Architectural Intelligence

RESEARCH ARTICLE

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A preliminary study of multidimensional semantic evaluation of outdoor thermal comfort in Chinese

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Abstract

Traditional method to evaluate outdoor thermal comfort which used indicators (UTCI, PET, SET, etc.) has its limitations. Firstly, emotional factors are not included in the assessment, and secondly, the results lead to less accessibility, and it is difficult for non-experts to understand.

Due to the above reasons, some scholars have investigated how to evaluate outdoor thermal comfort by 'English vocabulary', and there is still a gap in exploring the multidimensional semantic assessment of outdoor thermal comfort by using 'Chinese vocabulary'. This paper established a 'Chinese vocabulary' thesaurus for outdoor thermal comfort evaluation through online and on-site questionnaire survey including 63 words, and an outdoor experiment was carried out to validate the effectiveness of the thesaurus. The results showed a significant correlation between the 2-phases results, revealing the effectiveness of the multidimensional semantic Chinese thesaurus. PET value has a wide range when Thermal Comfort Vote (TCV) are the same, and the words people used to describe the thermal environment in 5 dimensions are very different. The results showed that it is necessary to evaluate the thermal environment by the way of multidimensional semantic, which could make up the short comings of the traditional way (thermal comfort indicators).

The field validation experiment of this study was only carried out for 3 days in spring in Shenyang city, thus the result was highly influenced by the experiment conditions and has its limitations. This study could be a fundamental exploration of thermal comfort evaluation by semantic way in Chinese words.

Keywords Outdoor thermal comfort, Outdoor thermal environment, Multidimensional semantic evaluation, Chinese vocabulary

1 Introduction

With the ongoing economic and scientific advancements, people's demands for comfortable built environments are progressively increasing (Zhong et al., 2022). The Society of Heating, Refrigerating and Air-Conditioning Engineers (SHRAE) provides a definition of thermal comfort as 'a psychological state that assesses the level of satisfaction with various thermal environments' (ANSI/ASHRAE., 2017). The initial index to evaluate thermal comfort, known as the 'Effective Temperature (ET)', was created in the 1920s. Subsequently, many scholars suggested other indices such as the wind cooling index (WCI), standard effective temperature (SET), physiological equivalent

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temperature (PET), predicted thermal sensation index (PMV), and universal thermal climate index (UTCI). On the basis of effective temperature (ET), due to variations in evaluation objectives and indicators, influence factors and weights may differ across evaluations.

Traditional assessments of outdoor thermal comfort concentrate on the impact of objective physical indicators on thermal comfort. While establishing an evaluation system paradigm, emotional elements including thermal sensation, thermal pleasure, thermal anticipation, and other emotional information should be integrated; individual factors such as age, gender, health status, thermal experience, metabolic rate, and other subjective considerations also affect thermal comfort assessments (Nikolopoulou & Lykoudis, 2006; Vanos et al., 2010; Klemm et al., 2015). Thermal comfort is a complex and multidimensional concept, and the conventional evaluation method may not be universally understood and applied by non-experts (Liu et al., 2017). Previous research has revealed that people typically prefer a different temperature range than the thermo-neutral temperature. AN et al. investigated the outdoor thermal comfort in summer on a Shanghai campus and found that the favored temperature (favored temperature is the temperature at which people feel more comfortable living) was 24 °C which is 1.4 °C below the thermo-neutral PET (An et al., 2022). An even greater difference was identified in a year-long field study conducted in Arizona, United States of America, which indicated that the thermo-neutral PET was 28.6 °C, whereas the favored temperature was 20.8 °C (Middel et al., 2016). Wang Qiaochu et al. contrasted and evaluated the thermal perceptions of tourists from diverse backgrounds in the same location, revealing that when field visitors had lower comfort ratings, their contentment with the thermal setting remained higher (Xi et al., 2019).

de Dear et al. incorporated the lexicon from the English language into their analysis of outdoor thermal comfort, taking into account the influence of emotional factors on individuals' assessment of said comfort through the language used in daily speech (Liu et al., 2020). As a result, they developed a multidimensional semantic evaluation framework consisting of 6 dimensions pertaining to thermal comfort. The ASHRAE standard employs four physical quantities: temperature, humidity, wind, and solar radiation as descriptive dimensions to evaluate outdoor thermal comfort. de Dear et al.'s study was bifurcated into two phases. The first phase consisted of using an online questionnaire, following a defined evaluation framework, to acquire a thesaurus of outdoor thermal comfort ratings comprising of 76 English words. The feasibility of the terms obtained in phase one is confirmed through the implementation of a field experiment during the second phase. Ultimately, the findings of this study are substantiated.

