engineering
Xi'an Jiaotong University
Xi'an, China
hufeihu@xjtu.edu.cn

Ma Qianli
School of Electrical Engineering
Xi'an Jiaotong University
Xi'an, China
419199771@qq.com

***Abstract*—The precision air conditioner accounts for 10% of energy consumption in data center. It is important to study how to adjust precision air conditioner to reduce energy consumption. Computational Fluid Dynamics (CFD) model is the most common method to simulate the temperature field in computer room, but the simulation time of existing software is large and the efficiency is low. In this paper, the proper orthogonal decomposition (POD) method is adopted. By taking the temperature field of the computer room under discrete configuration parameters as input, the proper orthogonal decomposition of each temperature field is performed to obtain the proper orthogonal basis of the temperature field, and then the approximate value of the temperature field of the computer room is obtained. Simulink is used to build air conditioning model and computer room model, and the temperature field under random load level is simulated. The results show that POD method has a great advantage in computing speed under the premise of little difference in accuracy.**

Keywords—component, formatting, style, styling, insert

I. Introduction

In recent years, with the increasing number and scale of data centers, how to build a green data center has become a concern of industry and academia. The air conditioner in the computer room accounts for about 10% of the total energy consumption of the data center. Among various methods to reduce the energy consumption level of the data center, it is the simplest and most effective to adjust the operation mode of the precision air conditioner. After adjusting the precision air conditioner, in order to study the change of the temperature field inside the computer room, the traditional computational fluid dynamics (CFD) model is often used for simulation, which takes a long time. For example, it takes about 30 minutes to simulate the temperature field change in standard room with 6SigmaRoom. In this paper, the proper orthogonal decomposition (POD) method is adopted. By taking the temperature field of the computer room under discrete configuration parameters as input, the proper orthogonal decomposition of each temperature field is performed to obtain the proper orthogonal basis of the temperature field, and then the distribution of the temperature field is obtained.

II. Computer Room Simulation Model

The air conditioning room of data center computer room can be divided into three parts: the air with certain humidity, the outer wall of the room in contact with the external environment and the precision air conditioner with heat exchange. In this paper, the whole computer room space is divided into three spaces to build the model, which are respectively: the air outlet of air conditioner, the server cabinet and the return air aisle[1]. Considering the timeliness of forecast, the forecast time span should not be too long or too short. Considering comprehensively, the temperature distribution in the next 5 minutes is taken as the prediction target in this paper.

A. Construction and Prediction of Air Conditioning Room Model

Simulink Simscape is used to build the air conditioning room model of the computer room, as shown in Fig.1.

Among them, the AC Room MA (Moist Air) Volume module simulates the real physics simulation model of the air conditioning room under the circumstance of humidity air and external environment (Env 1 module) and return air. Occupant Moisture/CO2 Gain simulates the effects of air humidity (breathing water vapor) and carbon dioxide on the condition that there are people in the computer room[2]. The module AC Room Heat Transfer simulates its heat transfer characteristics, and its heat transfer structure is shown in Fig.2.

