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Thermal comfort investigation of rural houses in China: A review

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ABSTRACT

Researchers have conducted extensive research on the thermal environments of rural houses worldwide. The greatest number of studies on thermal comfort in rural areas have been conducted in China. However, no studies have reviewed or summarised the literature. This paper summarises the literature from three perspectives: climate zones, thermal comfort approach, and other factors (wind speed, humidity, and building construction) that influence thermal comfort. The research commenced by categorising and examining all relevant papers based on climatic comfort and thermal comfort approaches to find commonalities and differences. The limits of existing thermal comfort standards were then inspected. Finally, suggestions for further research on rural thermal comfort were provided. Our conclusion was that thermal comfort temperature is influenced by various factors. Further research on the thermal comfort of older adults is required, especially in rural areas. The Adaptive Thermal Comfort model was more suitable for rural housing than the Rational Thermal Comfort model. Large-scale studies on thermal comfort in rural houses are required to establish specific thermal comfort standards. Wind speed and humidity are two aspects that require further research in rural thermal comfort.

1. Introduction

Developed countries such as the United Kingdom and the United States have no obvious urban-rural distinction in building forms, façades, and indoor environments because of the high economic level. However, in developing countries such as China and India, rural development often lags behind that of urban areas. China is a largely agricultural country, with 36.1% of its population living in rural areas. During its rapid urbanisation, urban residents living environments have been enhanced, but the situation for rural residents has not improved. Due to different economic conditions, lifestyles, environmental factors, physiological adaptations, and expectations, the comfort levels of urban and rural residents differ. Therefore, research on the thermal comfort of urban dwellings is not generalisable to rural dwellings [1,2].

Rural houses in China are primarily self-financed and self-built, and the comfort of rural residents is based on their subjective perceptions. However, Wang [3] indicated that rural residents' housing situation has a significant relationship with income. Most rural houses have no insulation (Fig. 1). According to a survey conducted in northern China [4], 34.6% of rural families had not adopted building insulation measures, and 16.5% of rural households had adopted housing insulation measures in all rooms. Therefore, the current living environments of rural populations could be improved to support human health.

To improve the living conditions of rural residents, the Chinese government has implemented a series of policies promoting the construction of new rural areas. Although large-scale rural construction has improved the living conditions of rural residents to a certain extent, the problems of high energy consumption and low comfort persist. According to the literature, in China, the energy used in daily life in agriculture accounts for 37% of the total energy used in buildings nationwide [5]. Therefore, focusing on residential thermal comfort in rural areas would promote a comfortable living environment for rural residents and the construction of a 'green countryside'.

Compared to China, research in other regions is scattered and less numerous in this field of study. Research on thermal comfort in India has investigated that regarding vernacular buildings in the northeast region [6]; vernacular buildings in rural areas, which are gradually being modernised in warm and humid areas in the southern India [7];

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traditional mud houses in rural areas [8]; and kitchens in rural areas, which resulted in suggesting appropriate retrofitting strategies [9]. A thermal comfort study in East Nusa Tenggara, Indonesia, demonstrated that occupants perceived the temperature of their vernacular houses to range between slightly cool and cool [10]. A study on the thermal performance of passive housing designs in rural Tanzania showed that the traditional vernacular design (mud-pole walls and thatch roofs) provided greater thermal comfort than modern designs (brick or concrete walls and iron roofs) [11]. A thermal comfort study of traditional houses in five regions within three climatic zones in Nepal showed that neutral temperature differs by the climatic zone and that residents were satisfied with the thermal environment of their houses because they have adapted to the thermal conditions [12]. Studies on the thermal comfort of rural dwellings have also been conducted in Europe. A study in rural Spain showed that the indoor environment for reusing abandoned rural buildings could be more comfortable with less energy consumption than that of new buildings [13]. Research on the thermal comfort of older adults in urban and rural regions in Greece's Heraklion Regional Unit has explored the thermal experiences of senior individuals and their thermal senses, preferences, and adaptive reactions to increase their thermal comfort in their houses [14].

