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Study on the use of sensible heat load of the simulated load generator under summer conditions

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Abstract
The research team produced a simulated load generator applied to the steady-state condition of an air-conditioned room, but it has not been applied to a dynamic environment. This article aims to study the simulation of its dynamic sensible heat load. The state space method is used to establish the energy model of the room, and the corresponding model is obtained through model identification by using the heat preservation warehouse to understand the respective influences of the outdoor temperature and the simulated load generator. By programming the power of the simulated load generator according to time, it is found that it basically conforms to the room model, and the use of a suitable control rate can make the room temperature change according to a predetermined curve.

Keywords:*State space method,Room load,Analog load generator, Feedforward control,Air-conditioned room.*

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I. INTRODUCTION

The summer cooling load of the house changes with the time and location of the experiment. The closed cabin and the simulated load generator placed in the factory can simulate the summer fixed load. Simulating the real-time load is a fundamental task for studying the application of air-conditioning systems.

For the study of room cooling load, many experts have already given methods. Machine learning has been applied to predict cooling load[1].Yuanda Chenget al.[2]reviewed simple cooling load calculation methods commonly used in the world. The load at various set temperatures can be calculated. The temperature of the real-time room system is not a constant value, but a relatively stable value. Baptiste Schubnel[3] uses the state space method to conveniently handle multiple input and multiple output situations, and the amount of calculation is small. Feedforward control [4] has mature research in the field of air conditioning optimization [5], which can play a certain role in the development of intelligent buildings [6]. But there is no very practical machine that can simulate indoor load changes. Especially for marine air conditioning [7,8]simulationwill be of great help

The research content of this paper is how to output the sensible heat load of the corresponding simulated load generator according to the real-time state of the experimental cabin. The simulation cabin model and simulation load generator control method are established.

II. Math Model

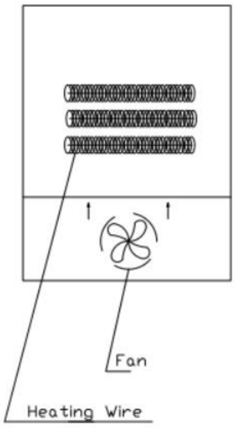
2.1 Introduction to Simulated Load Generator

The simulated load generator is composed of an electric heating wire and an electric hot water tank. In order to study the sensible heat load here, only the analog generator is considered as an electric heating device, and the electric hot water tank is not turned on. The heating power is 0-5kW.

The heating capacity of the analog load device is controlled by adjusting the power of the electric heating; the humidification capacity of the analog load device is controlled by adjusting the power of the humidifier. After the device is started, a period of preheating is required to make the water in the hot water tank reach boiling temperature.

The simulated load generator is often used in the simulated environment of thermal and humid conditions, and the working principle of heating is electric heating. The working principle of humidification is that saturated steam enters the humidifier from the steam inlet, and the steam flows axially in the steam jacket rod. The latent heat of the steam is used to heat the center spray rod to ensure that pure dry steam is sprayed from the center spray rod. Entrained steam with condensed water. The simulation in this paper only considers the influence of temperature, does not consider the humidity, and does not turn on the humidification function.

In order to be able to simulate the heat and humidity load generated by different weather conditions on the cabin, this experiment introduces a simulated load device. The device can be programmed to generate heat and moisture load to achieve the requirements of simulating the real cabin environment. The device includes components such as fan, electric heating, humidifier and so on. The schematic diagram of the device is shown in Figure 1.a, and the physical diagram is shown inFigure 1.b.



a. Schematic diagram

b.physical diagram

Figure 1:heat load generator

2.2 Introduction to Simulated Load Generator

Yao Ye [9] and others used the state space method to establish a room state space model for the cabin, and here is a further simplification of the model they made. Establish a mathematical model of the cabin to describe temperature changes.