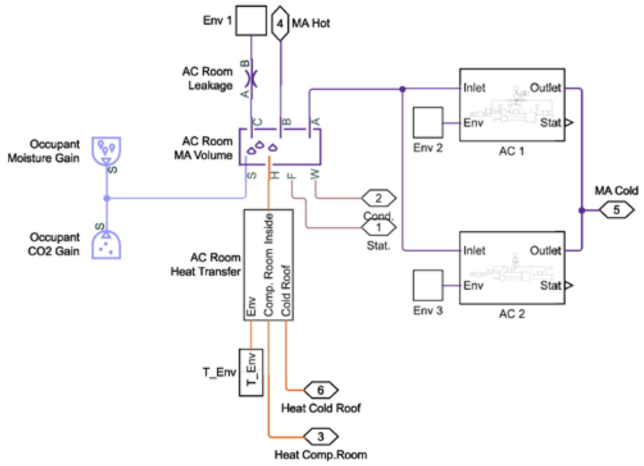


Fig.1. overall model of air conditioning room

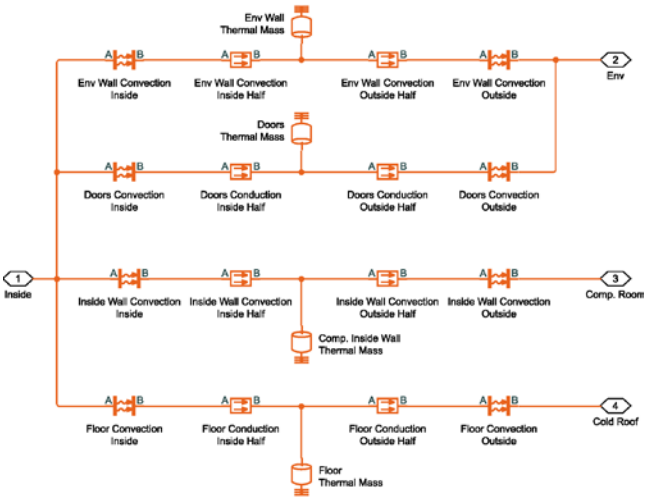


Fig.2. heat transfer model of air conditioning room

In Fig.2, the air in the air conditioning room transfers heat mainly through the external wall, door and external environment of the computer room, exchanges heat with the hot air in the computer room space through the inner wall of the computer room (the wall separating the computer room and the air conditioning room), and exchanges heat with the cold air in the connecting room through the ground.

Fig.3 describes the basic model of the precision air conditioner. Recirculation Flap is a mixing module of the computer room's hot return air and ambient temperature, which is mainly used when the ambient temperature is lower than the set temperature of the air conditioner (the air conditioner is in the condition of supply air and not refrigeration). Blower simulates the fan inside the precision air conditioner, and changing the fan's set speed can change the wind speed of the air conditioner's air outlet. It is worth noting that after passing through the fan, the air is accelerated and given extra kinetic energy, so there is some energy consumption in this part[3]. However, energy consumption of this part only exists at the beginning of the model. After passing through the Blower fan module, the humid air with a certain amount of water vapor passes through the Evaporator module, exchanges heat with the cooling liquid cooled by the cooling compressor, and changes from hot air to cold air and is sent to the connecting room.

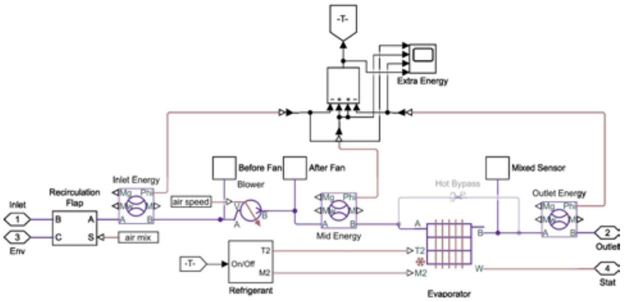


Fig.3. heat exchange model of precision air conditioner

B. Construction and Prediction of Connecting Room Model

The model structure of the connecting room is relatively simple. It only needs to simulate the air exchange between the connecting room and the air conditioning room, the heat transfer between the connecting room and the external environment, and the air exchange between the connecting room and the computer room space[4].

Fig.4 depicts the basic structure of the connecting room model. MA (Moist Air) Comp and MA (Moist Air) AC represent the aisles between the connecting room and the computer room and the air conditioning room. Air with a certain humidity enters the connecting room from the air conditioning room, passes through air diffusion, heat exchange between the outer wall and the environment, and some air leaks into the environment (module Leakage), and finally enters the computer room (cabinet cold aisle) [5].