Some studies have reviewed the research on thermal comfort. Halawa and van Hoof (2012) reviewed the foundations, underlying assumptions, and findings of an adaptive approach to thermal comfort [15]. De Dear et al. (2013) reviewed the perspectives of thermal comfort over the past 20 years and proposed a direction for thermal comfort research over the next decades [16]. Zhao et al. (2021) reviewed existing thermal comfort models from various perspectives and summarised the models for different groups of people [17]. Mishra and Ramgopal (2013) reviewed thermal comfort field studies conducted over the past few decades and used Köppen's climate classification to group them [18]. Wang et al. (2018) reviewed climate chamber and field studies and identified individual variations in preferred neutral comfort temperatures [19]. Rupp et al. reviewed 466 articles related to human thermal comfort and found that types of buildings were investigated [20]. Other studies have reviewed thermal comfort for specific building types. Khodakarami et al. (2012), Pereira et al. (2020), and Yuan et al. (2022) have reviewed studies on thermal comfort in hospitals [21–23]. Martínez-Molina et al. (2016) overviewed research on energy efficiency and thermal comfort in historic buildings [24]. Zomorodian et al. reviewed thermal comfort field studies of educational buildings over the past five decades [25]. So far, there is no report on thermal comfort research in rural areas in the literature.

In addition, no relevant article details the research on thermal comfort in rural areas in China. Thus, the aims of this study were to understand the thermal comfort requirements of rural residents in different regions and the main thermal comfort approaches and measurement data used in the literature. This study also aimed to explore the limitations of the current research, suggest possible research directions, and provide a reference for further work on this topic. To improve the understanding of thermal comfort research in rural areas, key points were extracted by comparing and contrasting previous studies. This study classify and review the literature in terms of climate and thermal comfort methods to identify similarities and contrasts, discuss the limitations of the current thermal comfort standards and the influence of other factors on thermal comfort research, and present recommendations for further research on rural thermal comfort.

2. Literature search method

This study used Google Scholar, Web of Science, and China National Knowledge Infrastructure (CNKI) scholars as the main literature databases. Google Scholar and the Web of Science are the largest and most commonly used academic journal databases, respectively. We chose CNKI because it is the largest full-text academic information website available in China. Although much of the research available on CNKI scholars is in Chinese, it covers most scientific studies in the Chinese region. The following keywords were used to gather relevant publications: 'thermal comfort' OR 'neutral temperature' OR 'comfort temperature' OR 'preferred temperature' AND 'rural' OR 'village' OR 'countryside', AND 'residential' OR 'house'. There were 191 results from Web of Science, 355 from CNKI scholars (in Chinese), and 17,000 from Google Scholar. This study aimed to summarise the findings of a field investigation of the thermal comfort of rural houses, not assess retrofitting energy supplements or existing conditions. Therefore, the searched papers were screened, and the 'title', 'abstract', and 'keyword' sections were reviewed, to ensure that the research topic was within the field of 'field investigation on thermal comfort in rural houses'. Similar results from various databases were removed during the search process.

Ninety-eight papers were selected from the initial list. We surveyed the full text and selected 78 papers using two criteria.

- collected primary data from rural houses through field investigations (i.e. they could not mention thermal comfort without a field investigation);
- determined the thermal performance of residents (e.g. neutral temperature, comfort temperature, and preferred temperature).

The 78 papers included journal articles, conference papers, and theses (including PhD and postgraduate theses): 20 were in English, and the others were in Chinese. Among them, all English papers were from Google Scholar, 17 were also found on Web of Science, and all papers in

Table 1
Research collection in different database.

Database	Number of research
CNKI	58
Web of Science	17 (also in Google Scholar)
Google Scholar	20

Fig. 1. Picture of rural house in China.

Chinese were obtained from CNKI (Table 1). The 78 papers were stored in a 'papers' folder, which constituted the research database for this study.

3. Results from literature analysis

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines thermal comfort as a subjective feeling of human satisfaction with the thermal environment [26]. Subjective perceptions are influenced by human psychological or physiological factors; therefore, thermal comfort field surveys include objective and subjective surveys. Statistical methods, such as linear regression, demonstrate the relationship between objective and subjective data. The length of field surveys varies from several days to one year, depending on the research needs. The rural houses in this study were mainly naturally ventilated, and all the studied cases followed standards such as ASHRAE 55–2004, ISO 7730, and EN15251.

