Impacts of Indoor Temperature and Velocity on Human Physiology in Hot Summer and Cold Winter Climate in China

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ABSTRACT

The impacts of indoor thermal environment on body physiology have been carried on for four years (2003-2007) in laboratory in Chongqing, a typical city located in hot-summer and cold-winter region in China. Experimental objectives used are healthy university students. The range of indoor air temperature in summer is 25 °C - 37.5 °C. The objectives’ physiological changes (Motor nerve Conduction Velocity, Sensory nerve Conduction Velocity, Skin Temperature etc.) under different temperatures and ventilations have been tested.

The results show that the effect of air temperature on skin temperature is significant; Skin temperature has a linear and positive correlation with MCV and SCV; Air temperature has a significant effect and a positive correlation with MCV and SCV when indoor air temperature are not too high (25 °C - 32 °C); In this temperature range, mechanical ventilation can significantly improve the thermal comfort sensation. However, increasing indoor air movement has a little effect on MCV and SCV when indoor air temperature is above skin temperature (34 °C - 37.5 °C).

Such experiments can provide basic data to establish the standard of acceptable indoor thermal environment for hot-summer and cold-winter region in China.

Keywords: thermal comfort, indoor thermal environment, human body physiology, Motor nerve Conduction Velocity, Sensory nerve Conduction Velocity

INTRODUCTION

Buildings are designed to suit the climate in which they are located and the functions for which they are intended. There is a unique relationship between an individual, the
environment and the building he or she inhabits. Everyday experiences tell us that there are a host of factors which are relevant to this concept. Air and surface temperatures, humidity, air movement have an important role. A deficiency in one of the physical factors can spoil the balance of the environment. The physical environment can enhance one’s work but an unsatisfactory environment can hinder work output. As building service engineering and building environmental control systems become more complex and expensive, cost justification becomes a greater issue for decision makers. Factors such as poor lighting, both natural and artificial, poorly maintained or designed air conditioning, and poor spatial layouts are all likely to affect performance at work. The variations in thermal comfort and well being were influenced by temperature changes.

The indoor thermal environment will directly influence human physical and psychological health, sense of comfort, as well as human’s well being\[1, 2\]. Professor Fanger published the famous thermal equations based on experimental data\[3\]. He created the currently widely-used indexes: Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfaction (PPD) to assess thermal comfort, based on the human body thermal equivalence equation\[4\]. The thermal comfort standard recommended by ASHRAE55-2004\[5\] and ISO7730\[6\] are widely used in the world to measure thermal comfort based on Fanger equations. However, more and more researches show that the PMV-PPD index obtained through experiment in Laboratory in the 1970s can not be suitably applied to all the countries and regions, especially for the free running buildings\[7, 8, 9, 10, 11\].

The indoor environment of the hot-summer and cold-winter region is very much different from those experimental conditions in Professor Fanger’s air-conditioned Laboratory. The suitability of applying Fanger’s result as an international design standard into different local building conditions is now argued by experts. The impact of indoor thermal environment on human physiology has been carried on for four years (2003-2007) in Laboratory in Chongqing, a typical city located in hot-summer region in China. Experimental objectives used are healthy university students. The range of indoor air temperature in summer is 25 °C - 37.5 °C. The objectives’ physiological changes (Motor nerve Conduction Velocity, Sensory nerve Conduction Velocity, Skin Temperature etc.) under different temperatures and ventilations have been tested\[12, 13, 14, 15\]. The results show that the effect of air temperature on skin temperature is significant; Skin temperature has a linear and positive correlation with MCV and SCV; Air temperature has a significant effect and a positive correlation with MCV and SCV when indoor air temperature are not too high (25 °C - 32 °C); In this temperature range, mechanical ventilation can significantly improve the thermal comfort sensation. However, increasing indoor air movement has a little effect on MCV and SCV when indoor air temperature is above skin temperature (34 °C - 37.5 °C).
METHODOLOGY

The impacts of indoor thermal environment on body physiology have been carried on in Laboratory in the region of the hot-summer and cold-winter in China. The parameters of physiology including Motor nerve Conduction Velocity, Sensory nerve Conduction Velocity, Skin Temperature etc, have been selected. The impacts of indoor temperature and velocity on human physiology have been measured and analyzed.

The human nerve system consists of trillions of neurons, which have converted to functions to recognize, conduct and analyze information of other cells and environmental information. Nerve system is the quickest responding to heat among all parts of human body. For example, sensory cells receive the stimulus from the climate in a hot environment, and then conduct it to the human brain to cause a feeling of hot or cold. Consequently, nerve system is a main physiological system which has a directly influence on the reception and process of information of heat in the environment[16].