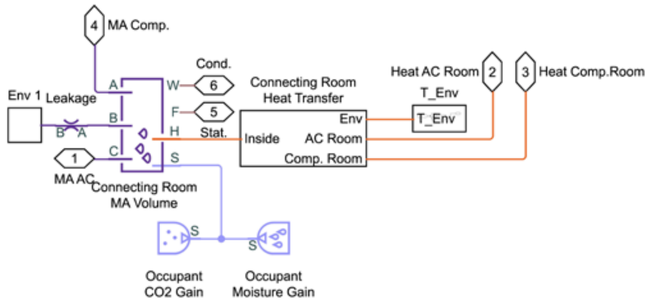


Fig.4. overall model of connecting room

Fig.5 shows the heat transfer model of the connecting room. Since the heat transfer structure of the computer room and the air conditioning room and the connecting room are realized in the corresponding modules, the heat transfer module of the connecting room only needs to realize its own heat exchange between itself and the environment through the outer wall.

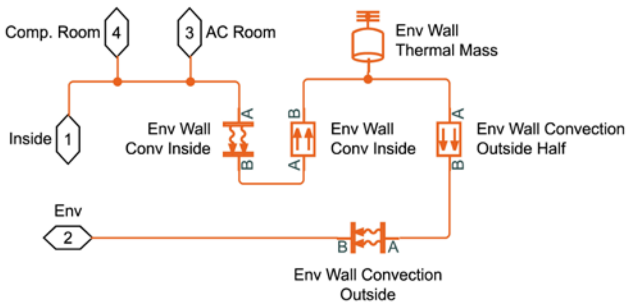


Fig.5. heat transfer model of connecting room

C. Construction and Prediction of Computer Room Model

Fig.6 shows the overall model of the computer room. Different from the air conditioning room and the connecting room, due to the isolation of the cabinet, the computer room can be further divided into two sub-spaces: cold aisle and hot aisle. The cold aisle is the part that separates each group of cabinet from the external environment through the cabinet door and the cabinet outer wall[6]. The cold aisle of each group of cabinet is relatively independent and only connected to the connecting room through the vents on the ground. There is no absolute division of the hot aisle in space. Generally, the aisle between two sets of cabinets (that is, the corridor opposite to the outlet of the server fan) is the hot aisle. In fact, the hot aisles of each group are actually connected to the whole space of the computer room. For calculation purposes, it is assumed that the hot aisles of each group are connected with each other, the temperature distribution is uniform, and the air diffusion time tends to zero, that is, the air diffusion is completed instantaneously.

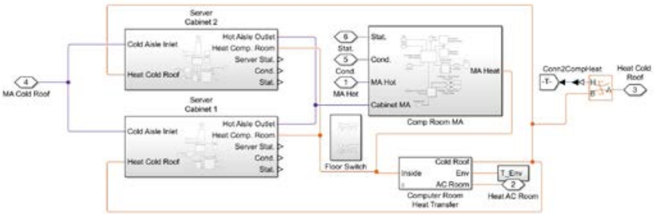


Fig.6. overall model of computer room

Fig.7 depicts the model structure of the cabinet. The Server Cabinet accepts air from the cold aisle through the Cold Aisle Inlet and then enters the Cold Aisle Moist Air Volume through the vents on the ground[7]. Meanwhile, the cold aisle and the external computer room space (hot aisle) and the connecting room space conduct heat transfer. The air in the cold aisle is used as the input of the air inlet of the server, and is heated by the server Heater Core, and the output hot air enters the hot aisle space of the computer room.

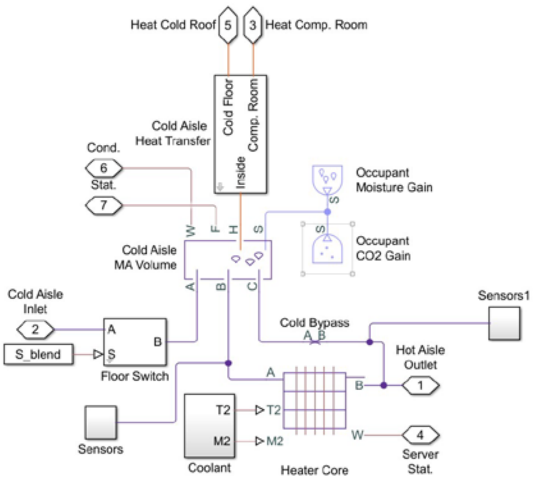


Fig.7. server cabinet model

It is worth noting that the cold aisle "bypass" (leaking into the hot aisle without passing through the server Heater Core) is depicted in the literature[8]. The model uses a small-sized pipe "Cold Bypass" to simulate the process, which makes the model more realistic.