The main objective of the survey was to measure physical parameters. According to standard instrumentation and procedures used for indoor climate measurements, there are three classes of thermal comfort investigations (Table 2) [27]. From Class I to Class III, the measurements were simpler. Almost all of the research in the Chinese rural thermal comfort field investigations used the Class II field experiment protocol, measuring environmental factors (i.e. air temperature, relative humidity, air velocity, and radiant temperature). Few studies have used the Class III field experiment protocol, which measures only temperature and humidity [28–32]. The measurement requirements for Class I are relatively stringent, and no studies have used this classification. In addition, because of particular heating practices in rural areas, few studies have measured the concentrations of gases such as carbon dioxide [2,33,34].

Subjective surveys are a crucial component of thermal comfort research. Most field surveys employ descriptive measures such as the seven-point ASHRAE or Bedford scale to evaluate thermal sensations, the three-point McIntyre scale to assess thermal preferences, and clothing and activity checklists [18]. Almost all the articles on thermal comfort research in rural China have used the 7-point ASHRAE scale, and a few studies have simplified the 7-point scale to a 5-point scale because of the level of understanding of the respondents [35]; other studies have used the 9-point extended scale of ISO 15001 (ISO, 2002) for thermal sensation ratings because of climatic conditions [36].

China has a vast geographical area. In the study of the Chinese regions, different provinces, cities, seasons and populations were involved. Research on thermal comfort in rural areas has been more extensive than that in other regions. The following is a summary of the research on rural thermal comfort field studies in China from the perspective of climate zones; the thermal comfort approach; and other factors that influence thermal comfort, such as wind speed, humidity, and house construction.

Table 2
Three broad classes of thermal comfort field investigation [27].

Classification	Requirements
Class I	All sensors and procedures are in 100% compliance with the specifications contains in ASHRAE standard55 and ISO 7730. Three heights of measurements above floor level (0.1,0.6 and 1.2 m).
Class II	Field experiments in which all physical environmental variables (t_a, t_r, T, rh, clo, met) necessary for the calculation of heat-balance SET* and PMV/PPD indicts were collected at the same time and place as the thermal questionnaire were administered, but most likely only at one height of measurement.
Class III	Field studies based on simple measurements of indoor temperature and possibly humidity at one height of measurement above the floor. Possibly asynchronous and noncontiguous physical (temperature) and subjective (questionnaire) measurements.

3.1. *Climate zone influences thermal comfort*

According to the Chinese National Standard GB 50176 (2016), there are five main climatic zones: severe cold, cold, hot summer and cold winter, hot summer and warm winter, and mild (Fig. 2). However, no studies have investigated the thermal comfort of rural houses in mild regions. Therefore, this study analysed studies conducted in the other four climatic regions. First, we divided the four regions, severe cold, cold, hot summer and cold winter, and hot summer and warm winter, into four groups, A, B, C, and D, respectively. Each group was studied in different seasons, as shown in Fig. 3. The main seasons studied were winter and summer. Spring and autumn are transitional seasons, and the climate is more comfortable than in winter and summer; therefore, no research has exclusively focused on spring or autumn. All the studies were conducted in naturally ventilated rural houses.

The data showed that the largest group of studies was conducted in Group B (39.7%), followed by Group C (37.2%). The number of studies conducted over one year was small. In Group A, all studies were conducted in winter, mainly in Harbin, Heilongjiang Province. In Group B, most studies were conducted in winter, followed by summer and winter. In Group C, most studies were conducted in both winter and summer, with more scattered research locations, including Hunan Province and Chongqing Municipality.