As far as the human nerve system is concerned, the most frequent and direct parameter is nerve conduction velocity, which is calculated along certain nerve phase, meaning the fastest (both sensory and motion) velocity of neuraxis[16]. When the electricity stimulates nerve, the impulse is conducted by motor, sensor or mixed nerve. In consideration to convenience and feasibility, the experiment chooses the right-hand median nerve as the stimulated nerve, as Fig.1 shows. The median nerve sensing fiber is mainly distributed in the hand palm side and hand outside skin. The experiment applies the surface stimulation by electrode to test. The stimulated parts and electrodes are located, as Fig.2 shows.

Skin temperature is an important physical indicator that reflects the effect on human body by surrounding climate condition and outside body condition (subjects’ activities and clothes). In normal case, the skin temperature of human body varies between 15…42 °C. The skin temperature on any point of body surface depends on local balance between the heat streams that flowing from central to this point of skin and the
heat radiation from there to outside surroundings. Since skin temperature is a physical indicator that reflects the effect on human body by surrounding climate conditions, it is easy to be affected by the surrounding conditions, which is a sensitive indicator.

Hanada’s research found that different parts of the human body have different feelings of warmth [13]. The body parts such as the chest, upper arm, and legs are easy to feel cold, while the cold stimulation is most sensitive when the upper arm, forearm, and leg are feeling together. Considering the practical condition, a normal experiment can measure skin temperature of 3 to 10 points to reflect the average skin temperature of the whole body. In the experiment, the 6-point method has been used. Skin temperature also affects nerve conduction velocity, which is the most important physical factor that affects conduction velocity. When skin temperature varies between 25…35 °C, the decrease of nerve conduction velocity displays a linear relation, namely each 1 °C increase in skin temperature results in 2…3m/s increase of conduction velocity. Generally, when skin temperature is higher than 30 °C, temperature effects will be little. Therefore, the experiments focused on analysis of nerve conduction velocity, skin temperature and relationship between skin temperature and nerve conduction velocity in different thermal environmental conditions.

Because the experiments relate to measurement of thermal environment physics parameters and the human physiological parameters, the measuring instruments are grouped into two terms: Environmental parameters and Physical parameters measuring instruments. There are Copper-Constantan Thermocouple to measure outdoor and indoor air temperatures, Multifunctional Intelligent Data Acquisition Instrument for checking and measurement, Indoor Air Quality Tester to measure indoor air relative humidity, Portable Hot Wire Anemometer to measure indoor air velocity; Twelve-Channel Electrocardiograph ECG-9103P and Multifunctional Intelligent Environmental Data Acquisition Instrument, MEB-9104 to measure nerve conduction velocity MCV and SCV, Digital Electroencephalogram System EEG-8200 Human Skin Impedance Tester is used to measure skin impedance, Infrared Thermometer to measure skin temperature.

All the testing apparatus have been debugged and adjusted. The testing apparatus and instruments have very high precision. Experts have invited to adjust instruments after installation. Inside the room, 30 thermocouples have been evenly distributed and settled at the height of 1.7m from the floor to monitor the distribution of the air temperature in the whole laboratory. The temperature of ceiling, floor, window, wall etc is measured directly by infrared temperature measuring instruments. The causal measuring points are located at 4 places, which are when the subject is away from the floor at 4 heights: 0.1m, 0.6m and 1.1m, which refer to the three body parts when the subject is sitting: feet, belly and head, and 0.5m, which refers to the lying gesture of the subject.
The experiments measure the subjects’ physical parameters include EEG, MCV, SCV, ECG, skin temperature, skin resistance, heart beat rate, blood pressure, body temperature. These experiments include two extreme environments in winter and summer from July 2003 to Feb. 2007.

<table>
<thead>
<tr>
<th>Time</th>
<th>Experiment parameters</th>
<th>Winter mainland parameters</th>
<th>Summer mainland parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter Indoor air temperature (13.2±1.5 °C)</td>
<td>Wind speed near human body: (0.17±0.2)m/s</td>
<td>Comparative indoor air humidity: (80.9±4.2)%</td>
<td>Indoor air temperature: (13.2±1.5) °C Wind speed near human body: (0.35±0.2)m/s Comparative indoor air humidity: (80.9±4.2)%</td>
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<tr>
<td>Summer Indoor air temperature (32.4±0.7) °C</td>
<td>Wind speed near human body: (0.10±0.02)m/s</td>
<td>Comparative indoor air humidity: (73.6±7.4)%</td>
<td>Indoor air temperature: (24.2±0.7) °C Wind speed near human body: (0.35±0.2)m/s Comparative indoor air humidity: (44.2±5.3)%</td>
</tr>
<tr>
<td>Summer (High-temperature indoor environment) Indoor air temperature (37.3±0.6) °C</td>
<td>Wind speed near human body: (0.10±0.02)m/s</td>
<td>Comparative indoor air humidity: (65.4±7.2)%</td>
<td>Indoor air temperature: (37.3±0.8) °C Wind speed near human body: (0.47±0.02)m/s Comparative indoor air humidity: (63.8±6.7)%</td>
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**RESULTS**