Fig.8 depicts the heat transfer model of the cold aisle. The cold aisle exchanges heat with the connecting room through the ground, and exchanges heat with the glass cabinet and the whole heat aisle.

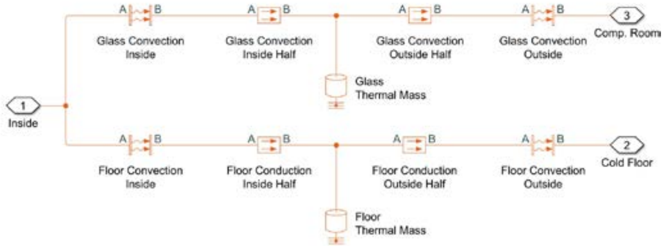


Fig.8. heat transfer model of cold aisle

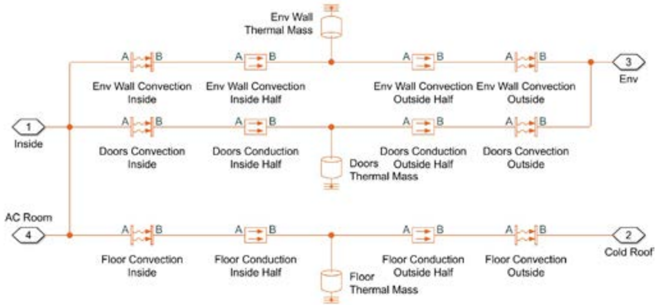


Fig.9. heat transfer model of hot aisle

Fig.9 depicts the heat transfer model of the overall space of the computer room (the hot aisle). Different from the cold aisle, the cold aisle itself is "inside" the hot aisle, so in addition to transfer heat with the cold aisle and the connecting room, the hot aisle also exchanges heat with the environment through the outer wall[9].

D. Estimation Model and Forecast of Energy Consumption

The red part in Fig.10 is the measurement part of the air conditioning energy consumption. The energy consumption measurement is divided into two parts. The first part is the mechanical energy consumed by the air conditioner fan to accelerate the air[10]. The model obtains the energy consumed by the fan by measuring the energy change of the air after passing through the fan, that is, the difference between Mid_Energy and Inlet_Energy. The second part is the heat consumed by the heat exchange between the refrigerant and the air. It is obtained by calculating the difference between the air energy of the air inlet and the air energy of the air outlet in the heat exchanger of air conditioner, that is, the difference between Mid_Energy and Outlet_Energy[11]. Compared with energy consumption estimation based on temperature field, the calculation time of this part is more time saving, which can be estimated in real time while physical simulation. In addition, since the energy consumption scale data is all the current cumulative energy consumption, it needs to be converted into the power value of the current time when input the model. The specific method is to subtract the cumulative energy consumption value of the previous moment from the current cumulative energy consumption value, and divide the result by the time scale (this project is 1 minute).

