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Research on Summer Environmental Thermal Comfort Model of Buildings in Hot Summer and Cold Winter Area

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Abstract: According to people's subjective reaction under extreme indoor environment conditions, this paper synthesizes the comprehensive comfort evaluation model of hot summer and cold winter area by using penalty substitution method, compares and analyzes the influencing factors of human comprehensive comfort, and obtains the main factors affecting human comprehensive comfort. At the same time, the peak area and allowable area of comprehensive comfort are divided, and a series of common operating parameters of comfort zone line are given. Finally, by monitoring the laboratory and collecting relevant research data, a thermal comfort model of hot summer and cold winter area is established by using the neural network theory, and the model is preliminarily tested and described through the investigation of typical climate characteristic areas.The experiment proves that the indoor thermal comfort model used in hot summer and cold winter area has certain practical significance to adjust the indoor environmental factors, which can achieve a better comfortable state and realize building energy saving.

Keywords: areas with hot summer and cold winter; comprehensive comfort; neural network; Building energy efficiency; typical climate region

1 INTRODUCTION

The construction of buildings needs to rely on the external material environment and resources. People have long-term experience and wisdom in the use of climate and natural resources in a certain time dimension and geographical category coordinates, forming a stable and unified form that ADAPTS to the external environment and is conducive to living comfort. Therefore, architectural forms show typologies in specific regions and climates. The thermodynamic mechanism of buildings is different in different regions and climate environments. Its form requires energy collaborative optimization of multiple physical environments in the climate environment, such as scenery, heat and humidity [1]. The path and law of architectural transformation between climatic environment and architectural form.

At first, the indoor thermal environment comfort was studied, and a lot of research has been done on the influencing factors, evaluation indexes and physiological reaction mechanism of thermal comfort, and abundant research results have been achieved. Take ASHRAE standard [2] as an example; its investigation and research results in terms of thermal comfort provide necessary reference data for improving indoor thermal comfort and increasing people's average satisfaction. Analysis of thermodynamic mechanism should be based on qualitative understanding and quantitative study of energy flow characteristics in buildings [3, 4].

To sum up, the most stable core in various regional architectural systems has type induction, form visibility and quantitative analysis in its climate environment. Firstly, through the research of existing thermal comfort, the shortcomings are found, the research purpose of this paper is clear, and the physical environmental factors and personal factors that need to be measured in the selection of the research scope are determined. The parameters of related physical environment factors were obtained through continuous monitoring of indoor environment, and the subjective comfort information of people with hot summer and cold winter on indoor thermal comfort was obtained by means of subjective questionnaire survey; based on the correlation analysis of the parameters of physical environment factors measured in the laboratory and the data obtained from the questionnaire survey in the laboratory, the model was preliminarily tested and described through the investigation of areas with typical climate characteristics.

2 RELATED WORK

It has been widely recognized and applied in conventional and atmospheric indoor environments [5], and the thermal response of human body in variable temperature environment is inconsistent with that in steady state environment. Not only does thermal environment affect building energy consumption, but according to statistics, lighting energy consumption accounts for about 30% of the entire building energy consumption [6]. The difference of indoor illumination comfort interval of different light sources is obtained through testing. The effects of fluorescent lamps with three color temperatures under different illuminance were compared through experiments [7, 8]. The experimental results show that both illuminance and color temperature have an impact on light comfort. Meanwhile, the wind cooling index of the range with comfortable illumination in a specific indoor environment is used to evaluate the high temperature environment and the cold climate [9].

Many valuable results have been obtained from a large number of tests and experiments, which can be used as reference points for further research. There have been some important conclusions [10]. For example, human thermal sensation, skin humidity, the quality of clothing, air quality and human health [11]. Dirty air will further worsen the dryness of the skin under low humidity conditions [12]. The longer the time in the environment with low dew point temperature [13], the greater the impact [14]. It is recommended that the relative humidity in summer should be less than 60%, mainly considering that if the relative humidity is too large, the mold will quickly deteriorate the air quality and reduce the comfort of the human body [15]. In addition, local human discomfort zones caused by asymmetrical radiation zones (such as cold Windows and heaters), local convection cooling, contact with cold or hot floors [16].

This paper summarizes the application of machine learning algorithms, in the field of architecture, which can improve the model prediction effect through self-learning [17]. Five influencing factors, namely solar radiation, temperature, wind speed, humidity and working hours, were selected to predict the daily electricity consumption of an administrative building [18]. Outdoor temperature, wind speed (m/s) and building use time were selected as influencing factors, which improved the prediction accuracy and stability compared with traditional BP neural network [19]. Genetic algorithm is used to optimize the connection weight of neural network by selecting 14 variables such as building layout, building orientation, building size coefficient, building area, window wall ratio, heat transfer coefficient, thermal inertia index and heat transfer coefficient [20]. The prediction accuracy and prediction time have been greatly improved [21]. Seventeen influencing factors, including coefficients of the envelope structure, were selected [22]. Eleven input parameters were selected as sample features from three aspects: historical energy consumption data, climate factors and time cycle factors [23]. Six influencing factors were selected to establish an office building energy consumption prediction model with high accuracy [24, 25].