In order to facilitate model derivation, the following assumptions are made:

1. The regional air is evenly mixed
2. The temperature inside and on the surface of the enclosure wall is uniform and consistent
3. The surface temperature of the heat storage body is uniform
4. No humidity source indoors
5. Ignore radiation
6. The heat transfer coefficient of the solid surface is constant
7. Only the external wall affects

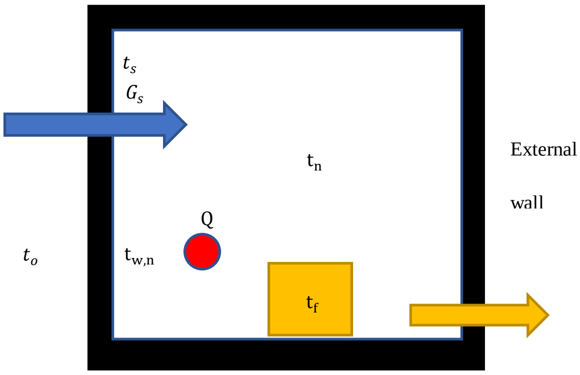
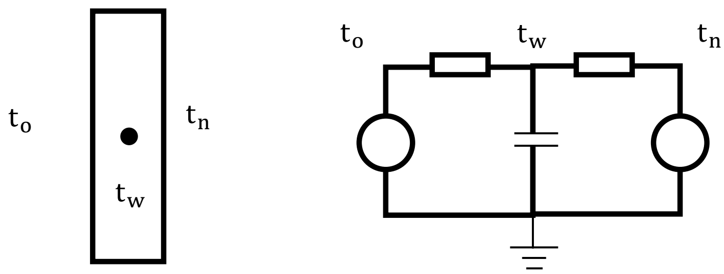


Figure 2 Cabin model

Air temperature energy balance equation

$$c_a M_a \frac{dt_n}{d\tau} = c_a G_s(t_s - t_n) + a_{w,n} A_{w,n}(t_{w,n} - t_n) + a_f A_f(t_f - t_n) + Q_e \qquad (1)$$

According toFigure 3Simplify the envelope structure and construct the energy balance equation of the envelope structure.



a. Schematic diagram of enclosure structure **b.Schematic diagram of heat balance control**

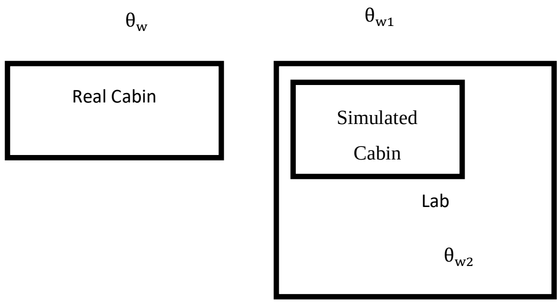
Figure 3: Envelope structure system diagram

$$c_w M_w \frac{t_{w,n}}{d\tau} = a_{w,o} A_{w,o}\left(t_o - t_{w,n}\right) + a_{w,n} A_{w,n}\left(t_n - t_{w,n}\right) \quad (2)$$

Energy balance equation of heat storage body

$$c_f M_f \frac{dt_f}{d\tau} = a_f A_f (t_n - t_f) \quad (3)$$

2.3 The difference between real cabin and simulated cabin



a. Real cabin **b Simulated Cabin**

Figure 4:Comparison diagram of cabins

Comparing the real cabin and the simulated cabin, especially for the research of air-conditioning system, we hope that the simulated cabin and the real cabin should have the same input air volume G and input air temperature t_s. Change the formula （1).

Real cabin:

The dynamic energy differential equation of air temperature:

$$c_a M_a \frac{d\theta_i}{dt} = c_a G_a (\theta_s - \theta_i) + a_x A_x (\theta_x - \theta_i) + Q_w(\theta, t) \quad (4)$$

Among them, $Q_w(\theta, t)$ is the load value at the current temperature. It has been calculated by calculation software. Simulation cabin: The dynamic energy differential equation of air temperature:

$$c_a M_a \frac{d\theta_n}{dt} = c_a G_a (\theta_s - \theta_n) + a_x A_x (\theta_x - \theta_n) + Q_e + a_w A_{w,n}\left(\theta_{w,n} - \theta_o\right) \quad (5)$$

If the analog load generator has no delay and no heat absorption, it can be considered that $Q_e$is the actual output power of the analog load generator。

$$Q_w(\theta, t) - a_w A_{w,n}(\theta_w - \theta_i) = Q_e \quad (6)$$

The influence of the simulated load generator on the cabin can be shown in **Error! Reference source not found.**.Equation（7） is a correction to the real cabin, and Equation (（8）is the energy balance equation of the simulated load generator heat storage body.