Chinese, as a complex language system, has developed distinct phonological, lexical and grammatical features throughout its extensive historical evolution. Within linguistics, temperature words provide an illustrative example of the tense system, demonstrating four types of lexical meaning—temperature meaning, action meaning, psychological feeling meaning and abstract concept meaning which arise from the 'temperature phenomenon → physical sensation → psychological sensation → abstract concept' (Ren, 2006). Consequently, vocabulary serves as the primary means by which people can describe objective physical phenomena and communicate their subjective ideas. Vocabulary is a potent means for describing physical phenomena without bias and conveying personal emotions. Table 1 illustrates examples commonly used outdoor environment vocabulary (Jiang, 2022).

2 Method

This study is structured into 3 research phases. As presented in Fig. 1, the first phase involves data collection to establish the initial thesaurus. The second phase is dedicated to creating a preliminary thermal comfort evaluation thesaurus. The third phase comprises conducting field experiments to discuss the necessity of the study and verify the Thermal Comfort Evaluation Thesaurus's validity.

2.1 Establishment of Chinese evaluation thesaurus for thermal comfort

In this study, the multidimensional semantic evaluation framework is utilized to assess outdoor thermal comfort. The framework comprises 5 dimensions, namely

Table 1 Examples of Chinese vocabulary to describe outdoor thermal environment

	Chinese Character	Explanation in English	Sentence examples in English
1	炎热	Extremely hot, at an intense and scorching temperature	This year is a '炎热' summer
2	骄阳似火	The weather is extremely hot, with the sunlight shining intensely, as hot as fire	In the '骄阳似火' weather, only a few people dare to venture outside

