What do we feel and what do we do
The research work of thermal comfort in Tianjin University and in China

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Abstract: By looking backwards of ancient Chinese did for indoor comfort environment, this paper describe questionnaire work in Tianjin University, with this work we can find what Chinese people like for indoor air and there are significant difference sensitivity to indoor environment between southerners and northerners in China. The Author oppugns the rationality of using thermal comfort standards without revise in China; discusses the thermal sensation difference between Chinese and Americans, Europeans and analyzes the main factors resulting in the difference.

Key Words: Thermal Comfort, Indoor Environment, Questionnaire

INTRODUCTION
Research into the thermal conditions necessary to provide building occupants with comfort has been undertaken in many regions of the world. But the overwhelming majority of contributions have come from the United States and Europe. The current universally used across all building types, climatic zones, and populations thermal comfort standards such as ANSI/ASHRAE Standard 55-1992 [1] were established according to the studies mainly done in those countries. Now researchers are beginning to challenge the assumption of universality, arguing that it ignores important cultural, climatic, social, and contextual dimensions of comfort, leading to an exaggeration of the need for air conditioning [2].

China, with its population, is the largest country in the world. But its research on thermal comfort is behind the developed countries. To understand what our Chinese feeling to the indoor environment and what Chinese people really like, we should have done many research work and try to find something useful to improve the indoor environment in China. The objective of the present paper is to analyze these factors may result in different thermal sensations of the people in different areas and reveal the importance to carry out more thermal comfort studies in China.
LESSONS FROM ANCIENT CHINA

As ancient civilized nation, China is one of the most s in the world and has been playing an important role in human development. Chinese experience in constructing healthy buildings is significant. Courtyard style buildings have been handed down from one generation to another and can be found almost everywhere in China. These building styles vary depending on many aspects, such as the local climate, different cultural backgrounds, and lifestyles. But no matter how different they are, they demonstrate good environmental conditions. Such examples include the development of old cave the dwellings arranged in atrium style, which still exist in North-West China(Fig.1), and the courtyard buildings style(Fig.2). The walls of these buildings, which surround the courtyards, are linked to a water drain at ground level. The performance mechanism is shown in Fig.3 and the model of a courtyard building is shown in Fig.4.

Fig.3: The performance mechanism of the courtyard buildings

The surrounding walls prevent the intrusion of outdoor polluted air and therefore, keep the indoor air clean and quiet. At the same time, the courtyard introduces daylight, rain, fresh air, long-wave sky and solar radiation. The courtyard forms an opening towards the sky, keeping a good climate in the courtyard and in all the rooms around it. Comfort in Chinese courtyard buildings is distinguished by heating in winter, cooling in summer, and plenty of fresh air. The principal aim of courtyard buildings is to maintain a natural climate conducive to human health.

Fig.4: The model of courtyard in principle

1. Around building
2. Courtyard
3. Light particles up
4. Weighty particles down
5. Inlet of sewer

Fig.5: The differential equation for pressure with light change

It is very important for healthy buildings to have a good source of outdoor air. The outdoor air at ground level contains pollutants, such as dust and gases and these affect the indoor air quality. Outdoor pollutant concentration decreases exponentially with increasing height. The differential equation for variation of atmospheric pressure with height is (see Fig. 5)

$$dp_i = -\rho_i g dh$$  \hspace{1cm} (1)

where $dp_i$ is the pressure element due to the weight of elemental air column height $dh$, $\rho$ is the mass density; $g$ is the acceleration due to gravity. According to Dalton’s Law,

$$p_i = \frac{P_i}{\mu_i} RT$$  \hspace{1cm} (2)

where $\mu_i$ is the molecular weight; $T$ is absolute temperature $<K>$ and $R$ is the universal gas constant. Then we can get
\[
\int_{p_0}^{p} dp_i = n_i = n_o \exp\left( -\frac{\mu_i g}{RT} h \right) \quad (3)
\]

If \( T \) is constant and if the gas pressure \( p_i \) is proportional to the concentration \( n_i \), expression (4) can be written as 

\[
\frac{\mu_i g}{RT} h \quad (4)
\]

where \( n_o \) and \( n_i \) are the concentrations of the gas with the molecular weight \( \mu_i \) at the ground surface (i.e., \( h = 0 \)) and at height \( h \) respectively. As \( h \) increases, \( n_i \) becomes larger; \( n_i \) rapidly decreases as the height \( h \) increases. In general, the particle distribution with height is given by 

\[
n = n_o \exp(-\alpha h) \quad (5)
\]

\( n_o \) and \( n \) are the concentrations of any pollutant at the ground surface (i.e., \( h = 0 \)) and at the height \( h \) respectively; \( \alpha \) is a coefficient determined by measurement.