The average neutral temperatures in each climate zone are presented in Table 3. The average neutral temperatures in the four groups did not differ significantly; however, they showed an increasing trend from north to south in winter and summer. Group A had the lowest average thermal neutral temperature in winter. This finding indicates that inhabitants of severely cold regions are better able to adapt to colder indoor environments than those in the other groups. Group D had the highest average thermal neutral temperature in summer. This finding indicates that the occupants in this region can better adapt to hot indoor environments than those in the other groups. Comparing the neutral temperature ranges demonstrated that areas with a high number of studies had a relatively wide range, such as winter research in Group B and summer research in Group C. The average neutral temperatures in winter in Group A ranged from 12.9 to 20.5 °C. The highest neutral temperature was reported in Hohhot, Inner Mongolia [37]. This study was conducted on elderly individuals, a group whose thermal comfort needs may differ from those of the normal population. In Group B, the highest [37] and lowest neutral [38] temperatures in summer were all in Xinjiang Province. The main reason for this finding is the vast area of Xinjiang Province, with significant climatic differences between the southern and northern regions. In Group C, the neutral temperature in winter ranged from 11.49 to 23.9 °C, with the lowest reported by older people (aged over 60 years) in the west of Hunan Province [39]. Summer neutral temperatures ranged between 18.4 and 29.8 °C, with the lowest temperature in brick dwellings in western Hunan Province [40] and the highest in Shanghai [29]. This finding proves that the inhabitants of western Hunan Province have a relatively high tolerance to cold and a relatively low tolerance to heat. There are a small number of studies in Group D, on Beihai [41], central Hainan [42], and Xiamen [43], and they proposed neutral temperatures in summer. In two other studies, using air temperature as an indicator, neutral temperatures were predicted for the whole year, 22 °C [44] and 26.4 °C [45], respectively.

The number of studies on acceptable temperatures is relatively smaller than that on neutral temperatures. The acceptable temperature limits for each climate zone are listed in Table 4. In Group A, some researchers proposed a 90% acceptable air temperature for occupants, and others proposed an 80% acceptable air temperature. Much of the literature mentions only the upper or lower limits of acceptable temperatures, with no exact proposed temperature range. In a comparison of the 80% and 90% acceptable air temperatures, the 90% acceptable air temperature was noticeably higher than the 80% acceptable air temperature. The main reason for this finding is that the studies proposing a 90% acceptable comfort temperature investigated a sample of older

Fig. 2. Climate zones in China.

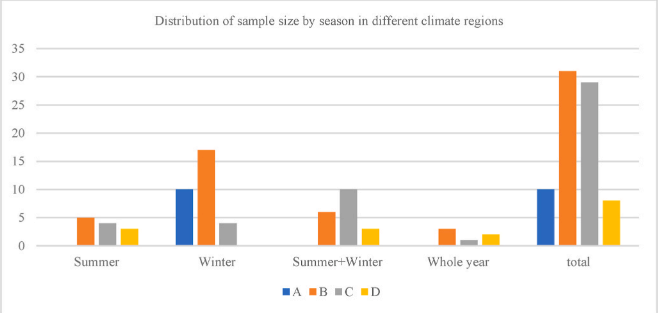

Fig. 3. Distribution of sample size by season and climate region.

Table 3
Climate versus average neutral temperature (unit °C).

Climate	Range of winter neutral	Average winter neutral	Range of summer neutral	Average summer neutral
A	12.9–20.5	16.4	/	/
B	11.7–25.6	16.6	23.4–32.5	25.8
C	11.5–23.9	16.7	18.4–29.8	25.6
D	/	/	23.6–27.3	26.1

people, whose needs differ from those of the normal population [46–48]. A comparison of the 80% acceptable air temperatures revealed that the colder the climate, the lower the acceptable temperature in winter. The lowest 80% acceptable air temperature in winter was in Group A. This finding suggests that the colder the area, the more tolerant the inhabitants are to cold weather conditions. The highest acceptable upper winter air temperatures in Groups A and B were observed for older people, which suggests that the acceptable temperature for older people in rural areas is higher than that of the general population in winter. However, in summer, the hotter climate, the lower the inhabitants' heat tolerance. Group B had the highest acceptable air temperature. This finding is observed because in the warmer areas, despite higher outdoor temperatures, buildings are relatively well-ventilated, and the use of air conditioning is high [42,43]; thus, the thermal adaptation of the inhabitants is reduced, generally lowering the heat tolerance. This finding also proves that the magnitude of the thermal comfort temperature is not entirely influenced by the climatic zone but rather by the long-term living conditions of inhabitants, such as insulation or ventilation methods.

