The Visualization Study on Research Progress of Thermal Comfort for Indoor Environment Based on CiteSpace

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Abstract. The papers published from 2000 to 2019 in CNKI database were collected. CiteSpace software was used as visualization tool to analyze the research progress of indoor thermal comfort in China based on those papers. The results showed that the period, from 2000 to 2004, was the initial developing stage of researches on thermal comfort in China. From 2005 to 2019, there were two research fields developed of thermal comfort. One was to study the adaptive thermal comfort in different climates in China and try to promote the prediction model according to different climate characteristics. Another research keyword was to expand the field of thermal comfort research, e.g. studying the thermal comfort of the elderly and children, and studying rural houses and tall space buildings. Literature analysis also disclosed that "thermal sensation" and "thermal environment" were the core keywords in the field of thermal comfort from 2000 to 2019. According to research methods, "numerical simulation", "field research" and "questionnaire" were commonly used. Recently, Thermal comfort under natural ventilation became the hot keyword in thermal comfort research. From 2011 to 2019, thermal comfort of rural housing had become a hot topic.

1. Introduction

Human thermal comfort had been a hot issue in building environment. Domestic and foreign scholars had established a relatively complete knowledge system of indoor human thermal comfort through qualitative analysis, experimental research, questionnaire research and quantitative analysis [1-2]. However, with the deepening of the research on thermal comfort, diversified research centers and frontier branches had emerged. Therefore, it is crucial to identify the research core of thermal comfort and accurately grasp the research frontier of thermal comfort. This paper tried to analyze the recent hot field keywords of human body thermal comfort and explore new research frontiers.

2. DATA and METHODS

2.1. Data Selection

The keywords of the academic papers are important contents for readers to retrieve the literature [3]. "thermal comfort" is used as the keyword to search literature related to indoor human thermal comfort in CNKI database. Here, the journal articles from 2000 to 2019 are retrieved with 1-year interval to accurately obtain the data of relevant literature every year. After removing irrelevant papers, 5560 papers...
were selected as samples. In order to observe the phased progress of domestic thermal comfort researches more clearly, the period of 2000-2019 is divided into four time stages, and representative articles in each stage were selected for visualization analysis.

2.2. Research Methods
CiteSpace software[4] is used in this paper to analyze the sample literature with information visualization, literature metrology, illustrating the spectrum of knowledge[5-6]. The analysis steps of CiteSpace software can be summarized as steps of the article being filtered in the CNKI database and exported in Refworks format, and then converting the Refworks file into the file identified, and intuitive cluster view, timeline view and time zone view being generated through visual analysis[7].

3. RESULTS and DISCUSSION

3.1. Literature time distribution analysis
From Figure 1, it can be seen that from 2000 to 2018, the number of articles published in CNKI database in the field of indoor thermal comfort increased from 26 in 2000 to 805 in 2018, which was 670 in 2019 based on incomplete statistics. In order to more accurately grasp the research context of thermal comfort, 2000-2019 is divided into four time periods according to the time interval. The research changes of indoor thermal comfort from 2000 to 2019 are observed through the clustering view of four longitudinal analyses time periods. Then, the four high frequency keywords in the time domain are analyzed horizontally.

![Figure 1. Annual literature volume of indoor human thermal comfort from 2000 to 2019](image)

3.2. Analysis of thermal comfort research topics
It can be found from Figure 2 that the venation diagram centered on thermal comfort is relatively simple compared with other diagrams, with fewer lines and clear venation. At this stage, the key words of literature and journals mainly focus on thermal comfort, thermal environment, indoor air quality, air distribution, thermal sensation and energy saving. Thermal comfort and thermal environment have strong centrality, which is the core of this field. This stage is the initiation stage of the development of China's indoor thermal comfort, also is the essential stage, in the time domain appeared more cited rate very high review papers, on the important theory combing to certain basis to the research of the time domain[8-9].
Figure 2. Keyword association map of 2000-2004 and 2005-2010