Multiple variables such as thermal comfort, visual comfort and sunshine amount in winter and summer of near-zero energy buildings in southern Italy [26, 27]. The best solution for building environment comfort [28, 29]. A multi-objective optimization simulation model predictive control method based on building operating cost and thermal comfort was proposed [30]. An indoor environmental energy saving control scheme based on particle swarm optimization was proposed, which comprehensively considered the rational distribution of lighting consumption [31, 32]. The objective function of genetic algorithm was established to finally obtain the optimal solution of indoor thermal comfort control parameters [33, 34]. Considering the indoor thermal environment can more reflect the comprehensive comfort of the human body [35]. At present, this has become the main direction to study the comprehensive quality of indoor environment [36, 37]. Winter and summer seasonal climate characteristics although there are no cold areas and hot summer and warm winter areas with bad climate. And this area is not within the scope of the heating area, most areas are not with centralized heating, people take their own cooling and heating measures, the lack of scientific guidance. Under the same thermal comfort condition, the building operation energy consumption per unit of construction area is even higher than that in cold areas. It is urgent to establish a thermal comfort environment control standard suitable for hot summer and cold winter areas, so as to guide the indoor thermal environment design of buildings and create ideal comfortable and energy-saving ecological buildings.

3 CONSTRUCTION OF HUMAN THERMAL COMFORT MODEL IN HOT SUMMER AND COLD WINTER AREA

3.1 Main Influencing Factors and Measuring Methods of Building Thermal Comfort

At present, due to the special areas, the heat insulation requirements of the building envelope are very high, because the air is humid, the ventilation requirements are higher, so that the ventilation energy consumption has increased significantly. Buildings in the area require air conditioning for cooling and heating for a long time, about half a year in total. To achieve the ideal state of comfort, its energy consumption per unit of building area is much higher than that of cold areas. Creating a comfortable indoor environment is the guarantee that people in the area can work and live normally.

Firstly, the factors affecting the comfort of heat, light and sound are analyzed. The effects of hypoxia on human thermal, light and sound comfort were studied to provide theoretical support for experimental research and evaluation model revision under low pressure conditions. Secondly, based on the results of the network questionnaire survey, the importance ratio of the evaluation indicators was obtained. Thirdly, the atmospheric pressure comprehensive comfort is established. The influencing factors of comprehensive comfort level are compared and analyzed in order to obtain the leading factors affecting comprehensive comfort level. According to the comprehensive evaluation model, the peak parameter and tolerable zone of the comprehensive comfort were calculated and discussed respectively, and a series line model of normal pressure parameter conditions was provided for the comprehensive comfort zone, which was reliable and intuitive. The research frame diagram is shown in Fig. 1.

There is radiation heat exchange between various objects in the environment and the human body, and the average value of heat exchange can be expressed by the average radiation temperature. The average radiation temperature is:

$$t_{avg} = t_i + 2.5 v^{\frac{1}{2}} \left(t_i - t_{air} \right) \tag{1}$$

where t_{avg} is the mean radiation temperature, t_i is room temperature, t_{air} is air temperature, v is air flow rate

According to the definition of *PMV*(Predicted Mean Vote), people are most satisfied with body thermal comfort when *PMV* is 0. *PMV* calculation formula:

$$\begin{aligned} PMV = 0.038\left(M - W\right) - 3.1\times10^{-3}\left(M - W\right) - \\ -1.7\times\left(5.78 - P_n\right) \end{aligned} \tag{2}$$

In the formula: M human metabolic heat production, W external mechanical work performed by the human body, W/m^2; P Related to ambient temperature and humidity