The above phrases align better with typical language usage in daily contexts

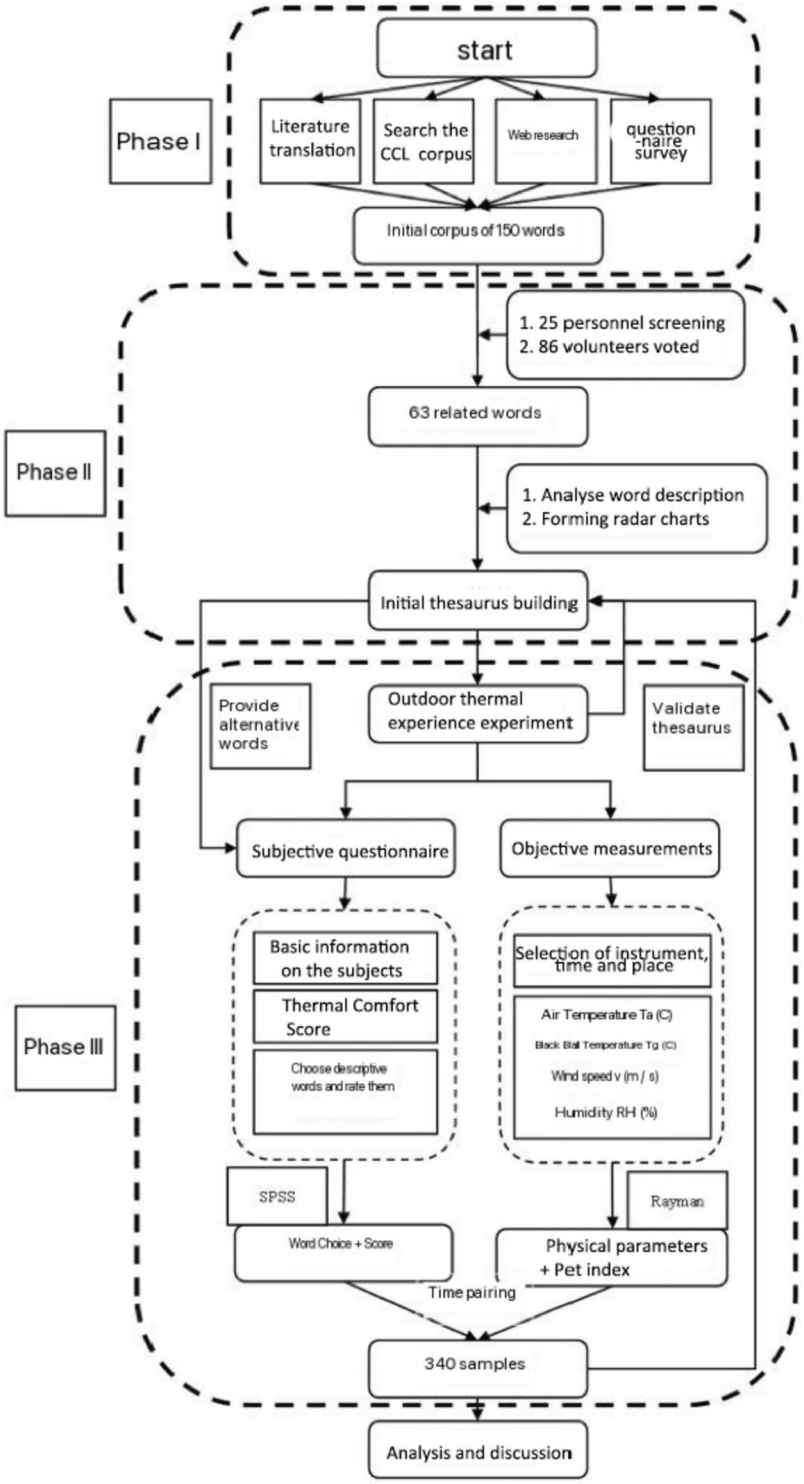


Fig. 1 Flow chart of the study

'Temperature', 'Humidity', 'Wind speed', 'Radiation' and 'Thermal pleasure'. The assessment is conducted through a percentage bipolar scale represented in Fig. 2. We referred to de Dear's research but excluded the thermal intensity dimension, which may be challenging to comprehend in Chinese.

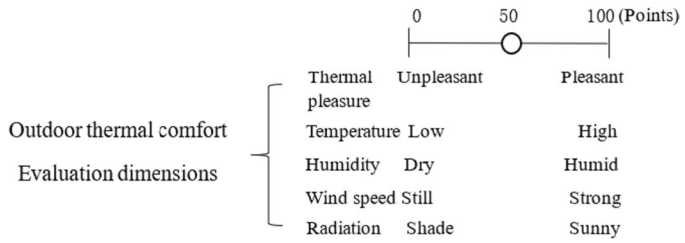


Fig. 2 Multidimensional semantic evaluation framework. *The bipolar scales are used to evaluate people's emotions by 'Thermal pleasure', and to evaluate people's sensation about the environment by 'Temperature, Humidity, Wind speed, Radiation'

1) Original thesaurus

The initial step of the study involved reviewing foreign literature related to the subject to translate and organize English semantic evaluation vocabulary of thermal comfort into corresponding Chinese vocabulary. Based on the research results of de Dear et al., the research group translated their English thermal comfort evaluation thesaurus into Chinese. These new vocabulary additions were then integrated into the main thesaurus.

The research group secondly surveyed approximately 20 researchers in the field of thermal comfort and requested them to extract Chinese words related to thermal comfort evaluation from the Chinese literature they had read. This included, but was not limited to, dictionaries, literature, and various published works such as the CCL Chinese thesaurus (Center for Chinese Linguistics PKU) et al. The words obtained in this part are relatively professional, such as '冷'(cold) '热'(hot). etc.

Thirdly, the research group collected words related to thermal comfort evaluation used in daily life through online surveys. Respondents, using questionnaires edited by the research group, provided words they thought might be used to describe daily. Most of the words obtained in this part are dialects, such as '热乎', '干巴', etc. In the end, 170 relevant questionnaires were collected.

After completing all the necessary procedures, we merged the duplicate entries (Zhan et al., 2003) to obtain the initial thesaurus, comprising 150 words.