However, in the same group, the differences between the upper and lower limits of the acceptable temperature were significant. The upper limits in winter in Group B were compared and showed that the maximum acceptable air temperature for the human body in winter was 10.3 °C in Turpan Xinjiang Province [49] and 29.7 °C in Jiaozuo Henan Province [50]. These significant disparities indicate that the acceptable temperatures for the inhabitants of different regions differ even in the same climate zone.

3.2. *Thermal comfort approach in different research*

Thermal comfort studies can be divided into two main categories by the thermal comfort approach: the Rational Thermal Comfort (RTC) model (e.g. the Predicted Mean Vote [PMV] model) or the Adaptive Thermal Comfort (ATC) model (e.g. the operational temperature [To] model).

The rational approach uses data from a climate chamber to support this theory. In field investigations, several researchers have found deviations between the PMV and the Actual Mean Vote (AMV). Only 31.4% of the studies used only the RTC model, and other studies used either the ATC model or a combination of the ATC and RTC models (Fig. 4). Of the studies that used the RTC model, 37.3% compared the gap between the PMV and thermal sensation vote (TSV), with 68.2% showing a significant difference between the predicted and actual thermal sensation. The results of these studies are summarised in

Table 4

Climate vs acceptable temperature (unit °C).

Climate	80% acceptable air temperature				90% acceptable air temperature			
	Winter		Summer		Winter		Summer	
	The lowest limit	The highest limit	The lowest limit	The highest limit	The lowest limit	The highest limit	The lowest limit	The highest limit
A	4.4	17.8	/	/	8.39	26.25	/	/
B	6.6	29.7	8.9	32.7	/	/	/	/
C	9.85	27.1	21.3	32	/	/	/	/
D	/	/	/	30.2	/	/	/	/

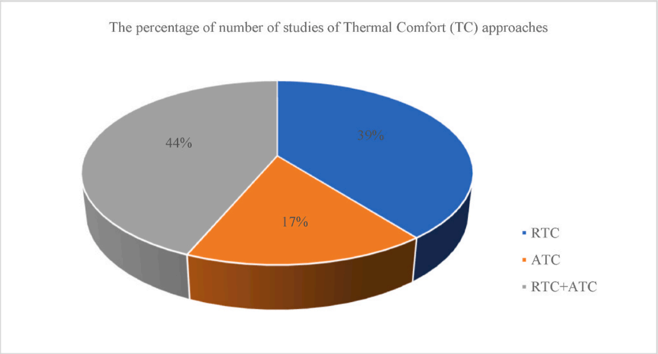

Fig. 4. of studies of thermal comfort approaches.

Table 5. One of these studies used the PMV model to accurately predict the true thermal sensation during winter [49]; in the remaining studies, the true thermal sensation was not accurately measured.

The adaptive approach originates from field studies and aims to analyse the real acceptability of the thermal environment, which is heavily influenced by the occupants' surroundings, behaviour, and expectations. ATC consists of the 'ePMV', 'aPMV', and 'cPMV' indexes, which use an expectancy factor and an adaptive coefficient to widen the use of the PMV model in a natural ventilation environment. Rural houses are predominantly naturally ventilated, and residents regulate their thermal comfort by opening windows or adding or removing clothing. Therefore, adaptive models are more applicable to the study of rural houses. Several studies have shown good agreement between predicted and subjective voting by using corrections for expectation factors and adaptive coefficients [60]. The literature has also noted that for studies of thermal comfort in naturally ventilated buildings in areas where the thermal environment is not extreme, using the PMV model and choosing an appropriate expectation factor e to modify the PMV model is recommended; for severe thermal environments, the aPMV model can be used to modify the PMV model [59].