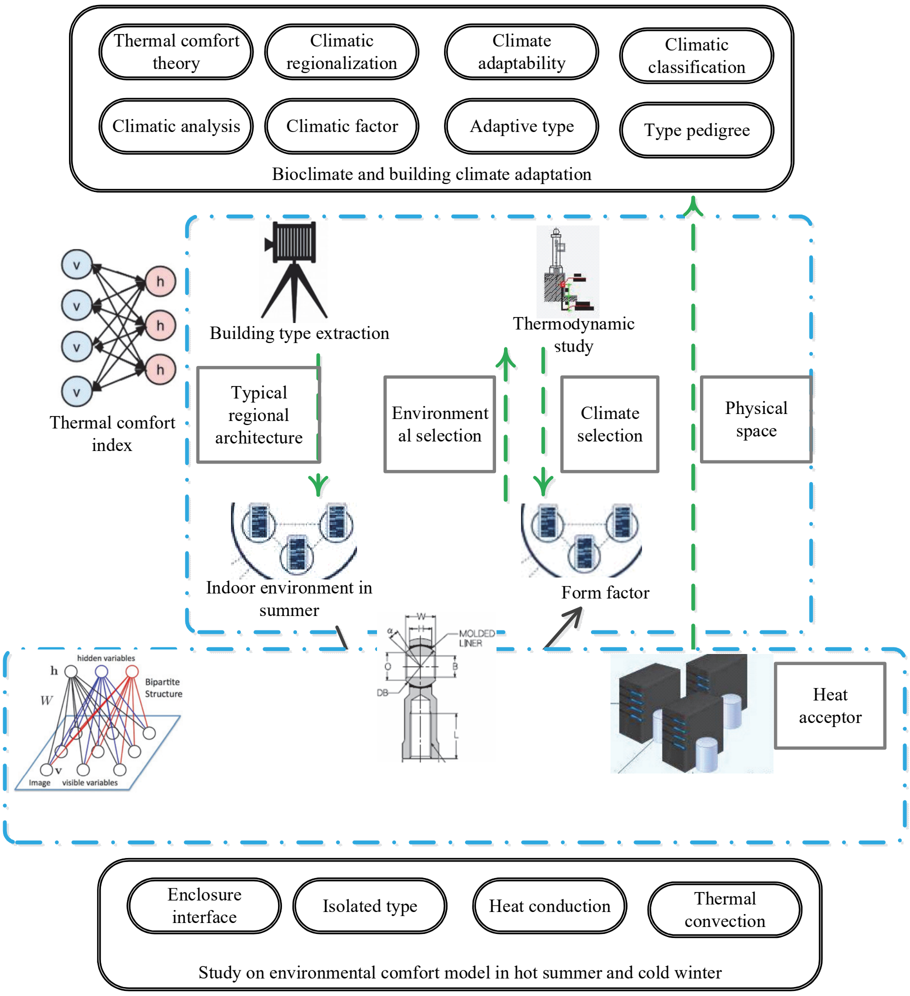

Figure 1 Research framework of thermal comfort model in hot summer and cold winter

3.2 Comprehensive Evaluation Index of Indoor Thermal Environment

It is necessary to synthesize several variables of environmental parameters into one variable to evaluate the indoor thermal environment. A change in one element is compensated for by a corresponding change in another.

The predicted average thermal sensation voting index (PMV) is divided into 7 levels, and its significance is shown in Tab. 1:

Table 1 Seven indexes of thermal sensation

Thermal sensation	hot	warm	tepid	moderation	A little cool	cool	cold
PMV	3	2	1	0	–1	–2	–3

Under conditions above and below thermal neutrality, the thermal response of human body under dynamic environment is characterized by slow change of thermal sensation when the thermal stimulus is hot, fast change when the thermal sensation is cold. When the human body temperature is higher than neutral, the cold stimulus will cause human comfort or rapid response. When below neutral conditions, skin temperature decreases steadily as the ambient temperature decreases, and average skin temperature is a good predictor of feeling and discomfort. As shown in Fig. 2, when the skin temperature drops between 28 and 32 °C, the feeling of comfort increases rapidly. Once the sweating response begins, the sweating response limits the rise in skin temperature, which remains basically constant, while the temperature feels like it rises only slowly.

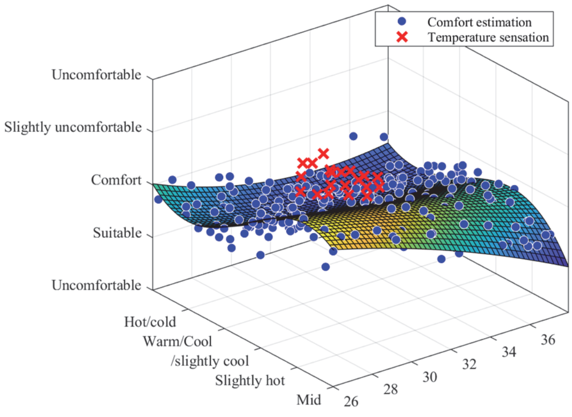

Figure 2 Average skin temperature in relation to sensation and comfort

The utility function can reflect the joint action of convection and radiation in the thermal environment of the subject.

$$t_{air}=\frac{r_c t_a + r_r \overline{t_r}}{r_c + r_r} \tag{3}$$

where t_{air} ambient air temperature, $\overline{t_r}$ average radiation temperature, r_c convective heat transfer coefficient, r_r radiant heat transfer coefficient, t_{front} begin radiation temperature

Average radiation temperature:

$$\bar{t}_r = \frac{0.17(t_{\text{top}} + t_{\text{down}}) + 0.21(t_{\text{right}} + t_{\text{left}})}{2\times(0.17+0.21+0.32)} + \\ + \frac{+0.32(t_{\text{front}} + t_{\text{back}})}{2\times(0.17+0.21+0.32)} \tag{4}$$

The color temperature of different light source also has certain influence on the comfort. Glare can also cause discomfort, and controlling glare is particularly important. However, in practice, the illumination level is mainly used as an objective indicator of lighting conditions, and in the relevant lighting specifications, most of the illumination value is used as the main parameter to provide lighting conditions.