2) Original thesaurus correction

The vocabulary was sifted through by 25 specialists in the field of thermal environment utilizing 5 dimensions. Eventually, 76 pertinent terms were distinguished, which the research team employed to arbitrarily select 86 university students from diverse majors (Fig. 3) to finish the questionnaire. As illustrated in Fig. 4, the sliding bar has a minimum value of 1 and a maximum value of 100. Participants can adjust the cursor to indicate their evaluation of the vocabulary's position on the dimension. If the cursor remains at the default position, it signifies that the

Fig. 3 Second round of amendments on site

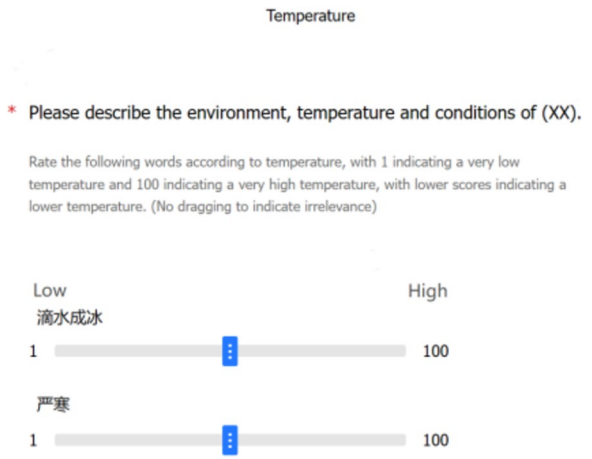


Fig. 4 Example of questionnaire

words cannot be utilized to convey information on the dimension. Based on statistical cases, words selected above a 70% threshold are associated with evaluating thermal comfort (Zhang et al., 2022). A preliminary Chinese thesaurus for multidimensional semantic evaluation of thermal comfort was created, consisting of 63 words.

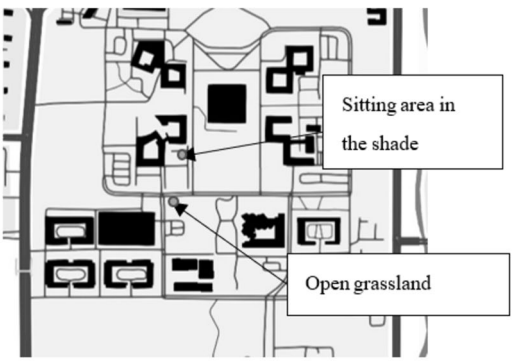
2.2 On-site measurement and questionnaire research

The study site, illustrated in Fig. 5, was selected as comprising an outdoor space in an open grassy area and a shaded area within the confines of a university campus situated in Shenyang. Shenyang, positioned at 41.8°N, 123.4°E, is located in the extreme northeastern region of China and is categorized as a severe cold B zone, as per the Thermal Design Code for Civil Buildings (GB 50176–2016). Shenyang has a brief springtime period with abundant sunshine and a changeable climate, which undergoes periods of strong winds with an average daily temperature range of anywhere from -4 °C to 7 °C.

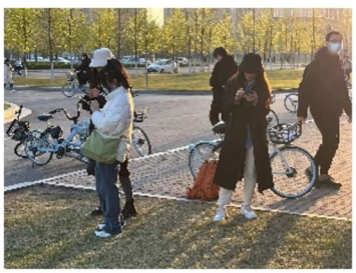
This study selected 20 university students as participants. Additionally, during the experiment, approximately 32 passersby expressed interest in our study. After explaining how to participate, these 32 individuals also joined our experiment.

The research was conducted over three days—4th April 2023, 16th April and 24th April. We inquired about the local weather forecast before the experiment began.

Prior to the on-site measurement, we explained how to complete the experiment in a classroom, and they were required to arrive at two experimental locations three times a day during the specified time intervals: 8:00–10:00 AM, 11:00 AM-2:00 PM, and 3:00–6:00 PM.



(a) Site plan



(b) Open grassland

(c) Sitting area

Fig. 5 Schematic diagram of the research site

Students visited the two research sites three times during the day—morning, midday, and afternoon. They voted on a 100-point scale for thermal comfort in their current environment and chose the word that best describes the outdoor thermal environment. To prevent influencing participants' word choices, the questionnaire displayed all the words without indicating their scores in the thesaurus. It's worth noting that all the words were sorted by their scores in the thesaurus, allowing participants to quickly locate suitable words. They then scored the words on a bipolar questionnaire scale across various dimensions.

