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Knowledge Mapping on Literature Research Progress of Human Thermal Comfort in buildings Based on Web of Science

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Abstract. This study focused on hot topics and front of thermal comfort in buildings by knowledge mapping of 577 research papers from 2009 to 2019 in the database of Web of Science as samples. CiteSpace software was used as the analyzing tool. The results showed the trend of the published researches on thermal comfort by analyzing high-frequency co-occurrence keywords and the keywords' frequency variation. The results also showed that the researches on thermal comfort about health had increased rapidly in recent years. Moreover, the institutions and authors involved in healthy indoor thermal environment were mostly from economically developed countries or regions. However, the productive author collaboration network had not been formed yet. Improving environmental quality is the forefront of current researches. The research of indoor environmental quality based on health may be a hot topic in the future.

Keywords: Visual analysis; Thermal comfort; Classic literature; CiteSpace; Web of Science.

1. Introduction

Research on indoor thermal comfort had appeared since the 1920s. One of the most famous achievement was the Predicted Mean Vote (PMV) model proposed in the 1970s by professor Fanger[1]. The theoretical basis of the PMV model was thermoregulation and heat-balance equation. However, as the research going on, it was pointed out that the PMV model concluded thermal comfort with thermal neutrality was not accurate[2, 3]. Many scholars found people still feel uncomfortable in the air-conditioned rooms with constant temperature, constant humidity, very low air pollutant concentration and adequate air volume[4]. With the further improvement of thermal comfort research, people began to pay attention to the health of indoor environment, and the influence of environmental parameters on human physiological parameters.

At present, the definition of healthy thermal environment is still in the qualitative stage[5, 6], the theory was proposed in a short time compared with the research of thermal comfort, a visual analysis of the existing literature can help sort out the knowledge network for further research. To facilitate further exploration in the future, this paper will use CiteSpace to sort out and excavate literature related to



healthy indoor thermal environment from 2009 to 2019 to explore the correlation between indoor thermal comfort and health to provide ideas for future research.

2. Data sources and methods

2.1. Data sources

Using Web of Science (WoS) as the data source. The search method of this paper is topic retrieval, the searching words are: Topic= (indoor thermal comfort) And Topic= (health), journals are selected from SCI journals, EI journals and core journals, the time range is limited from 2009.1.1 to 2019.11.1. After removing the repeated literature, 577 related literature were analyzed.

The selected 577 papers included 1,750 authors, come from 251 different publications, their authors have a wide distribution and they come from 660 institutions and 40 countries or territories. China is the biggest source of papers; it was followed by USA and UK.

2.2. Method

Bibliometrics and CiteSpace[7] (ver. 5.5.r2), a software for mapping scientific knowledge, were used to review the studies on thermal comfort taking health factors into account, carry out quantitative and qualitative visual analysis from the perspectives of the number of papers, authors, the research institution, and the hotspot of cutting-edge clustering. CiteSpace is one of the representative software in scientific bibliometrics in recent years[8], it can transform a large amount of literature data into a visual network map.

Mapping knowledge domain is a spatial map that shows the proximity and relative location of a subject, field, professional knowledge, an individual article or author, and other related entities[9], has the dual property of "graph" and "spectrum", it can analyze the structure, hot spots and development status of this field through data mining, information processing, clustering analysis and quantitative processing, shows the complex relationships among knowledge groups, such as crossover, correlation, evolution and derivation, and reveals the future development direction and dynamic development law[10], this has great practical value for the progress of a subject. In the domestic construction industry, CiteSpace has been used to sort out the knowledge of architecture.

3. Results

3.1. Timeline of literature

In the core collection of Web of Science (WOS), there were 577 literature related to indoor thermal comfort and thermal health in the time range from 2009.1.1 to 2019.11.1, 57.7 papers published per year on average. As shown in Figure 1, the total number of articles published increased with time, the average annual growth rate was 17.6%. To some extent, the amount of publications in a discipline can reflect the development and research level[11], so it can be seen that the subject is stably developing. The distribution of literature publications along with time is shown in Figure 1.