The hierarchy of the evaluation structure to determine the comprehensive comfort level of human body in indoor environment should be developed around the purpose of comprehensive evaluation. Each subsystem is decomposed in detail to determine the indicators of each sub-level, including both quantitative and qualitative indicators, and finally the hierarchy structure is obtained Fig. 3.

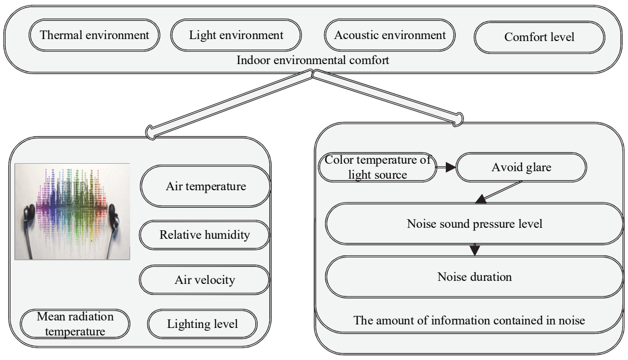

Figure 3 Hierarchical structure diagram of evaluation indicators

Human Thermal response is a Thermal Comfort Vote (TCV) that evaluates thermal comfort based on ASHRAE Standard. It is a 5-level index ranging from 0 to 4, as shown in Tab. 2.

Table 2 Thermal comfort voting

Thermal comfort voting TCV				
0	1	2	3	4
comfort	Slightly uncomfortable	uneasiness	Very uncomfortable	intolerability

There is no uniform evaluation grade standard for thermal comfort, optical comfort and sound comfort. The quantification of qualitative indicators must first have directivity, and secondly, the new indicators without dimension should have the same meaning, and the scale distance of indicators is consistent. The evaluation index of the physical stimulus response to the three factors was adopted on a scale consistent with the thermal comfort voting (TCV), that is, a 5 - level scale index ranging from 0 to 4. The environment stimulus and the evaluation index value is given in Tab. 3.

Table 3 Thermal environment, light environment, sound environment and comprehensive evaluation index values correspond to physical stimulation comfort

y	0	1	2	3	4
Thermal comfort	comfort	Slightly uncomfortable	uneasiness	Very uncomfortable	intolerability
Light comfort	moderation	Light (dark)	Light (dark)	Very bright (dark)	Can't stand light (dark)
Acoustic comfort	comfort	Slightly uncomfortable	uneasiness	Very uncomfortable	Unbearable (feeling of irritability caused by noise)
Comprehensive comfort	comfort	Slightly uncomfortable	uneasiness	Very uncomfortable	intolerability

3.3 Comfort Model Based on the Weight of Built Environment Factors

The built environment comfort model can be expressed as the combination of four environmental factors' influence on comfort.

$$t = w_1 t_1 + w_2 t_2 + w_3 t_3 + w_4 t_4 \tag{5}$$

where, w_1, w_2, w_3, w_4 are the weights of each factor in the built environment, that is, the importance of each factor's influence on comfort; t_1, t_2, t_3, t_4 are the comfort models of each factor in the built environment, as shown in Fig. 4.

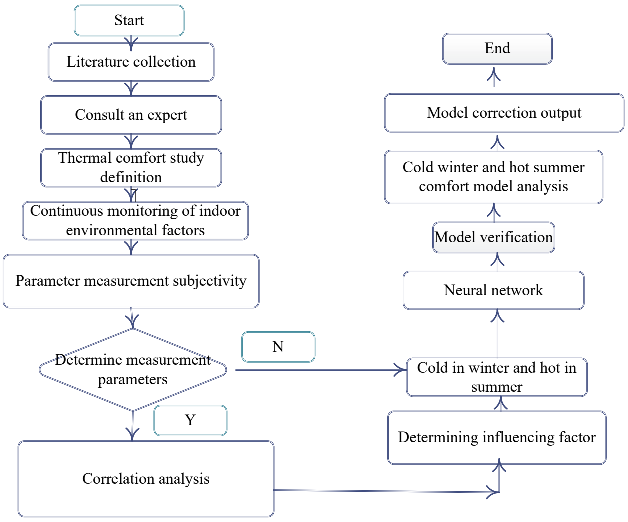

Figure 4 Research flow of thermal comfort model

The weight calculation constructs the results of each questionnaire into the form of a judgment matrix, which is the result of pairwise comparison of each element.