The environmental variables were captured automatically by the designated measuring equipment, and their mean values were logged every 5 min from 8:00 to 18:00. All instruments were selected in accordance with the ISO7726 standard, and their technical specifications, including model, range, and accuracy, are presented in Table 2.

2.3 Methods of analysis

1) Analysis of lexical dimensional correlations: the study converted lexical scores in multidimensional positioning into multidimensional semantic radar charts to analyze the thesaurus, and quantified the correlations between the thesaurus and the dimensions.
2) Analysis of the necessity of the thermal comfort thesaurus: first, the study matched the sample data obtained subjectively in the second stage with the physical environmental parameters measured by the instruments, which in turn resulted in 340 entries. the scores containing the objective physical parameters, the TCV of the thermal comfort vote, as well as the words selected by the subjects and the 5 dimensions. The study selected the TCV of the thermal comfort vote as the 1-dimensional thermal comfort evaluation index of the thermal environment thermal comfort at this stage, and used Rayman software (Matzarakis et al., 2010) to calculate the PET, and selected the PET index as the reference index of the thermal environment evaluation. By comparing and analyzing the relationship between PET, thermal comfort voting TCV and the 5 dimensions of related words, the necessity of the thermal comfort thesaurus is verified.
3) Validation of the effectiveness of the thermal comfort thesaurus: The selection of vocabulary in the thermal comfort evaluation in the second stage is counted, the selection rate is analyzed and discussed, and a correlation analysis is carried out with the thermal comfort evaluation thesaurus established in the first stage.

3 Results and analysis

3.1 Multidimensional semantic thesaurus

3.1.1 Basic information of semantic evaluation thesaurus

People's locution scores for words were obtained by correcting, screening and scoring the thesaurus vocabulary in the first stage. People's locution scores were expected to be influenced by individual differences, psychological and physiological factors. The locution scores corresponding to 5 dimensions of each word were averaged (Lin, 2009; Liu et al., 2016, 2020), resulting in a thesaurus of 63 words related to multidimensional semantics. Samples of word scores and sources are shown in Table 3, and the number of words and the percentage of words related to each dimension are shown in Table 4.

The proportion of words related to 'Thermal pleasure, Temperature, Humidity, Wind speed' are all above 80 percent, accounting for 87.5, 82.81 and 89.06 percent of the total. The number of words related to wind is 46 (71.88%) and there are only 38 words related to 'radiation', with the lowest percentage of 59.38%. The results show that people have more words to describe thermal pleasure, temperature, humidity and wind speed, and relatively fewer words to describe radiation.

3.1.2 Multidimensional semantic radar map

By plotting the score information of the 63 words on a radar chart, we can see the distribution of each word's scores in each dimension. For example, when the word '闷热' is used to describe the environment (Fig. 6), it is assumed that it can describe 5 dimensions: muggy describes an environment with relatively high temperature and radiation intensity (Temperature 79.90, Radiation 71.60), moderate humidity (Humidity 54.54) and low wind intensity (Wind 9.11). People's feelings related to thermal pleasure are low (Thermal pleasure 14.19) when they use this word to describe the thermal environment.

Table 2 Instrument technical parameters

Meteorological parameters	Instrument Model	Range	Accuracy	Sampling rate
Wind speed (V)m/s	testo 405i anemometer	0 ~ 30 m/s	± 0.1 m/s	2 s ~ 12 h
Temperature (Ta)°C	AZ87786 Thermal Index Meter	0 ~ 50 °C	± 0.6 °C	10 s ~ 24 h
Humidity (RH)%	AZ87786 Thermal Index Meter	0% ~ 99%	± 3%	10 s ~ 24 h
Black sphere temperature (Tg) °C	AZ87786 Heat Index Meter	0 ~ 80 °C	± 1.5 °C	10 s ~ 24 h

Table 3 5-dimensional semantic rating scale (Samples)