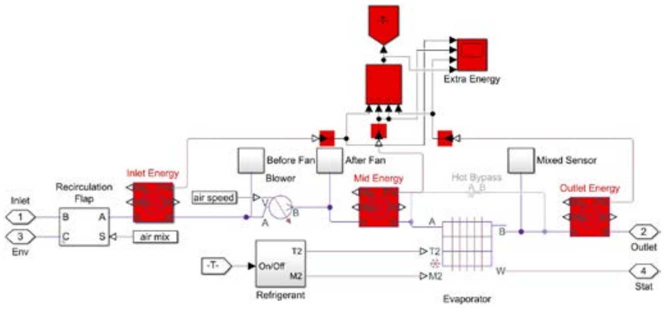


Fig.10. energy consumption measurement model of air conditioner

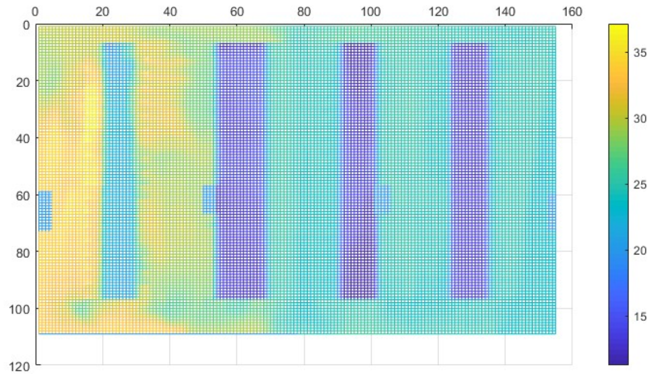
III. Prediction and Simulation of Temperature Field in Computer Room Based on Proper Orthogonal Decomposition

The computer room itself is a complex physical system that includes a variety of variables and a variety of physical models. If it is modeled by traditional methods, its computational complexity will increase exponentially and it is difficult to converge in a limited time[12]. Considering the complexity of the problem, the computational complexity is reduced to polynomial by referring to literatures and combining with proper orthogonal decomposition, and a fast temperature field estimation model with multiple parameters is realized.

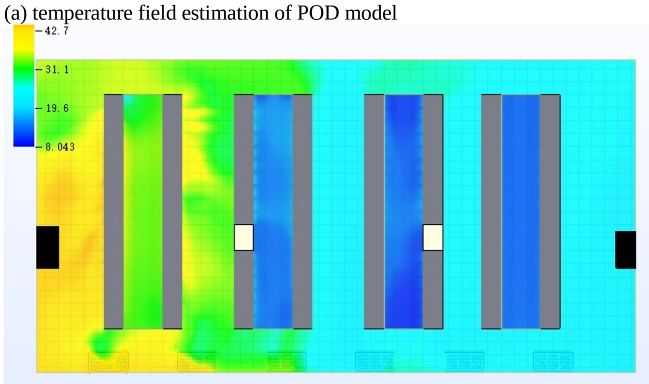
The basic analysis of the model is to average the temperature fields at different times to obtain the baseline temperature field T_0. By calculating the difference between the temperature field of each time period and the average value, the temperature distribution difference T_i^x of each time point is obtained[13]. By performing proper orthogonal decomposition on T^x at each time point, the POD modes and bases of temperature field at that time can be obtained. By interpolating the basis, the corresponding proper orthogonal basis $b_i(t)$ at any time can be obtained, and then the difference between the temperature field and the baseline temperature field under current conditions can be obtained by multiplying and summing with the corresponding proper orthogonal modes[14]. By summing up the difference and the baseline temperature field, the temperature field at this time can be restored. Formula (1) describes the basic calculation method of proper orthogonal decomposition used in this paper[15].

$$T_0(x,y,z) = \frac{\sum_{i=1}^{n}(T_i(x,y,z;t_i))}{n}$$
$$T_i^x(x,y,z;t_i) = T_i(x,y,z;t_i) - T_0(x,y,z) \quad (1)$$
$$T(x,y,z,t) = T_0(x,y,z) + \sum_{i=1}^{k}\phi(x,y,z)b(t)$$

According to the above method, we can estimate the temperature field distribution at any operating parameters and load level by using the temperature field data obtained by MATLAB programming and 6SigmaRoom modeling and simulation[16]. Fig.11 compares the results of temperature field estimation based on proper orthogonal method and 6SigmaRoom based on traditional computational fluid dynamics (CFD) model.