It can be seen that the outdoor air is cleaner and fresher at higher levels than that at lower ones. The height of courtyard buildings is where the outdoor air is of good quality as shown in Fig. 6. This results in good indoor air quality. In addition, there is a channel at the lowest point of the courtyard ground surface, where rainwater is drained and gases are absorbed.

The air in the courtyard is almost static but being replenished continuously with outside air. This process lets the lighter vapors or gases rise (such as \( \text{H}_2\text{O} \)) but the heavier gases (such as \( \text{CO}_2 \)) fall to the bottom of the courtyard and the pollutants can then be collected in the ground water and carried away.

The equation of motion for a volume element can be deduced and finally we can get equation as follows (see Fig. 7).

\[
\frac{dp_i}{p_i} = \frac{\mu_i Ar^* g}{RT} dh \quad (6)
\]

where \( Ar^* = \frac{\rho_0 - \rho_i}{\rho_i} \) can be positive, negative, or zero corresponding to whether the gas is rising, falling or remaining static.

The air temperature at a certain level changes less than that at ground level. The expression is

\[
t_h = t_0 + \Delta t \quad (7)
\]

\( t_0, t_h \) are the air temperatures at ground and at height \( h \) respectively; \( \Delta t \) is the temperature difference caused by solar radiation which heats the ground and the building surfaces, producing longwave re-radiation and causing a temperature gradient. The temperature gradient is about \( \Delta t = \pm 3.42 \times 10^{-2} \text{ K/m} \). If the height is 100 metres, then \( \Delta t \) is \( \pm 3.42 \text{ K} \). This temperature difference is caused by the moisture phase changes in the air, expressed as

\[
\Delta t_1 = \pm 2.5 \times 10^3 r_m \quad (8)
\]
where \( r_m \) is the rate of moisture phase change; if \( r_m = 10^{-3} \)
then \( \Delta t_1 = \pm 2.5 \times 10^{-3} \). There is a potential change where
the temperature change is proportional to the height.

\[
\Delta t_2 = 10^{-2} \Delta h
\]

When \( \Delta h = 100 \text{m} \), \( \Delta t_2 = \pm 1 \times 10^{-3} \).

The sum of \( \Delta t_1 + \Delta t_2 \) is approximately \( \Delta t = 3.5 \times 10^{-3} \). But in
general, the range of \( \Delta t \) depends on the climate, \( \Delta t = -7 \times 10^{-3} \)
for low isolation; \( \Delta t = 0 \times 10^{-3} \) for overcast sky; and
\( \Delta t = 7 \times 10^{-3} \), for clear night skies.

The climate in courtyard buildings is warm in winter and
cool in summer. Due to the air exchange above the
courtyard, the air quality is good and the air temperature
around the year is mild, as shown in Fig.8. In summer,
the outdoor air transports some water vapor into the
courtyard, and causes the temperature to fall due to
evaporation.

We can see that courtyard buildings in ancient China have
been designed as an environmental form. This building
style has many advantages, especially regarding indoor
air quality. In the courtyard, the thermal, sound and
daylight conditions are improved. Air quality is
continuously renewed. The characteristics of courtyard
buildings, together with smart technologies, can extend
the aims of healthy buildings.

WHAT WE CHINESE PREFER

Many investigations and questionnaire survey in western
countries have been carried out to assess the indoor air
quality (IAQ) and the influence on human being. People
are most productive when their state of well-being is high.
And have become increasing aware that human health
and comfort complaints expressed by occupants of office,
institutional, and other public access buildings are in
many cases associated with poor IAQ. When a building is
subject to complaints sufficiently to convince
management to conduct an IAQ investigation, it may be
characterized as a "problem" or "sick" building. From
these studies, it has been recommended that one of the
first steps for indoor air quality surveys should be a
questionnaire.

The significant differences between southern and
northern people of China, included their living habits,
educational level, diet habit and so on. So people should
not design their air conditioning systems simply
according to the standards, no matter where the standards
are from. In China, we carried out the questionnaire
survey in order to find the demands of the indoor air
parameters that Chinese people like and the differences
between western and eastern people.