3.3. Other factors influenced thermal comfort

3.3.1. Humidity and wind speed

Wind speed and humidity are important factors that influence thermal sensation. However, when the air temperature is within a comfortable range, relative humidity has little effect on human heat sensation. However, when the humidity is excessively high, the human body feels stuffy. Moreover, wind speed has a more pronounced effect on human heat sensation. For example, increasing the wind speed in a hot environment can reduce human heat sensation. This phenomenon occurs because the increased airflow around the occupant's body promotes the evaporation of sweat, leading to the evaporative cooling of the skin. Consequently, the individuals had a better sense of thermal comfort. Moreover, wind speed offsets the effect of the increased indoor air temperature on occupant comfort, saving cooling energy. Wind speed and humidity were not adequately studied, with actual wind speed not measured in 38.5% of the studies and actual humidity not measured in 14.1% of the studies.

The wind speeds in all studies ranged from 0 to 0.85 m/s. Several studies demonstrated that measured wind speed differs by the structure [40], floor [61], and function [48,62] of the building. In addition, wind speed is influenced to some extent by seasonal factors. In winter studies, owing to the low frequency of window openings, the indoor wind speed was generally low [47,54]. The wind speed was ignored in many winter studies [63]. In the summer studies, the average indoor wind speed was much higher than that in winter because of the higher frequency of window openings in summer than in winter. Wind is a natural form of air movement; usually, but not always, the movement is horizontal. When wind enters a room, it becomes ventilated, and air movement always influences air purity, temperature, and moisture. Air movement directly affects human health, comfort, and well-being. Mastering the wind speed in a naturally ventilated building helps determine the type of microclimatic environment within a room. Studies in Xiamen [43] and Beihai [41] have shown that residents' perception of thermal comfort is

Table 5

Discrepancies between PMV and TSV.

Study	Samples	Seasons	RTC		
			Predicted well	Overestimated	Underestimated
[34]	5 urban residences and 10 rural residences	winter			x
[47]	187	winter		x	
[51]	108	winter		x	
[52]	160	summer			x
[53]	86	winter			x
[49]	160 (summer)128 (winter)	summer + winter	x (winter)		x (summer)
[54]	36 dwellings	winter			x
[33]	300 dwellings	winter		x	
[55]	327	winter			x
[38]	138 dwellings	summer		x	
[35]	1 dwelling	winter			x
[56]	130 (summer)136 (winter)	summer + winter		x (summer)	x (winter)
[57]	90 dwellings	Whole year		x	
[58]	103	winter		x	
[59]	300 dwellings	winter		x	

strongly influenced by wind speed; with increasing natural wind speed, residents' temperature sensitivity decreases, and their thermal neutral temperature increases.

Many studies have shown that indoor relative humidity is slightly higher in rural areas than in urban areas [34,64,65]. Therefore, the humidity in rural houses should receive additional attention in further research. In the study population, the indoor relative humidity was distributed between 24.9% and 82%. Large fluctuations in indoor relative humidity are influenced by several factors, including the actual environment and local climatic factors. For example, the relative humidity in different rooms can vary by the function of the building [28,61,65] and its structure [40]. Residents from different regions were not affected by humidity to the same extent. A survey in Hainan showed that relative humidity has a low impact on the comfort of residents [42].

Theoretically, thermally neutral and comfortable temperatures change when humidity and wind speed change, but most studies have not proposed comfortable humidity and wind speeds. Therefore, further research on the humidity and wind speed is required.

3.3.2. *Construction of buildings*

The architectural and constructional features of a building, such as layouts, space dimensions, window-wall ratios, external shading, and building thermal envelope characteristics, are closely related to its indoor thermal environment.