No	Chinese semantic	English meanings	Vote scores					Source
			Thermal Pleasure	Temperature	Radiation	Humidity	Wind	
1	碧空万里	The sky stretches out boundlessly, painted in a deep blue hue	83.9	57.7	54.4	53.6	16.0	The CCL Thesaurus
2	冰冷	Cold	30.5	22.2	-	41.0	-	Translation
3	冰爽	Icy	58.1	36.0	-	51.1	-	Translation
4	滴水成冰	lit. water dripping becomes ice	24.9	13.2	-	51.4	-	The CCL Thesaurus
5	毒热	toxic heat	7.9	93.3	91.1	22.3	-	Questionnaires
6	干巴巴	insipid	-	-	-	22.7	-	Questionnaires
…	…	…	…	…	…	…	…	…
63	烦热	feverish	21.0	83.2	76.1	36.5	11.7	Translation

Table 4 Word numbers and occupied percentage related to each dimension

	Word number	Percentage of total thesaurus
Thermal pleasure	56	87.50%
Temperature	53	82.81%
Radiation	38	59.38%
Humidity	57	89.06%
Wind	46	71.88%

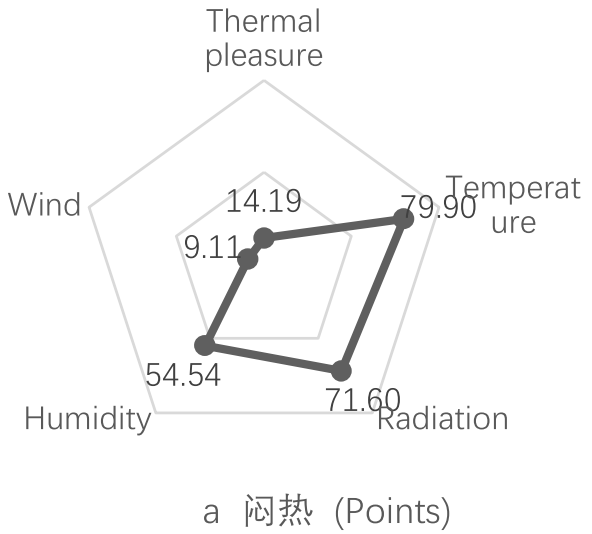


Fig. 6 Multidimensional semantic radar diagram (**a**)

Another example is when people use the word '冰爽' (Fig. 7), 3 dimensions of information can be described.'冰爽' describes an environment with good thermal pleasure (Thermal pleasure 58.11), lower temperature (Temperature 36.04) and moderate humidity values (Humidity 51.06), whereas wind and radiation conditions cannot be described with this word.

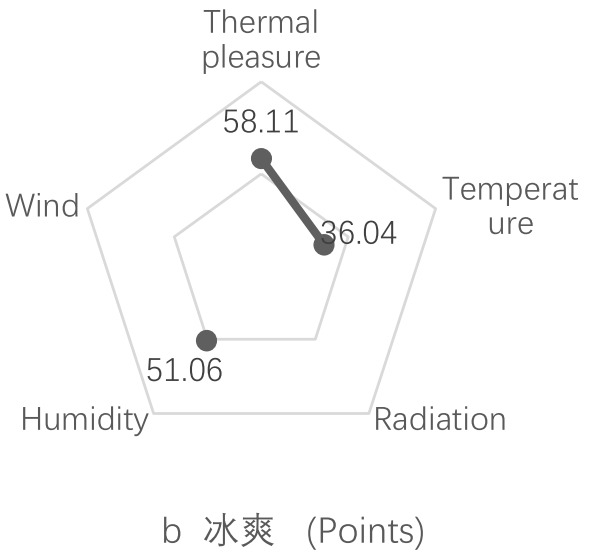


Fig. 7 Multidimensional semantic radar diagram (**b**)

3.1.3 Multidimensional semantic thermal comfort evaluation

This study compares TCV, PET and multi-dimensional semantic evaluation to analyze multi-dimensional semantic evaluation. TCV was obtained directly through questionnaires, and PET values were obtained by calculating objective parameters of 340 samples by Rayman software. The range of PET values and word selection were sorted out when TCV values were the same.