A good working environment will help to provide the
user with a good sense of well-being inspiration and
comfort. The main advantage of good environments is in
terms of reduced updating investment, reduced sickness
absence, an optimum level of productivity and improved
comfort level. It is said that productivity and comfort can
be related to quality and satisfaction of the workplace
environment. In western, the relationship of productivity
and the IAQ has been studied for many years. Researches
indicated that productivity could increase by as much as
15% when workers are satisfied with their environment[3].
There are lots of tell-tale signs when productivity is
suffering. Absenteeism, sickness leave, people coming
late and leaving early, extended tea and lunch breaks, risk
of accidents increasing. Increased complaints, excessive
socialization, slow work output and increasing in
mistakes, all of these are very popular in China. The
efficiency way to tell the relationship between the indoor
air quality and the things mentioned above is the
questionnaire survey and investigations in buildings.

We carried out the questionnaire survey with different
people from different place in China. The questionnaire
contains a common core of questions. Section 1 begins
with general background information regarding the
occupant, including type and states of his workplace, the
information about personal characters, including age, sex,
height and weight, smoking habits, educational level and
profession. Section 2 concentrates on how occupants feel
about their working environment, they were asked to
evaluate the influence of the office air parameters by
using number to sign them. For example, if they feel
temperature affect you more than others, they may sign
"1" to temperature, and if they feel humidity affect them
secondly, then they sign "2" to humidity, in the same way,
they can evaluate other parameters. In this section, 8
parameters provided were evaluated, including air
temperature, relative humidity, smoke odor, noise, dust,
fresh air, quantity and quality of light and other odors.
Four seasons were involved, but because there is no
obvious difference between spring and autumn, these two seasons were considered as one. Section 3 is divided into two parts. One is focused on how much they like their workplace, they were asked to rate their environment on a seven point scales, from extremely satisfied to extremely dissatisfied. They were also asked to rate their workplace on factors refer to section 2 in another part.

With section 2, we quantify the results of the occupants' chosen in a certain way, that is, the factor of "1" is quantified to 0.25, factor of "2" is 0.20, factors 0.15, 0.12, 0.10, 0.08, 0.06, 0.04 are the factors of "3", "4", "5", "6", "7", "8" respectively. Use this method the priority of each parameter can get.

Figure 9 shows that there are obvious apices and vales on the curves. The apices indicate that Chinese have sensitivity to these factors, and the vales indicate that the factors are not so important for Chinese. From figure 9, we can also found that, in winter the fresh air is the first important factor to Chinese. It has the highest priority to all other factors, which are 175.15. Temperature is the second important one its priority is 173.31. The third one in winter is dust concentration in the air, its priority is 163.88. In summer, the most important factor is air temperature, which is much higher than any other factors and it is 203.30 for priority; the second and the third ones are fresh air and noise, the priorities are 160.18 and 156.41. In spring and autumn, the important factors are quite different to that in summer. The most important one is not the temperature or fresh air, but the dust in air, which has 171.48 for priority, the second one is fresh air, 165.52 for priority, the third one is noise, 157.72 for priority.

Figure 9 shows us that the important factors influence occupants in these three seasons. According to the questionnaire results, we understand that it is necessary for the designing of air conditioning system to consider synthetically. The important factors are not only temperature, relative humidity as they used to consider, but the fresh air, dusts in air and noise is acting important roles. A good air conditioning system should be able to ensure the indoor environment under fitting temperature, fitting relative humidity, sufficient fresh and clean air, and to the best of one's abilities to control noise according to standards.

There are sensitivity differences exited in Chinese, especially between southerners and northerners, including their living custom, diet habits and so on. This questionnaire study investigates 1203 Chinese occupants, they were 805 northerners and 281 southerners. The work focuses on the relationship between southerners and northerners in office. For the reasons mentioned above,
the results show that they have different demands to their working environment, shows in figure 10 and 11. When designers design the air conditioning systems in China, the differences should also be considered according to the building location.

Figure 10 shows the evaluation results of the workplace as a whole. It indicates the subjective opinions of occupants and reflects the satisfaction of occupants to their working environment. The satisfaction extent is from "extremely satisfied" to "extremely dissatisfied", the quantity is from 1 to 7 in the figure. In figure 10, collectivity means Chinese people as a whole, including people working in south and in north, in east and in west. From this figure, we can see clearly that there is scarcely any differences between collectivity and northerners, but different to southerners. More than 45% of people consider the IAQ of their working environment is acceptable, few people consider their working environment is extremely satisfied or dissatisfied, more than 20% think they are preferable.