**Analysis of the winter measurements results**

The experiments in the winter mainly measure the influence of air temperature and draught on nerve conduction velocity. From the Fig. 3, it can be observed that the longer the mechanical ventilation is, the more MCV is obviously decreasing. During the whole process, the MCV can be divided into 3 stages. The first stage is from no-draught to 5 mines time of mechanical ventilation, and the MCV has a sudden drop, for the human body is affected suddenly by draught under cold thermal environment, which leads to the bigger heat loss. In the second stage from 5 mines to 20 mines time of mechanical ventilation, the MCV is still decreasing, but with slower speed compared with the first stage. Although the human body heat loss is affected, the human body can automatically moderate its temperature under some environmental parameters. Thus the lowering of MCV caused by draught is controlled. In the third stage after 20 mines time of mechanical ventilation, The MCV change rates are increasing compared with the second stage, The longer the time of draught that subjects suffered, the more MCV decreases rapidly The thermal environments have a bigger influence on MCV.
The time of draught blow is negatively correlated to MCV and SCV. The regression equations are $y = 29.253e^{-0.062x}$ and $y = 47.968e^{-0.0621x}$ respectively for MCV and SCV, and correlation coefficients are $R^2 = 0.9932$ and $R^2 = 0.9867$ respectively.

Fig. 4 shows that there is an obvious decrease trend for skin temperature with the strong draught. And a sudden decline emerges from no-draught to draught. When draught duration is 5 min, the decline of skin temperature decreases about 5 °C. With the whole testing period, the skin temperature reduces 10 °C with the final value of 15 °C. There is an obvious effect of draught in winter on skin temperature.
Analysis of the summer measurements results

The impacts of air temperature and velocity on the nerve conduction velocity and skin temperature in summer have been measured and assessed similar in summer and in winter. The MCV and SCV have downtrend with the time of ventilation. Fig. 5 shows there is a short suspension of SCV downtrend between 15min and 20min after ventilated. That means the subjects have had a corresponding physiological response to the stimulation made by ventilation during this period. For example vasoconstriction or increase metabolic heat production and reduce heat exchange with the outside to inhibit skin temperature falls, thus inhibiting nerve conduction velocity decline. Subsequently, the cooling capacity of the environment over the body heat production capacity, and the skin temperature further decreases and SCV has further reduced. Comparing to the experiment, the MCV and SCV downtrend in summer with ventilation are far little obvious than that in winter with draught. The subjects’ skin temperatures with MCV and SCV have linear correlation.

Analysis of extremely high temperature (in summer) measurements results

The summer of 2006 in Chongqing has suffered the rare high-temperature and dry conditions for the last 100 years. Outdoor air temperature above 40 °C lasts for many ten days. The disastrous weather has provided a valuable opportunity for the experiment for us and gain a number of extremely high-temperature environments indoor physiological data.

The nerve conduction velocity has no significant difference for the environment condition. The ventilation could not affect the value of MCV and SCV in extremely high temperature environments. In the extremely high temperature environments, the outside air temperature is higher than the skin temperature; evaporation heat is the only way to dispel heat for the human being, so that the cooling effect of heat dispelled by convection would be ineffective when air flows. Comparing the average value of MCV
and SCV in normal conditions with the average value of MCV and SCV in extremely high temperature in summer, the value of MCV and SCV under the extremely high temperature is higher. That means the higher the air temperature is, the faster the subjects’ nerve conduction velocities are. The subjects would be prone to fatigue and be adverse to human health. The heat stress will increase the body's physiological load of the organizations and organs.

**DISCUSSION**

The impacts of indoor environments on human’s physiology and thermal comfort in the regions of hot in summer and cold in winter is very representative and has important practical significance. In this paper, the human physiological parameters, which are affected by environmental factors change obviously (e.g. MCV, SCV, skin temperature, etc.) have been selected and measured in the region of hot-summer and cold-winter in China. The impacts of thermal environments, indoor temperature, draught and ventilation on Human Physiology have been assessed.

The results show that MCV and SCV decline obviously with the time of draught in the winter. The skin temperature corresponding to the MCV and SCV show a linear correlation. The higher the indoor temperature is, the higher the value of MCV and SCV are. The MCV and SCV in free-running room with high air temperature are higher than that in air condition environment. The impacts of draught on MCV and SCV in winter are much bigger than the impacts of ventilation in summer.

The effect of air temperature on skin temperature is significant; Skin temperature has a linear and positive correlation with MCV and SCV; Air temperature has a significant effect and a positive correlation with MCV and SCV when indoor air temperature are not too high (25 °C - 32 °C); In this temperature range, mechanical ventilation can significantly improve the thermal comfort sensation. However, increasing indoor air movement has a little effect on MCV and SCV when indoor air temperature is above skin temperature (34 °C - 37.5 °C). Draught has to be carefully avoided in the winter in order to achieve a comfort thermal environment. Such experiments can provide basic data to establish the standard of acceptable indoor thermal environment for hot-summer and cold-winter region in China.

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