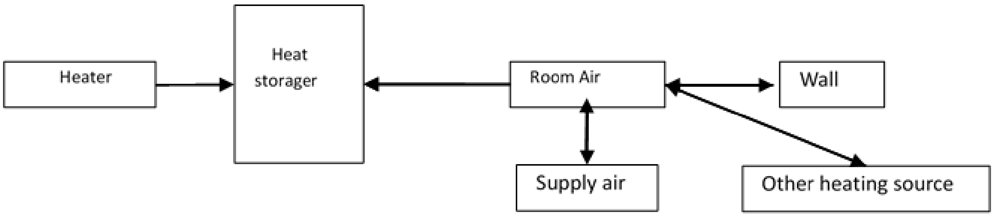


Figure 5: Heat transfer model system diagram

$$c_a M_a \frac{dt_n}{d\tau} = c_a G_s (t_s - t_n) + a_{w,n} A_{w,n} (t_{w,n} - t_n) + a_f A_f (t_f - t_n) + Q_e + a_{simu} A_{simu} (t_{simu} - t_n) \quad (7)$$

$$c_{simu} \frac{dt_{simu}}{d\tau} = a_{simu} A_{simu} (t_n - t_{simu}) + q \quad (8)$$

Figure 6 shows a simplified system model and we use it.

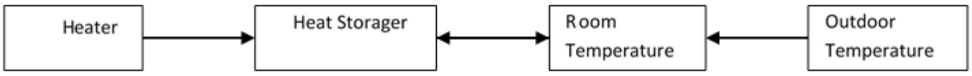


Figure 6:Simplified system diagram of heat transfer model

$$C_1 \times \frac{d\theta_1}{dt} = \frac{\theta_n - \theta_1}{R_1} + q \quad (9)$$

$$C_2 \times \frac{d\theta_n}{dt} = \frac{\theta_1 - \theta_n}{R_1} + \frac{\theta_w - \theta_n}{R_2} \quad (10)$$

Where C_1 is the heat capacity of the heat storage body, J/°C; $\theta_n$is the indoor temperature, ˚C; θ_1 is the heat storage body temperature, ˚C; $\theta_w$is the outside temperature, ˚C. q is the input power of the simulated load generator, W; R_1 is the thermal resistance of the regenerator and the room ˚C/W; $R_2$is the room and The external thermal resistance ˚C/W.

III. Analog load generator control strategy

In order to explore the operating characteristics of the analog load generator, we need to study the control rate of the analog load generator. Obviously, the simulated cabin load itself cannot be higher than the real cabin load under steady-state conditions.It is still the same under dynamic conditions, because the power of the analog load generator cannot be a negative number. We expect the temperature change of the simulated cabin to be consistent with the real cabin change that we imaginary.As long as the simulated load generator and the outdoor temperature of the simulated cabin are controlled, the temperature change of the simulated cabin can be consistent with the real cabin change that we imaginary.For a system with constant supply air temperature and supply air volume, the system diagram in Figure 7 can be constructed by combining equations （4)（5)（6).y1 and y2 are the real cabin temperature and the simulated cabin temperature respectively.

3.1 Problem analysis

3.2 Control Model

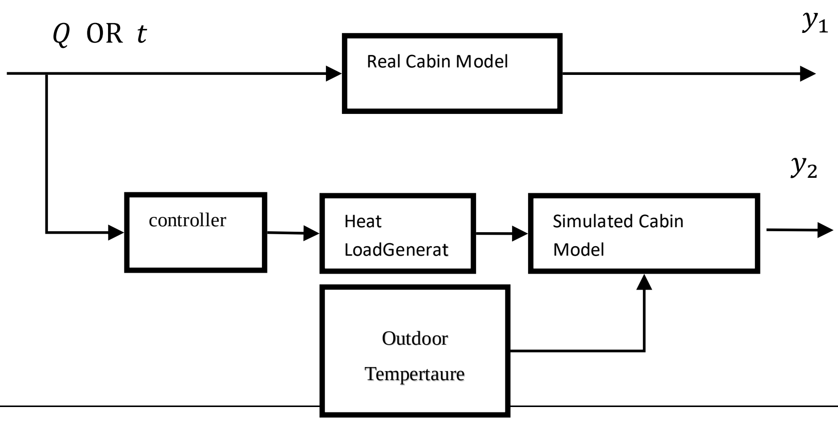


Figure 7:Simulation cabin control system diagram

There is no temperature rise in adjacent compartments. From Equation (1) (2) (3) the real compartment can be considered as a second order model. The state space method is now used as the control model. The reason for this is that it is easy to deal with multiple input situations.