Figure 11 shows the percentage of influence factors in workplace. From this figure we can see that factors 3,4,5, they are noise existing in the workplace, stale or stuffy air and odors existed, have no influence difference to Chinese. But factors 1,2,6, they are high temperature, low relative humidity and insufficient lighting, are distinct difference between southerners and northerners. More than 40% of northerners considered their working environment is too hot, but only 25% of southerners are dissatisfied with his working environment caused by high temperature. More than 45% of northerners and less than 25% of southerners considered their working environments were in low relative humidity. On the aspect of lighting, more than 25% of southerners are dissatisfied with the insufficient lighting that is much higher than that of northerners'.

From figure 9 we know that the demands of indoor air parameters are very different in different seasons of a year. On one hand, when an air conditioning system is being designed, and lately, run and control it, seasonal factors should be taken as first consideration. Secondly, traditional air conditioning design methods considered temperature and relative humidity as first needs and pay less attention to the fresh air. According to the results of investigation, fresh air need is as important as temperature and humidity needs, during a special period and in some place of China, the fresh air is even considered more important than the temperature and humidity control. On the other hand, it is important to run a conditioning system accurately because of the different demands of parameters in different seasons. In figure 9 the curves of winter and summer are coincident in the eight points of the parameters, but different to the curve of spring & autumn, especially at the point of temperature, that maybe because the temperature is pleasant for human being in spring and autumn of Chinese climate. The point of dust in air is at apex in curve of spring and autumn, that is to say the parameter of dust in air has highest priority in all parameters. It is obvious that there is so much sand blown by wind in spring and autumn, especially in the north of China, the point of dust in air at apex maybe of this reasons.

Figure 10 reflects the satisfaction of the occupants to their working environment, from this we know that there is scarcely differences between collectivity and northerners, but different to southerners. The amount of southerners who considered their working environments acceptable is much more than that of northerners.

With questionnaire of this paper, it is found that there are significant difference sensitivity to indoor environment between southerners and northerners in China. Chinese from different places have different demands to their working environment. Therefore, as a good air conditioning system design, it is strongly recommended the different demands of people from different places should be taken into consideration. From figure 11 we can see that noise, stale or stuffy air and odors have different influence to southerners and northerners, but
temperature, relative humidity and lighting are distinct between them. This tells us that there are differences between southerners and northerners.

DESIGN OF TEST WORK AND QUESTIONNAIRE
This test work and questionnaire were made in laboratory. There were about 200 tested people involved in, half are male and the others are female. In every test, 10 persons entry the testing room. All of them are health, have a good rest before test and no drink alcohol. The testing room was arranged in HVAC laboratory in Tianjin University (see Fig. 12). The testing and questionnaire work were arranged in the afternoon or in the evening, from April. 16th to May 5th. The testing lasted 2 and half hours. In the testing room, the airflow was maintained as a real air-conditioned room’s airflow and the air velocity is not larger than 0.15m/s. The temperature fluctuation was kept less than 0.3°C, and the humidity fluctuation was less than 5%.

To eliminate the effects of former environment, a prepare room was established. In this prepare room, the temperature was kept between 23 to 26°C. And the tested people should be staying in the prepare room for half hour before they entry the testing room.

RESULTS AND ANALYSIS
- According to the test and the questionnaires, the neutral temperature of the tested people is 24.7°C. The expected temperature is less than the neutral temperature. Female’s neutral temperature and expect temperature little higher than male’s, but the differences are not large. These mean that there are almost same thermal feelings for male and female. There are two curves of the relationship of EI*(New effective temperature) and TS can be gotten, one is for male and another is for female. The gradient of male’s curve is 0.30°C, and the female’s is 0.34°C. This means that female’s thermal sensitive is a little bit strong than male’s.
- When TS=0, LPPD₅=4%. The Chinese people LPPD₅ is less than Fanger’s LPPD₅ date (5%). This means that the tested persons are easy to be satisfied with thermal condition.
- The 80% satisfactory of thermal range of tested person is 21.1-27.5°C. this range is about 1°C lower than Fanger’s and Nevins’ results’. But the wide of the comfort range is almost same.

Compared with the thermal comfort range given in ASHRAE Standard 55-1992, the up limitation of this testing 1.5°C higher.

REFERENCE