(a) temperature field estimation of POD model



(b) computer room temperature field simulation of CFD

Fig.11. comparison of effects of POD model and physical simulation on temperature field estimation in computer room

It can be seen from Fig.11, there is little difference between the POD model and the traditional CFD simulation calculation results, but the time to calculate the POD once is about 10 seconds, which is much less than the time required for CFD calculation (about 30 minutes). POD has the advantage of greater computational speed without sacrificing greater accuracy[17].

IV. Conclusion

In this paper, the proper orthogonal decomposition (POD) method is used to simulate the variation of the temperature field of the computer room built by Simulink. The simulation results show that POD model takes much less time for simulation than CFD simulation under the premise of little calculation error, and has a great advantage of computing speed. If the calculation model is put into the actual temperature prediction of the computer room, it can quickly estimate the temperature distribution of the computer room, which is conducive to discover local hot spots and safety hazards that may exist in the computer room, reduce the probability of security accidents in the data center, and improve the security of the whole system.

References

[1] Greenberg S, Mills E, Tschudi B, et al. Best practices for data centers: Lessons learned from bench- marking 22 data centers[J]. Proceedings of the ACEEE Summer Study on Energy Efficiency in Build- ings in Asilomar, CA. ACEEE, August, 2006, 3: 76-87.

[2] Jones N. How to stop data centres from gobbling up the world's electricity.[J]. Nature, 2018, 561(7722): 163.

[3] Sartor D, Greenberg S. How to Save Money In Your Small Data Center[C]//. [S.l.]: Lawrence Berke- ley National Laboratory, 2018.

[4] Patel C D, Bash C E, Sharma R, et al. Smart cooling of data centers[C]//Proceedings of IPACK:vol. 3. [S.l. : s.n.], 2003: 6-11.

[5] Silver D, Huang A, Maddison C J, et al. Mastering the game of Go

with deep neural networks and tree search[J]. Nature, 2016, 529(7587): 484-489.

[6] Barroso L A, Clidaras J, Hölzle U. The datacenter as a computer: An introduction to the design of warehouse-scale machines[J]. Synthesis lectures on computer architecture, 2013, 8(3): 1-154.

[7] Shehabi A. Data center economizer contamination and humidity study[J]., 2007.

[8] Ebrahimi K, Jones G F, Fleischer A S. A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities[J]. Renewable and Sustainable Energy Reviews, 2014, 31: 622-638.

[9] Oga S, Takamatu T, Takahashi M. Indirect External Air Cooling Type Energy-Saving Hybrid Air Conditioner for Data Centers,"F-COOL NEO"[J]. Fuji Electric Review, 2014, 60(1).

[10] Tadich P. How Oceans are Being Used to Cool Massive Data Centres[J]., 2017.

[11] Rathi A. The newest green-tech idea: drown data centers at sea[J]., 2018.

[12] Lipton Z C, Berkowitz J, Elkan C. A critical review of recurrent neural networks for sequence learn- ing[J]. ArXiv preprint arXiv:1506.00019, 2015.

[13] Witten I H, Frank E, Hall M A. Data Mining: Practical Machine Learning Tools and Techniques (Third Edition)[M]. [S.l. : s.n.], 2005.

[14] LeCun Y, Touresky D, Hinton G, et al. A theoretical framework for back-propagation[C]//Proceedings of the 1988 connectionist models summer school:vol. 1. [S.l. : s.n.], 1988: 21-28.

[15] Samadiani E, Joshi Y. Multi-parameter model reduction in multi-scale convective systems[J]. Inter- national Journal of Heat and Mass Transfer, 2010, 53(9-10): 2193-2205.

[16] Ghosh R, Joshi Y. Rapid temperature predictions in data centers using multi-parameter proper or- thogonal decomposition[J]. Numerical Heat Transfer, Part A: Applications, 2014, 66(1): 41-63.

[17] Ghosh R, Joshi Y. Error estimation in POD-based dynamic reduced-order thermal modeling of data centers[J]. International Journal of Heat and Mass Transfer, 2013, 57(2): 698-707