$$T = \begin{bmatrix} 1, t_{12} \ldots\ldots t_{1n} \\ t_{21}, t_{22} \ldots t_{2n} \\ \ldots. \\ t_{n1}, t_{n2} \ldots 1 \end{bmatrix} \tag{6}$$

According to each judgment matrix obtained, the maximum eigenroot λ and its corresponding eigenvector are solved as the weight vector. For λ:

$$\lambda_i = \frac{\sum_{j=1}^{n} t_{ij} w_j}{w_i} \tag{7}$$

So there are:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Tw)_i}{w_i} \tag{8}$$

Partial pressure of water vapor in the air around the human body p:

$$p_{air} = \frac{\exp(1.56 - w_i)}{t_{ij} + 2.3} \tag{9}$$

Average indoor radiant temperature t:

$$t_r = t_{air} + 2.6\sqrt{v\left(t_{air} - \overline{t_r}\right)} \tag{10}$$

When the judgment matrix does not meet the consistency requirements, the consistency correction is carried out on the matrix. After two corrections, the consistency requirements are met. The final weight calculation results are shown in Tab. 4.

Table 4 Modified judgment matrix and weight calculation results

	Thermal environment	Air quality	Light environment	Acoustic environment	Weight w
Thermal environment	2	0.2	4	4	0.2543
Air quality	4	2	8	4	0.5878
Light environment	0.3	0.13	2	0.16	0.0354
Acoustic environment	0.2	0.18	6	2	0.1187

The thermal environment and air quality in summer vary greatly due to outdoor meteorological factors and indoor personnel density. Therefore, when classifying the weights of various factors in the built environment, the importance of each factor's influence on comfort in each type of built environment is expressed in the form of a bar chart, as shown in Fig. 5 and Fig. 6.

As can be seen from Fig. 5, in the office environment, the importance of the acoustic environment is slightly higher than that of the light environment. Because in the office environment, indoor personnel mainly work through the computer, indoor personnel can actively adjust to achieve a more comfortable visual effect, such as through the opening and closing of the curtain, switching lamps or adjusting the brightness of the computer screen, so indoor personnel pay less attention to the light environment. However, because the office indoor personnel are mainly engaged in mental work, they need a good acoustic environment, and because the acoustic environment is not easy to be controlled by the indoor personnel, the demand for a good acoustic environment has been enhanced.

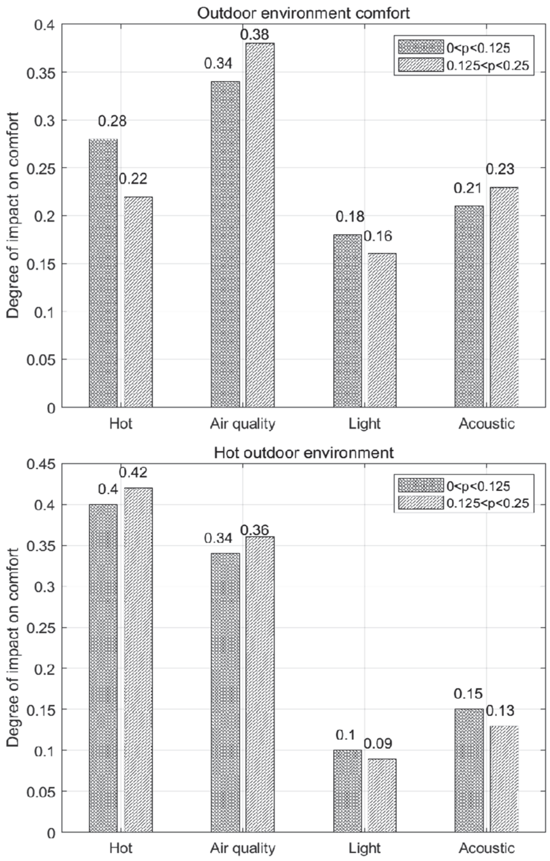

Figure 5 Importance of the influence of various factors on the comfort of the office indoor environment

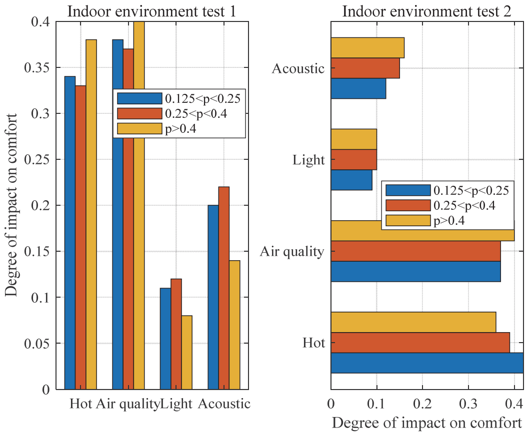

Figure 6 The importance of the influence of various factors on the comfort of the meeting room environment

As can be seen from Fig. 6, in the meeting environment, the influence of sound environment on comfort is significantly higher than that of light environment. Because indoor personnel can actively adjust the indoor light environment by opening and closing the lamps and curtains, so as to meet the needs of indoor personnel, indoor personnel think that the importance of the light environment is low. However, indoor personnel mainly use language to communicate with each other in the meeting, so a good acoustic environment is needed to ensure that the communication is not interfered with and affected, and because the acoustic environment is not easy to be controlled by indoor personnel, indoor personnel have a higher demand for the acoustic environment than the light environment.