The state space expression takes the form as following

$$\begin{cases} \dot{\boldsymbol{x}} = \boldsymbol{Ax} + \boldsymbol{Bu} \\ \boldsymbol{y} = \boldsymbol{Cx} + \boldsymbol{Du} \end{cases} \tag{11}$$

The ***A,B,C,D*** matrices are the system matrix, the control matrix, the output matrix and the direct action matrix respectively. u is the input vector, X is the state vector and ***y*** is the output vector

In contrast to the simulated chamber, the real chamber is actually missing the input of the simulated load generator. The input vector ***u*** is the (outdoor temperature), and the output vector ***y*** is the indoor temperature. The r and s subscripts represent the real chamber and the simulated chamber respectively

$$sys_{\mathrm{r}} = \begin{cases} \dot{x} = \begin{bmatrix} A_{11} & A_{12} \\ \mathrm{A}_{21} & A_{22} \end{bmatrix} x + \begin{bmatrix} B_{11} & B_{12} \\ \mathrm{B}_{21} & B_{22} \end{bmatrix} [U_{\mathrm{r},1}] \\ \mathrm{y} = [0 \quad 1]\mathrm{x} \end{cases} \tag{12}$$

If the system input in Figure 7 is changed to outdoor temperature changes, the changed system is also a single-input single-output control system. It is also easy to implement in the experiment.

The simulation cabin and the simulation load generator should be considered as a whole, the input vector u is (simulation load generator power, outdoor temperature), and the output vector y is the indoor temperature.

It needs to be subjected to an identification test to get the response of the simulated cabin and the real cabin to the input. If the controller is used to process the input signal input to the real cabin, the dynamic change of the indoor temperature of the real cabin can be simulated in the simulated cabin.

$$sys_{\mathrm{s}} = \begin{cases} \dot{x} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} x + \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} [U_{s,1} \quad U_{s,2}] \\ \mathrm{y} = [0 \quad 1]\mathrm{x} \end{cases} \tag{13}$$

The mathematical model of the simulated cabin is the situation of dual input and single output. In the division of the control system, the number of inputs and outputs of the system should be equal. Therefore, it is necessary to modify the control model (13) of the simulation cabin before using the system's division to satisfy the realization of the division. Now we only consider the dynamic impact of the simulated load generator on the cabin, and the temperature outside the cabin remains unchanged, that is, u2=0. Therefore, we reduce the input matrix and the direct action matrix in the expression of the simulated cabin condition space into one column, and a single input situation can be realized.

$$sys_{\mathrm{s}}' = \begin{cases} \dot{x} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} x + \begin{bmatrix} B_{11} \\ B_{21} \end{bmatrix} [U_{s,1}] \\ \mathrm{y} = [0 \quad 1]\mathrm{x} \end{cases} \tag{14}$$

3.3 Controller design

The controller needs to do feedforward control to compensate for an energy loss in the room.In the previous section, the number of inputs and outputs of sys_r and sys_s are the same.

$$sys_{\mathrm{ctl}} = \frac{\mathrm{sys_r}}{\mathrm{sys_s}'} \tag{15}$$

Get the control rate of the controllersys_{ctl}

IV. Experimental System

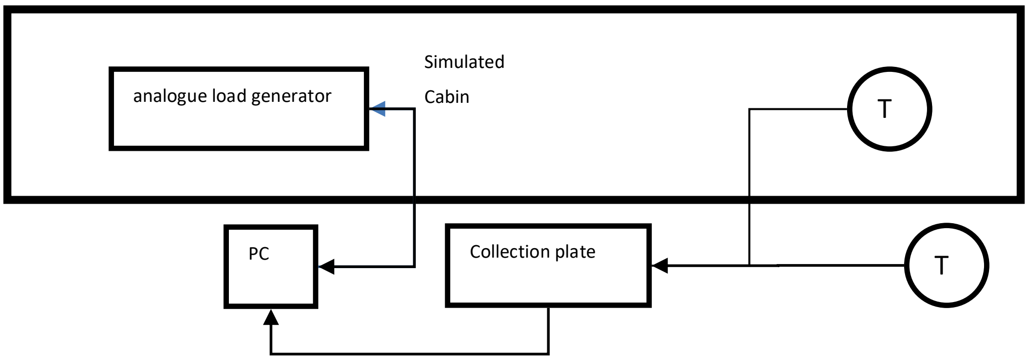


Figure 8 Experimental signal system diagram

The experimental system is based on the enthalpy difference laboratory of Shanghai University of Technology, Figure 8Overall experimental system diagram temperature sensor using a 4-wire platinum resistance. The computer collects the data from the acquisition card and also controls the start/stop of the analogue load generator and the electrical heating power. The chamber is an insulated chamber and is wrapped in insulation material. The analogue load generator is placed in the insulated analogue chamber with the temperature sensor inside the chamber away from the air outlet side and the temperature sensor outside the chamber on the side 0.5 m from the outside wall of the analogue chamber.