Figure 3. Keyword association map 2011-2015 and 2016-2019

Compared with Figure 1, the network structure is complex, and the center degree of thermal comfort is 0.49. As shown in Figure 3, the terms associated with the central word thermal comfort are thermal sensation, thermal environment, energy saving, natural ventilation, numerical simulation, PMV, airflow organization, etc. As mentioned above, most of the articles with high citation rate in the time domain 2000-2004 are summarized and analyzed by scholars. But between 2005 and 2010 scholars began to quantify these core points. In this time domain, a large number of indoor human thermal comfort indicators began to be applied to our actual climate conditions. Taking into account the reduction of energy consumption during seasons, scholars studied the thermal comfort level of human body in the state of natural ventilation. By improving the air distribution in the state of natural ventilation, people felt a satisfactory state of thermal sensation[10-12]. Liu's research group established a thermal adaptation model with the characteristics of climate conditions, and measured the adaptive comfort temperature as the design index of indoor environmental temperature[13].
3.3. Research hot spots and trend analysis of thermal comfort in different periods

In order to accurately grasp the evolution process of research hot spots, 360 articles of the first 90 thermal comfort research journals with high citation times were selected from four periods from 2000 to 2019. The literature selection Refworks format was imported into CiteSpace to form a Time zone diagram, as shown in Figure 4. The time zone diagram in CiteSpace software can give us reasonable predictions of future research trends[14,15].

According to Figure 4, during 2000-2004, the dominant keywords were "thermal comfort", "thermal environment", "thermal sensation", "numerical simulation", "energy saving", "air distribution" and "field research". Three of them are "thermal comfort", "thermal sensation" and "thermal environment", which are the core of the field of thermal comfort. The hot spots can be classified as indoor thermal environment, heat transfer between human body and environment, and energy consumption. Dominant words change over time. During 2005-2010, "evaporative cooling", "field research", "standard effective temperature", "natural ventilation" and "hot summer and cold winter area" appeared, but the relatively few dominant keywords appeared in this area were related to the small amount of literature in this period.

From 2011 to 2019, the number of sample papers published increased in a "blowout" manner, and new dominant words appeared. In terms of thermal environment, it is shown as "hot and humid area", "residence", "residential building" "rural residence", "separate air conditioning building" and "cold region". In terms of heat exchange between people and the environment, it is shown as "field investigation", "thermoneutral temperature", "wind sensation", "expected temperature" and "thermal sensation vote". In terms of energy consumption, there are few keywords involved, such as "natural ventilation", "building energy consumption" and "energy consumption", which indirectly reflects that attention to energy consumption is relatively low when considering indoor human thermal comfort in China. From the hot deductive process, it can also be observed that there is no key word of energy consumption problem in the middle part of the deductive graph, but the end appears again, indicating that attention to energy consumption problem has increased in recent years.

The research on thermal environment changes with the passage of time: "relative humidity", "natural ventilation", "hot summer and cold winter area", "hot and humid area", "residential", "rural residential", "thermal environment parameters", "cold region". It directly reflects the change of hot spots in thermal environment over time. Obviously, it is found that the changes of domestic scholars in the research area of thermal environment gradually change from the general thermal environment to the special geographical environment of China.

![Figure 4. Timezone diagram of hot keyword](image.png)
4. Conclusion

The following conclusions were drawn.

Firstly, from 2000 to 2004, Chinese scholars in the field of thermal comfort published fewer articles in CNKI database, and the growth was slow. Most influential papers in this period were review articles, with relatively single core contents. This period sorted out the knowledge framework of thermal comfort research at that time, laying a theoretical foundation for future researches on thermal comfort by Chinese scholars. According to the content of the study, the period from 2005 to 2019 is classified as a period. One of the cores of the study in this period is to study the adaptive thermal comfort in different climates of our country and modify the prediction model according to different climate characteristics. Another research direction is to expand the field of thermal comfort, from studying the thermal comfort of adults to extending it to the elderly and children, from studying urban residential houses to rural houses, from office buildings to tall space buildings and thermal comfort in the state.

Secondly, by observing the Timeline chart from 2000 to 2019, the movement of hot spots in the field of thermal comfort in the past 19 years is reflected in profile. First, "thermal sensation" and "thermal environment" are the core keywords in the field of thermal comfort, while "numerical simulation", "field research" and "questionnaire" are the commonly used research methods. As time goes on, the research focus also changes from thermal comfort under displacement ventilation to thermal comfort under natural ventilation. Second, domestic scholars study thermal comfort in different regions of China in the following order: hot summer and cold winter, hot and humid region, and cold region. From 2011 to 2019, research on thermal comfort of rural housing has become a hot topic.

The literature samples have limitations and in the follow-up study, the literature data considering the increase of international research on human thermal comfort will be compared with this study to observe the current situation of domestic and international research on thermal comfort.

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