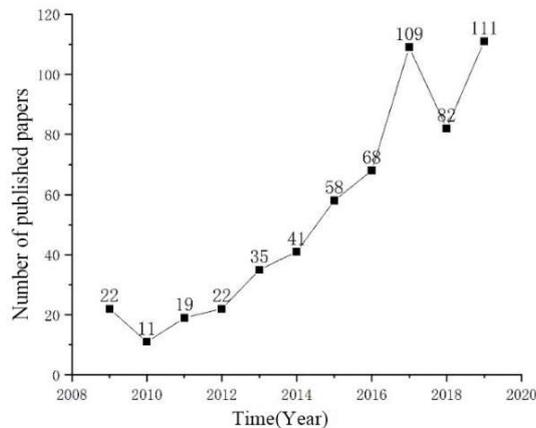


Figure 1. Number of papers about health-related indoor thermal comfort in 2009-2019

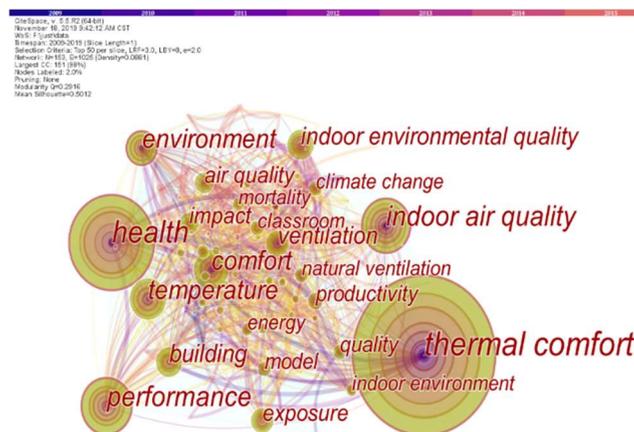


Figure 2. 2009-2019 health-related indoor thermal comfort research literature keywords visualization map

3.2. Keywords Analysis Results

CiteSpace can perform co-occurrence keyword analysis. By analyzing the frequency of keywords, we can judge the research hotspots in recent years. Setting the time range as 2009-2019, the node type is keyword, the threshold is set as top 50, then the keyword visualization spectrum is generated. 153 nodes and 1,025 wires are generated, and Figure 2 is obtained after adjustment.

In Figure 2, the font size and node size of keywords can intuitively reflect the research process and heat of indoor thermal comfort of the building, each circle node represents a keyword. The larger the node, the higher the frequency of the keyword and the greater its influence. Visualized data reveal the nature of health-related thermal comfort research: research on thermal comfort is developed for human health, comfort, normal performance of various functions and efficiency, it can effectively promote the improvement of indoor air quality and indoor environment. According to the visual network display, it is recommended to improve the indoor environment quality from the aspects of temperature, air quality and building.

There is a table of the keywords' centrality and frequency. Centrality is an important concept of graph theory, high centrality means that this keyword has a high correlation with other keywords, and there is much research based on this keyword[12], can be used to measure the influence of a keyword. Arrange the 12 keywords with the highest citation bursts, as shown in Table 1.

Table 1. The top 12 keywords with the strongest citation bursts

Keywords	Strength	Begin	End	2009~2019
Environment	2.964	2009	2012	
Energy saving	4.1483	2009	2014	
Sick building syndrome	2.7094	2009	2011	
Symptom	5.009	2009	2014	
Thermal environment	3.6003	2009	2015	
Model	2.7346	2012	2014	
Housing	3.1879	2012	2015	
Green building	2.6954	2014	2017	
Ventilation rate	2.6128	2014	2015	
Heat	2.7121	2015	2017	
Air pollution	3.2858	2016	2017	
Environmental quality	3.0601	2017	2019	

Table 1 is sorted by the timeline. The keyword with the strongest citation bursts is “symptom” (5.009) with a time span of 2009-2014, followed by “energy saving”(2009-2014), it means that these two keywords were the forefront and hot spot in this field. However, most of these keywords have dropped out of the list of research hotspots, except the keyword “environmental quality”, its hot period is 2017-2019 and may continue for some time. These keywords that have not yet ended the hot period can represent the research frontiers and trends in the research field. Based on the contents of chapter 1, it can be concluded that although there is no obvious hot spot in health-related indoor thermal comfort research, it is likely to appear in the future.

Combine the contents of Figure 2 and Table 1, it can be seen the keyword “symptom” have high frequency and a strong citation burst, modern buildings basically conform to the thermal environment standards based on the PMV model proposed by Professor Fanger, however, the proportion of people dissatisfied with the indoor environment is also gradually rising, and the indoor thermal environment conforming to the thermal comfort specification does not exactly fit the health needs of indoor personnel. Some research shows that the "comfortable environment" of constant temperature and humidity for a long time based on PMV model makes the human body lack of environmental stimulation, which will cause people to feel bored to the thermal environment, and reduce their thermal regulation ability, thus resulting in the decline of immunity and work efficiency[3,13], to some extent, contributing to the emergence of sick building syndrome. Lichtenbelt et al.[14] believed that a healthy indoor thermal environment should have certain fluctuations to make the body participating in the construction of thermal comfort.