V. RESULT AND DISCUSSION

The results obtained are as discussed below

5.1 Identification tests

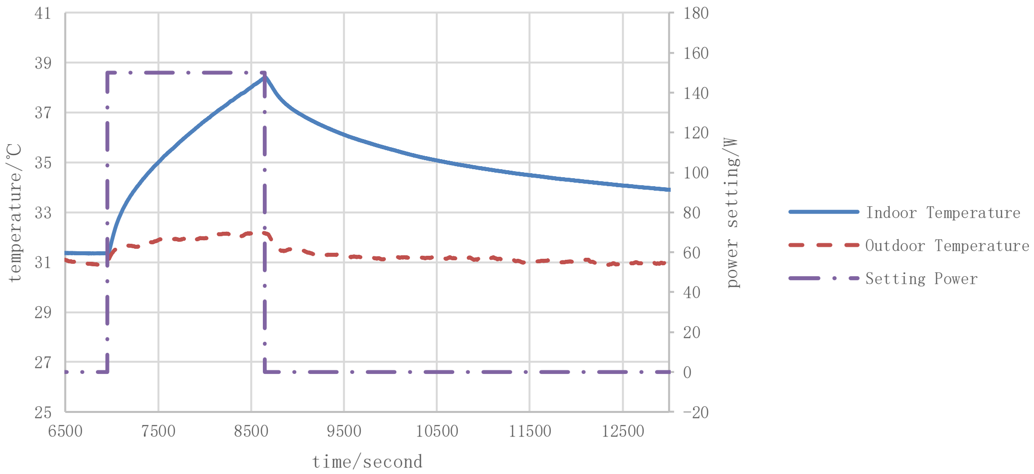


Figure 9:Experiment with identification model

The experimental curve is shown in Figure 9. The experimental curve was identified using the control model in the previous section and the results were obtained as Table 1.

Table 1:Result of Identification models

Matrix name	value	
A	-4.471×10^-05	0.0887
	2.479×10^-08	-0.0008
B	0.196	-0.0948
	1.915×10^-05	0.000855
C	0	1
D	0	

5.2 Control experiment

Assuming the model of the real cabin is Table 2

Table 2:Real Cabin Control Model Setting

Matrix name	value	
A	-0.0125	-2.500e-05
	1	0
B	1	
	0	
C	0	2.50e-05
D	0	

The control model of the controller is Table 3

Table 3: Controller Control Model

Matrix name	Value		
A	-0.0124	-0.00456	-0.00170
	0.00456	-1.4842×10^-05	-5.0010×10^-05
	0.00170	-5.0001×10^-05	-0.0003920
B	-1.145		
	0.0361		

	0.0693		
C	-1.1453	-0.0361	-0.0693
D	0		

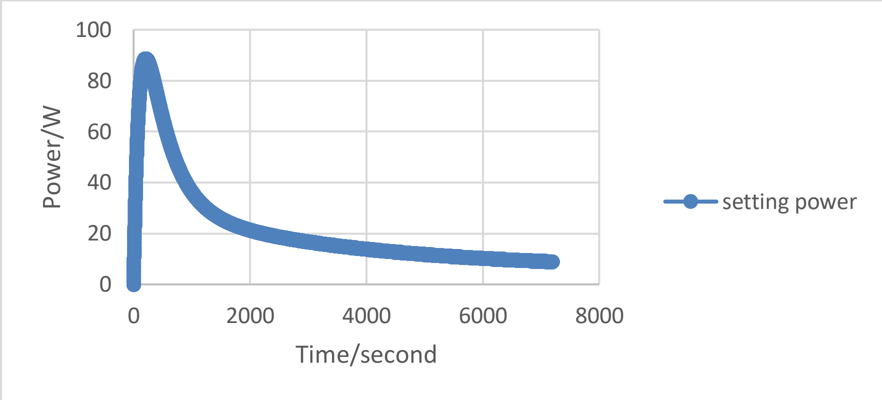


Figure 10: Controller step response diagram

Applying the power curve inFigure 10 to the real control will give the result in Figure 14.The temperature of the simulated chamber reaches a rapid temperature rise of 1 degree in time, the temperature rises and then drops again within a certain period of time and then rises again. The reason for the drop is that the rapid rise in temperature is such that the heat accumulator in the chamber is unable to rise in temperature in such a fast time, while the power of the simulated load generator drops so that the temperature of the heat accumulator accounts for the main effect, and the slow heating at the back enables the temperature to rise again slowly. The subsequent temperature rise shows a linear variation, which includes not only the power of the heater of the analogue load generator, but also the power of the fan of the analogue load generator, which cannot be ignored.