Architectural features and thermal properties of rural houses should also be considered. In severely cold regions, the external walls of the subjects were constructed of solid bricks of 370 and 490 mm [64,66–68], thicker than those in other regions. A study in Qiqihar, Heilongjiang Province, showed that 38% of the residential walls used insulation [42]. Another study in Qiqihar showed all windows had air leakage problems, thermal bridges and condensation on the external walls of several houses, and poor envelope characteristics such that more than 50% of homes had living room temperatures below the thermally neutral temperature [62]. In Heilongjiang Province, studies in Harbin, Mudanjiang, Qiqihar, and Jiamusi indicated that 94% of rural dwellings had no insulation [67]. Among the studies in cold regions, some of the dwellings in Henan [50,69], Shandong [53], and Xinjiang [70,71] used rammed earth as the main building material, and most of the remaining dwellings were brick and concrete constructions. A survey conducted in 9 urban communities and 2 rural villages in Beijing area shows only 44% of the houses used insulation, mainly for the north wall and roof [65]. Moreover, in a survey of 70 rural houses in 10 villages in Hebei Province, only one rural house in used EPS panels for insulation on the external walls [63]. Rural dwellings in cold winter and hot summer regions are mainly constructed of brick and concrete, with a few traditional dwellings made of natural materials such as timber [39,72,73] and rammed earth [74,75]. The walls have no thermal insulation. Windows are mainly single glazed [40,75–77], and window frames are mainly constructed of aluminium and wood. Wooden windows [59] and door frames [78] are predominant in some areas. Houses researched in regions with a warm winter and hot summer are mainly constructed of brick [41,44] and stone [36]. The literature suggests that the thermal comfort of traditional houses is better than that of modern houses, mainly because the semi-open spaces and variable envelopes (cloth screens over open hall openings and shading) make traditional rural houses more adapted to the local climate [45].

Rural houses have serious thermal insulation problems and are far less sealed than urban houses [34]. Therefore, rural occupants are more resilient to indoor temperatures than urban occupants. However, poor envelopes lead to energy consumption and waste during winter and summer cooling in rural homes. Several studies have been conducted on energy-efficient retrofitting of rural houses [46,79,80]. Few studies have been conducted on envelope upgrading from the perspective of occupant thermal comfort.

4. Discussion

The purpose of this study was to understand the state of thermal comfort field investigations of rural houses in China. This study clarifies the progress and limitations of the relevant studies in China. The findings help bridge the gap between theoretical standards and research practice and open new options for further research.

4.1. *Standards of thermal environment in rural China*

In the field investigation of thermal comfort in rural houses, a discrepancy was found between the data measured onsite and those required by the standard. Furthermore, China's current regulations for thermal comfort are imperfect. The two most influential and widely used thermal evaluation standards worldwide are ISO7730 and ASHRAE55; of the two, the ambient temperature requirements of ISO7730 are more stringent and applicable from 10 to 30 °C. Moreover, ASHRAE-55 is more extensive than ISO7730. The ambient temperature in the ASHRAE-55 standard is from 10 to 33.5 °C, which is broader than that of the ISO7730. However, studies have shown significant differences in thermal sensations among the populations in China, Europe, and the United States [81]. The adaptation models in ASHRAE-55 and EN15251 do not include China's data in their databases and are, therefore, not applicable in China. The adaptation models and standard values in thermal comfort standards GB/T 18,049–2000 [82] and GB/T 5701–2008 [83] issued in China were specified according to ISO 7730–1994 [84] and ASHRAE Standard 55–2004 [85]. Owing to the large differences in research objects, environments, climates, and other factors, the direct use of international standards has not been fully adapted to the evaluation and research of indoor thermal environments in China. In recent years, research on thermal comfort models for naturally ventilated buildings in China has gradually increased, thermal comfort models have begun to be established, and relevant standards have been published based on Chinese thermal comfort field survey data. GB/T 50,785–2012 [86] uses the aPMV model as a basis for establishing thermal comfort evaluation standards for different building climate zones. The aPMV model is used as the basis for establishing evaluation criteria for thermal comfort in naturally ventilated buildings.

Rural residents are more adaptable than urban residents; therefore, the acceptable temperature range of the former is often wider than that of the latter. However, there are no criteria for evaluating thermal comfort in rural areas. A review of the literature shows that the data obtained during the research process have significant differences from those specified in the standards [41,51], and some articles suggest using separate evaluation models for the region [87]. Therefore, because of cultural and technical differences, thermal comfort researchers should separately collect and analyse new databases of research in the field of thermal comfort in different regions to adapt and revise the criteria and obtain reliable comfort temperatures suitable for rural inhabitants.