For example (Table 5), when the thermal environment influence factors are quite different (Temperature, wind velocity, relative humidity Radiation, etc.), and the PET value fluctuate in a wide range (from 10.1 °C to 20.4 °C, as shown in Fig. 8), people's thermal comfort vote is the same (71), and people use different words to describe thermal environment, revealing that semantic evaluation

Table 5 Thermal comfort value, word choice and PET relationship

No	TCV (Points)	PET (°C)	Subjective semantic Picks					Objective parameter				
			Thermal pleasure	Temperature Sensation	Radiation Sensation	Humidity Sensation	Wind Sensation	Ta (°C)	Tg (°C)	RH(%)	V (m/s)	Clo
1	71	10.1	爽朗	爽朗	阳光刺眼	干爽	微风	13.8	31.8	13.3	0.7	0.9
2	71	10.1	阳光明媚	阴凉	舒适	干爽	微风	13.8	31.8	13.3	0.7	0.5
3	71	13.5	温和	舒适	碧空万里	清爽	微风	14.8	28.3	16.0	0.4	0.6
4	71	14.7	爽朗	冰爽	温润	阳光明媚	微风	16.7	23.6	17.6	0.6	0.8
5	71	15.4	清新	清新	舒适	清新	微风	12.3	43.0	19.3	0.9	1.1
6	71	17.0	清新	温和	温和	清新	微风徐徐	21.2	33.7	19.8	0.8	0.5
7	71	18.1	阳光灿烂	舒适	温暖	清爽	天朗气清	15.2	34.4	22.4	0.3	0.8
8	71	19.1	天朗气清	凉飕飕	天朗气清	干爽	微风	20.1	21.0	21.4	0.5	1.1
9	71	19.3	阳光灿烂	惠风和畅	风和日丽	清爽	天朗气清	14.4	30.9	22.7	1.4	1.1
10	71	20.4	温和	爽朗	阳光明媚	爽朗	微风	24.3	19.1	24.0	1.4	0.6

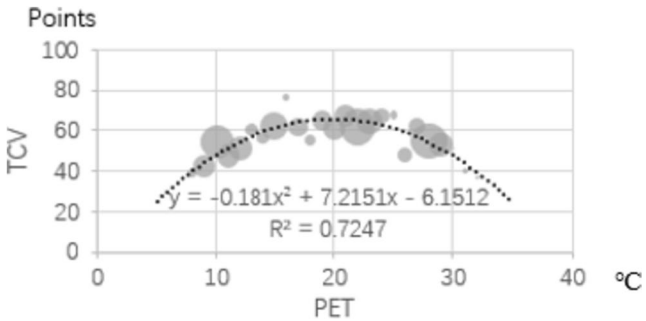


Fig. 8 PET and TCV correlation graphs

Table 6 Table of physical environment parameters

	ta (°C)	tg (°C)	RH (%)	v (m/s)
MAX	31.1	55.3	52.8	2.1
MIN	8.9	11	10.7	0.16
Average	19.7	24.3	26.0	0.85

method is needed to reflect people's senses in a multi-dimensional, comprehensive and systematic way.

3.2 Validation of thermal comfort thesaurus in Chinese vocabulary

3.2.1 Basic information of outdoor experiment

The physical environment parameters for three days at the two selected measurement sites are shown in Table 6. A total of 22 people from 22 different cities participated in the experiment, with a male to female ratio of 1:1. The participants are all young people with an average age of 24 years old, and the maximum age and minimum age are 29 years old and 18 years old respectively. The average body weight of the participants is 61 kg, and the average height is 170 cm.

The experiment collected 340 questionnaires, totally including 40 words related to thermal pleasure, 38 words related to temperature sensation, 37 words related to radiation sensation, 38 words related to humidity sensation and 24 words related to wind sensation.According to statistics, the study excluded invalid samples (p value ≤ 0.05 in validity test) (Wasserstein & Lazar, 2016).

As the climate in Shenyang city in spring is changeable, the PET index showed a more dispersed distribution, which covered a range from 8 to 32 (Fig. 9).