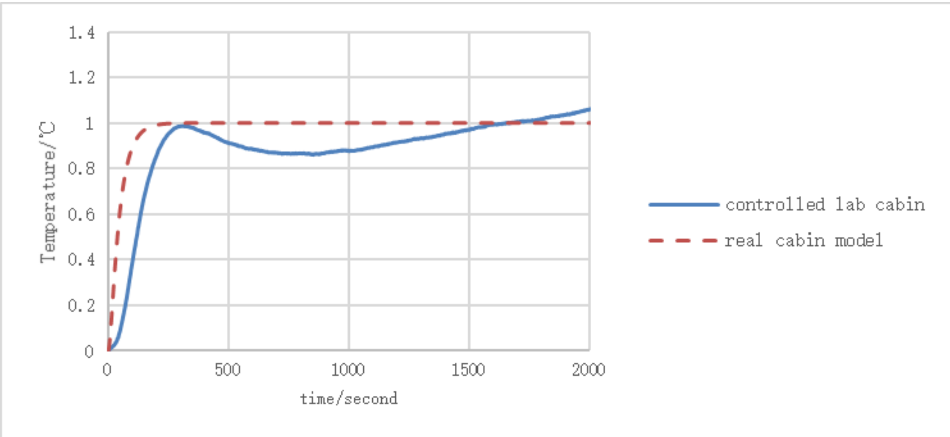


Figure 11:Simulated chamber temperature control results graph

VI. CONCLUSION

Using a simulated load generator when the outside world of the real chamber rises by 1°C and the outside temperature of the simulated chamber does not change, if there exists some simulated load generator whose power can make the room rise by 1°C faster than the real chamber, then a control method can be devised to make the simulated load generator work so that the simulated chamber as a whole simulates the dynamic changes of the real chamber. The present results are only for the simulation and experimentation of a single chamber, in the case of multiple chambers the effects of adjacent chambers should be considered. By changing the thinking the use of the simulated load generator can also be used to make state space and simulation effects for pre-experiments in CAV and VAV, for example by considering the air coming out of the simulated load generator as the air coming out of the air conditioning heater.

REFERENCES

[1]. Sha, H., Moujahed, M., and Qi, D. 2021. Machine learning-based cooling load prediction and optimal control for mechanical ventilative cooling in high-rise buildings. Energy and Buildings 242, 110980.

[2]. Cheng, Y., Yang, B., Lin, Z., Yang, J., and Du, Z. 2018. Cooling load calculation methods in spaces with stratified air: A brief review and numerical investigation. Energy and Buildings 165, 47–55.

[3]. Schubnel, B., Carrillo, R.E., Taddeo, P., et al. 2020. State-space models for building control: how deep should you go? Journal of Building Performance Simulation 13, 6, 707–719.
[4]. Ahmed, O., Mitchell, J.W., and Klein, S.A. 1998. Feedforward-feedback controller using general regression neural network (GRNN) for laboratory HVAC system. Part 3: Temperature control–heating. American Society of Heating, Refrigerating and Air-Conditioning Engineers ….
[5]. Gang, W. and Wang, J. 2013. Predictive ANN models of ground heat exchanger for the control of hybrid ground source heat pump systems. Applied Energy 112, 1146–1153.
[6]. Homod, R.Z. 2018. Analysis and optimization of HVAC control systems based on energy and performance considerations for smart buildings. Renewable Energy 126, 49–64.
[7]. Liu, F., Dai, Y., Sui, J., et al. 2021. Design, construction and preliminary test of a prototype of a heat-driven air-conditioning system integrated with marine aerosol removal. Energy Conversion and Management: X 10, 100080.
[8]. Yan, L., Li, J., Zhang, D., and Liu, C. 2011. The Modeling and simulation of marine Air-condition. Procedia Engineering 12, 141–148.
[9]. Yao, Y., Yang, K., Huang, M., and Wang, L. 2013. A state-space model for dynamic response of indoor air temperature and humidity. Building and Environment 64, 26–37.