4.2. *Implications for further research*

The literature review showed that most studies have focused on comfort temperature but that other factors, such as humidity and wind speed, require further research. In many coastal areas, indoor humidity and wind speed have a significant impact on thermal comfort. Thus, further research should include wind speed and humidity in these areas. In addition to known influencing factors (i.e. air temperature, humidity, air velocity, mean radiant temperature, clothing insulation, and metabolic rates), other factors can affect indoor thermal comfort and indoor environmental quality. Thus, further research should investigate other factors, such as lighting and heating methods.

There are regional and seasonal differences in the thermal comfort of rural houses. However, owing to the wide geographical area, the thermal comfort of rural houses in many regions has not been studied. In addition to being influenced by the geographical environment, the indoor thermal comfort of rural dwellings is significantly influenced by building construction. Owing to the insufficient of scientific and technical guidance, many rural residences lack thermal insulation measures, resulting in poor thermal insulation performance. Living in this environment for a long time has also made rural residents more tolerant of the indoor environment and less demanding of thermal comfort than urban residents are. However, poor envelopes result in high energy consumption and waste. Optimising the indoor environment of rural houses while reducing energy consumption requires further in-depth research. Many of the studies reviewed herein are case studies of single houses or several houses with relatively homogenous floor plans and building structures. Results from merely one type of building are often insufficient; thus, the data collection time and sample size should be expanded to increase the generalisability of the results, which could help refine standards and guidelines.

In addition, individual differences among residents are factors that should be considered in further research. Some studies have been conducted among older adults living in rural areas [34,65,88,89]. Currently, older adults in rural China account for a large proportion of the population. Several studies have demonstrated that thermal preferences differ by age [90,91]. Thus, the thermal comfort preferences of the rural elderly or a thermal comfort model for this group should be investigated.

5. Conclusion

Currently, most rural houses in China are designed and built by residents without scientific guidance, resulting in poor quality living environments and significant energy wastage. Therefore, a literature review on the thermal comfort of rural houses was necessary to improve the living environment of residents and reduce energy consumption. The main findings of this study and recommendations for further research are summarised as follows.

- Although neutral temperatures vary significantly within the same climate zone, research on thermal comfort should be limited to specific cities or regions.
- In comparing neutral and acceptable temperatures, studies on older people have shown either maximum or minimum values. Therefore, the thermal comfort of older adults may differ from that of the general population. However, there have been insufficient studies on the thermal comfort of older adults in rural areas.
- The ATC model is more suitable for rural housing than the RTC model. However, selecting an appropriate evaluation model for the local climate is important.
- The evaluation criteria for thermal comfort are imperfect, and there are no thermal comfort standards for rural areas. This study is recommended that scholars conduct large-scale research to improve the database and revise the thermal comfort evaluation criteria for rural areas.
- This literature review found that high and low humidity and wind speeds can also affect the thermally neutral temperature; therefore, further research on comfortable humidity and wind speeds is necessary.
- Most rural dwellings in China lack adequate insulation, which can lead to significant heat loss during the winter and heat gain during the summer. This phenomenon can result in uncomfortable indoor temperatures and high energy costs. Many rural houses in China are old and require repair; thus, implementing energy-efficient upgrades to improve thermal comfort is difficult. Strategies to support rural housing retrofitting include providing financial incentives, technical assistance, and education to homeowners and the government.

Improving thermal comfort in rural houses in China will require a multifaceted approach that addresses issues related to insulation, ventilation, energy access, and building retrofitting. Improving insulation includes adding insulation to walls, floors, and roofs, sealing air leaks and upgrading windows and doors. Strategies for improving ventilation can change the window-to-wall ratios. Moreover, many rural areas in China have limited access to energy, which makes it difficult for residents to use heating and cooling systems or implement energy-efficient upgrades in their homes. Strategies for improving energy access include expanding the availability of grid-connected electricity and promoting renewable energy sources. The use of energy-efficient heating and cooling systems, such as heat pumps, could help improve thermal comfort in rural houses while reducing energy consumption and costs.

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CRediT authorship contribution statement

Jinhao Zhang: Writing – original draft, Methodology. **Jun Lu:** Writing – review & editing, Supervision. **Wu Deng:** Writing – review & editing. **Paolo Beccarelli:** Writing – review & editing. **Isaac Yu Fat Lun:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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