Clustering the keywords network, and six co-cited clusters were obtained, the modularity value is 0.2916, and the mean silhouette value of the whole network is 0.5012, which indicates that the clustering result of the whole cited network is good. Figure 3 shows the automatic label, cluster size and mean silhouette value of the six co-cited clusters. Numbering the clusters from #0 to #5 according to the size of the cluster. It's clear that the ventilation rate and displacement ventilation can ensure the cleanness of indoor air, as to ensure production and health. Therefore, the requirements of healthy thermal environment for air quality should be paid attention to.

3.3. Distribution of authoritative scholars and institutions

Figure 4 shows the mixed map of the author and the institutions. Price, an expert in science and technology information science, put forward the theory in his book *Small science, Big science*: In the same topic, half of the papers are written by a group of highly productive authors, whose number is approximately equal to the square root of the total number of authors[15]. This law can be used to evaluate the influence level of scholars and the quantitative relationship between scientists at different levels. The most prolific author is Ulla Haverinen-Shaughnessy, published 8 articles. The author's institution is National Institute for Health and Welfare, published 10 articles, and shows the consistency

between the high-frequency author and the high-yield organization. According to the formula of price's law $MP=0.749 \times \sqrt{NP_{max}}$, substituting in the data can get $0.749 \times \sqrt{8}=2.12$. Basing on the principle of rounding, the figure shows that a total of 9 authors have published 3 or more papers, and a total of 39 papers have been published, less than half of the total number of articles, indicating that the high-yield authors have not formed a leading role, research on thermal comfort in health has not yet produced a stable and productive population of authors.

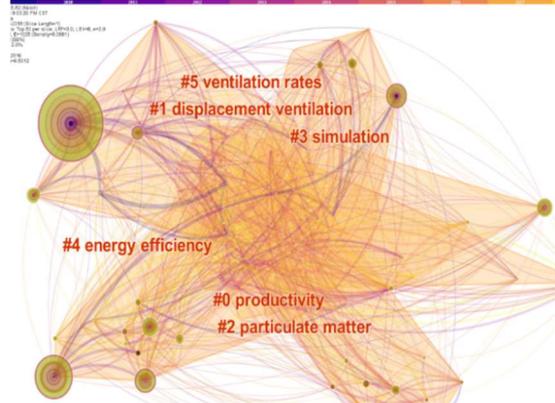


Figure 3. Keywords' clusters in health-related indoor thermal environment research

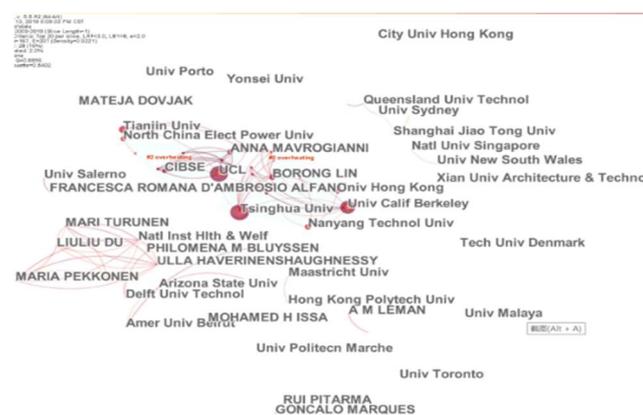


Figure 4. Mixed co-occurrence of author and institution

4. Conclusion

In this paper, CiteSpace is used to visually analyze the related literature from WOS. The conclusions are as follows:

(1) In the past decade, the number of papers on health thermal comfort research has been increasing year by year, with an overall growth rate of 17.6%, it is proved that indoor health-related thermal environment research is becoming a research hotspot.

(2) According to the data of the visualization map, except the retrieval keywords "thermal comfort" and "health", the keywords with high frequency are performance, indoor air quality, temperature, comfort, environment, building, ventilation and so on. From the aspect of citation burst, the keywords such as symptom, energy saving, thermal environment, air pollution, housing and environmental quality rank higher, this result objectively evaluates the development direction and hot spot of health-related thermal comfort research.

(3) The maximum number of papers published by high-yielding authors was 8, according to the results calculated by Price's law, high-yielding authors had not formed effective leadership.

Note: 577 articles from Web of Science were analyzed on 3 November 2019.

Acknowledgments

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