4 CONSTRUCTION OF HUMAN THERMAL COMFORT MODEL IN HOT SUMMER AND COLD WINTER AREA

The human body exchanges heat with the surrounding environment through the effects of temperature, radiant heat, water evaporation, etc. Thermal comfort studies can be understood as input-to-output mapping with "black box" characteristics.

The thermal comfort of the human body is taken as the output of the neural network (+3 means hot, +2 means warm, +1 means slightly warm, 0 means moderate, –1 means slightly cool, –2 means cool, –3 means cold). The network establishment process is as follows:

Input vector $\boldsymbol{T}$, where t_1 is the air temperature, t_2 is the indoor air humidity, t_3 is the indoor air flow rate, t_4 is the average wall radiation, t_5 is the metabolic amount and t_6 is the dressing amount. Hidden layer vector $\boldsymbol{R}$, where:

$$r_j = \exp\frac{\| T - C_j \|^2}{2\lambda_j^2} \tag{11}$$

The weight vector $\boldsymbol{W}$ of the network is obtained through the supervised learning algorithm, then the output of the network C, that is, the mathematical expression of the thermal comfort model, is as follows:

$$f(t) = \sum \exp\frac{\| T - C_j \|^2}{2\lambda_j^2} \times w_j \tag{12}$$

Average daily temperature below 5 °C or above 28 °C, and obtain the physical environmental factors required for the establishment of the model. Meanwhile, more than 100 subjects were surveyed by questionnaire to obtain individual factors and thermal comfort feelings. 300 learning samples were obtained, and part of the learning sample data are shown in Tab. 5.

Table 5 Partial learning sample data

Room temperature	Relative humidity	Indoor wind speed
8	43	0.02
9	46	0.2
12	54	0.1
13	72	0.13
15	54	0.12
10	76	0.09
16	80	0.08
17	63	0.06
20	54	0.06
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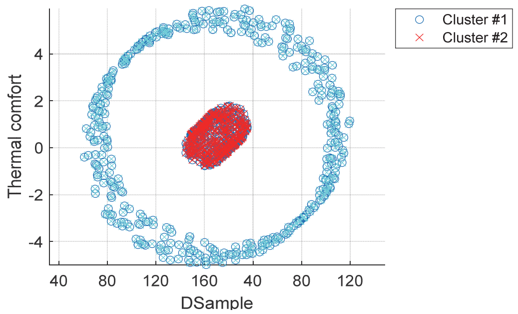

Figure 7 Comparison between model output values and survey values

In order to test the stability of the network, about 50 samples from the learning sample selection were also included in the test sample.

In Fig. 7, the red crosses represent the model output values and the circles represent the survey values. The maximum error between the output value and the survey value is 0.528, the minimum is 0.0022, and the average is 0.14. It is feasible to use neural network as a means of thermal comfort data processing, especially the establishment of neural network under unsteady state conditions. It makes it possible to predict the change of thermal sensation over time under the condition of abrupt environmental change, and it is more convenient to use.

5 SIMULATION

The adaptive thermal comfort theory in hot summer and cold winter areas assumes that the thermal neutral temperature changes with the change of the average indoor temperature. Fig. 8 shows the significant correlation between the thermal neutral temperature in winter and summer and the average indoor air temperature. This significant correlation between it and the average indoor temperature indicates that people will take corresponding adaptive adjustment measures to adapt to the average indoor air temperature. Therefore, the thermal neutral temperature is generally close to the average temperature that people experience over a long period of time.

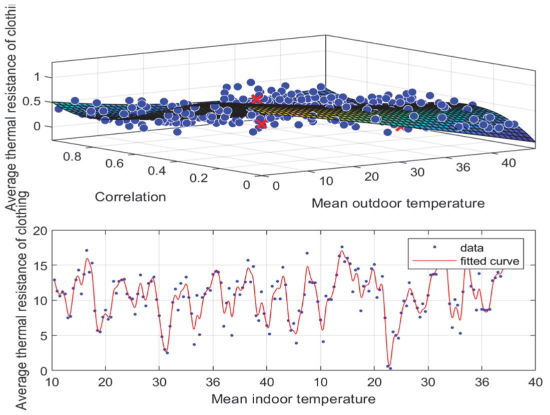

Figure 8 Relation between clothing thermal resistance and average indoor and outdoor temperature

As can be seen from Fig. 8, the amount of indoor clothing of residents in this region has a large seasonal change. The thermal resistance of people's clothing in winter ranges from 1 to 2 clo, mostly around 1.5 clo, while the average thermal resistance of clothing in summer is around 0.5 clo. This is also an adaptive adjustment measure for residents in this area to such a climate characteristic as "hot summer and cold winter". It can be seen that as the average indoor temperature changes, the amount of clothing people wear is also adjusted accordingly.

Due to the different operation mode, the heat transfer process of the wall is different, and the surface temperature and heat flow size are also different. Therefore, through the comparison between them, the thermal characteristics of the wall in different modes can be obtained. The following is a comparative analysis of the internal temperature periodic changes of the aerated concrete wall under different modes, and the calculation results are shown in Fig. 9, Fig. 10, Fig. 11, Fig. 12 and Fig. 13.

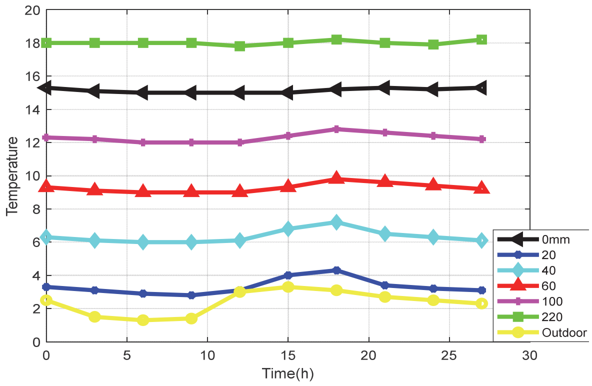

Figure 9 Temperature distribution of aerated concrete wall in continuous operation mode

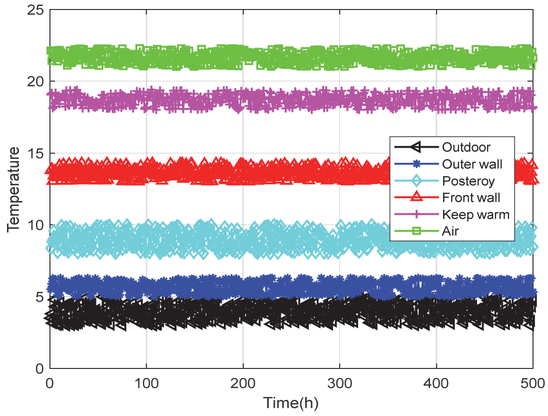

Figure 10 Temperature distribution of aerated concrete wall in intermittent 1 mode

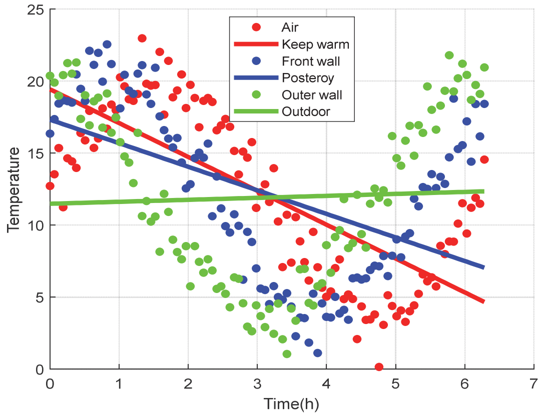

Figure 11 Temperature distribution of aerated concrete wall in intermittent 2 mode

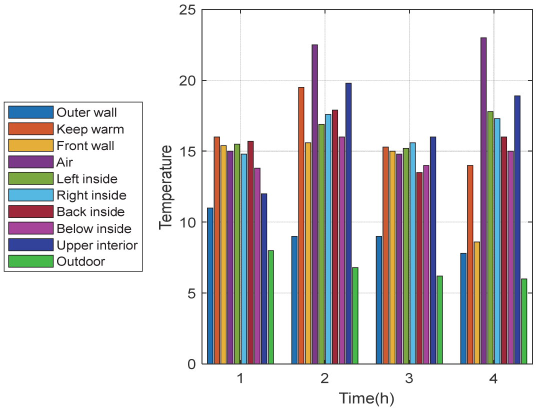

Figure 12 Temperature distribution of aerated concrete wall under intermittent 3 mode

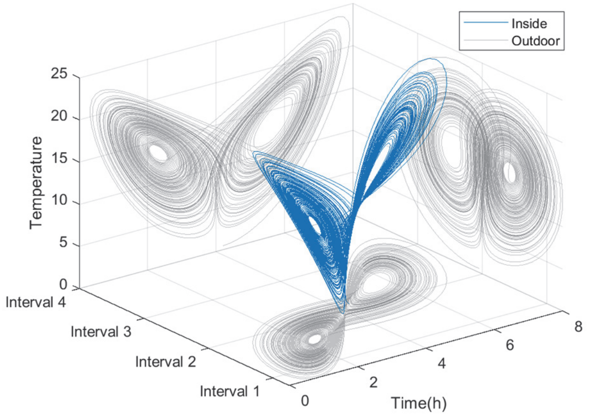

Figure 13 Temperature distribution of aerated concrete wall in intermittent operation mode

In hot summer and cold winter areas, the changes of indoor and outdoor air temperature in summer are distributed in a straight line like the steady-state heat transfer process. After the temperature on the surface of the wall and inside reaches stability, the temperature does not show a curve distribution of periodic fluctuations, and the amplitude of fluctuations is different under the influence of the operation mode. As can be seen from the above chart:

(1) In continuous operation mode, the temperature variation of the inner surface is mainly affected by the overall outdoor temperature. In intermittent operation mode, the indoor air temperature changes, and the internal surface temperature also changes accordingly.

In the intermittent mode, the indoor air temperature changes with a 2-hour period, and its periodicity is strong, and the internal surface heat storage coefficient is larger than that in the intermittent mode. Therefore, the fluctuation amplitude of the internal surface temperature changes periodically is smaller than that in the intermittent mode.

(2) Under different modes, the temperature changes on the outer surface of the wall are basically similar, and the average temperature is proportional to the operating time of the equipment.

Under different modes, although the temperature change of the inner surface is different, due to the resistance of the wall to the temperature, the temperature change of the outer surface is basically not affected by the change of indoor air temperature, and the temperature change is basically similar.

However, the temperature on the outer surface is directly proportional to the operating time of the equipment. This is because the wall has reached a stable periodic change state, and the average temperature of each layer is mainly determined by the temperature of the internal and external boundary conditions and the heat transfer coefficient of the wall. The higher the indoor temperature, the higher the internal temperature of the wall. In different modes, the average air temperature in the room is proportional to the operating time of the equipment, so the temperature on the outer surface is proportional to the operating time of the equipment.

At the same time, combined with the common sense of summer indoor air temperature changes in hot summer and cold winter areas, the following conclusions can be drawn:

(1) In continuous mode, the thermal comfort of the three

materials is better. Although the average temperature of the inner surface of the three walls is the same, its temperature is the most stable and the thermal comfort is relatively good. (2) In intermittent operation mode, the thermal comfort of the internal insulation wall of the three materials is better.

The temperature of the wall is basically in a state of rapid rise, and the temperature changes greatly, which is not conducive to thermal comfort. Although the average temperature of external insulation is second, the starting point of temperature is relatively high when starting, and the temperature changes relatively slowly, which has certain advantages in thermal comfort. In addition, the internal surface temperature of the external insulation wall decays slowly after the shutdown, and the average internal surface temperature of the external insulation is higher during the shutdown.

In terms of summer indoor air temperature changes in hot summer and cold winter areas, the air temperature of the room with the internal insulation wall rises quickly when the machine is turned on, but the temperature drops quickly after the machine is shut down, and the air temperature soon drops to lower than the external insulation. The change in air temperature of the room with the external insulation wall is the opposite.

The choice of intermittent operation mode is mainly to explore a way of energy saving, that is, the use of indoor air and internal surface temperature attenuation after shutdown can meet the residual heat under comfort conditions, to achieve the purpose of energy saving. The indoor air temperature of the external insulation decays slowly, so the average temperature is larger, and the inner surface temperature of the external insulation wall is higher than that of the calculation.

6 CONCLUSION

In this paper, through the experimental research under normal pressure and low pressure conditions, the evaluation model of human comprehensive comfort in summer in hot summer and cold winter area is established by the utility function method, and the evaluation model of human comprehensive comfort under low pressure conditions is modified. The methods of climate control structure of wall, roof and ground were analyzed respectively, and important interfaces were selected for performance simulation, and the morphological elements of enclosure interface with ecological and climate control significance were extracted. The relevant morphological elements are condensed and summarized, and the building thermodynamic models of hot summer and cold winter areas and hot summer areas are established. The established human thermal comfort model in hot summer and cold winter areas takes into account six subjective and objective influencing factors of thermal comfort, and reflects the weight of each influencing factor and the influence weight of each factor on thermal comfort through the weight relationship between neurons. The model parameters are easy to obtain, and the evaluation of human thermal comfort in hot summer and cold winter areas is more accurate and effective. It can provide better theoretical guidance for the assessment of building energy efficiency in this area. At present, the discussion on the climate control effect of various form elements and their combination is still mainly in the qualitative division. In the analysis stage, the comprehensive, scientific and effective quantitative performance simulation is still relatively shallow, and the quantitative analysis or reverse. The goal of guiding architectural design is still far away, and performance-oriented quantitative tools should be further mastered in the future.

Acknowledgments

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