3.2.2 Thesaurus effectiveness validation

Thermal pleasure showed a good relationship between two phrases, the initial thesaurus and the experiment data, with R^2 equals to 0.75(Fig. 10a), which is close to Liu's research (0.82). It is noticed that, when the assessment was biased towards positive (at the right side of the middle line), the assessment showed a good consistency between the thesaurus and the experiment (Fig. 11a). When the assessment was biased towards neutral or

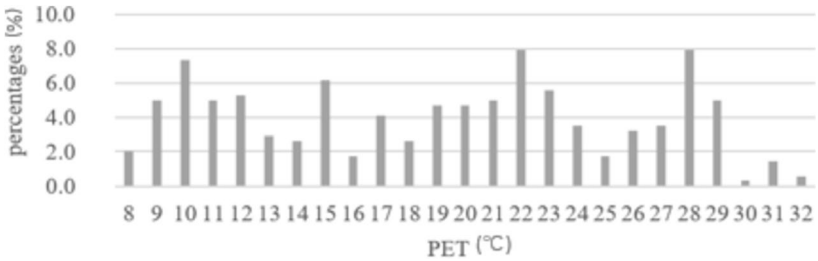


Fig. 9 PET index distribution

negative, some words voted scores showed a bigger difference. This phenomenon may be led by individual difference, and another reason could be the small size samples of the negative environment.

For the temperature dimension, the $R^2=0.68$ (Fig. 10b) which is lower than Liu's study (0.95). One possible reason is that the Spring in Shenyang city is a transition season, and the environment changes a lot from the morning to the evening, and the people's clothes differ a lot due to different dresses in a day. Another reason is that in Liu's study, they carried out field experiment in an open place, and this study carried out field experiment at 2 different points, a shaded place and an open place, so the people's feelings in this study may be very different when they were located in an outdoor environment with close temperature but different radiation. Most words tend to be positive assessment (Fig. 11b), and the word '暖和' showed a high coincidence between the two phases.

Radiation showed the best consistency among the 5 dimensions with $R^2=0.85$(Fig. 10c), which is almost the same with Liu's research. Some words showed a big difference between the initial thesaurus and the experiment, for example, '炎热' was thought to be a high radiation environment in the initial thesaurus, and in the field experiment people voted a low score (Fig. 11c). This may due to the word's season deviation, because according to Liu's study, the words people used to describe the environment existed seasonal differences in sematic descriptions.

On the humidity dimension, $R^2=0.62$ (Fig. 10d) has the second highest difference with Liu's study ($R^2=0.88$). The possible explanation could be people's environment experience. In Shenyang city, people do not experience high humidity environments, and there are not many people who can exactly tell how the humidity influence their feelings to the thermal environment.

For the wind velocity, $R^2=0.63$ (Fig. 10e), which was very close to Liu's study (0.66). The results of the wind are very different from other dimensions (Fig. 11). It showed that R^2 of wind was very close to that of humidity, but each word has a bigger difference between the initial thesaurus and the experiment compared with the other 4 dimensions. It is noticed that, in Liu's study, the wind and the radiation results showed the same trend as the wind result of this study. Except for each word's bigger difference between the initial thesaurus and the experiment, people used more words to describe the wind and radiation environments compared with the other dimensions. The results of this study and Liu's study implied that compared with temperature, humidity, thermal pleasure and thermal intensity, people's feelings in the outdoor environment seemed to be more diversified and influenced by personal partiality.

4 Discussion

In this section, we compared our study with the findings of other researchers and provide a brief statement on future possible research directions.

1) This study referenced the work of de Dear et al., establishing a 5-dimensional thermal comfort evaluation framework comprising a thesaurus of 63 Chinese words related to thermal comfort assessment. In de Dear's study, a 6-dimensional thermal comfort evaluation framework was established, incorporating a multi-dimensional thesaurus of 76 English climate adjectives. The experimental location for this study was in the cold region of Shenyang, China, while de Dear et al. selected Sydney, Australia. Despite the similar thesaurus sizes in both studies, China's vast expanse and diverse climate zones, coupled with variations in local languages used by people in different regions, suggest the need for future research to encompass more regions in China.
2) In this study, three methods were used to compare and analyze the evaluation results under the same environmental conditions. A 1-dimensional thermal comfort evaluation method (TCV) was used for subjective evaluation of outdoor thermal comfort; a physiological equivalent temperature (PET) index including temperature, humidity, radiation, wind speed, clothing, and metabolism was used to characterize the influence of objective and personal factors

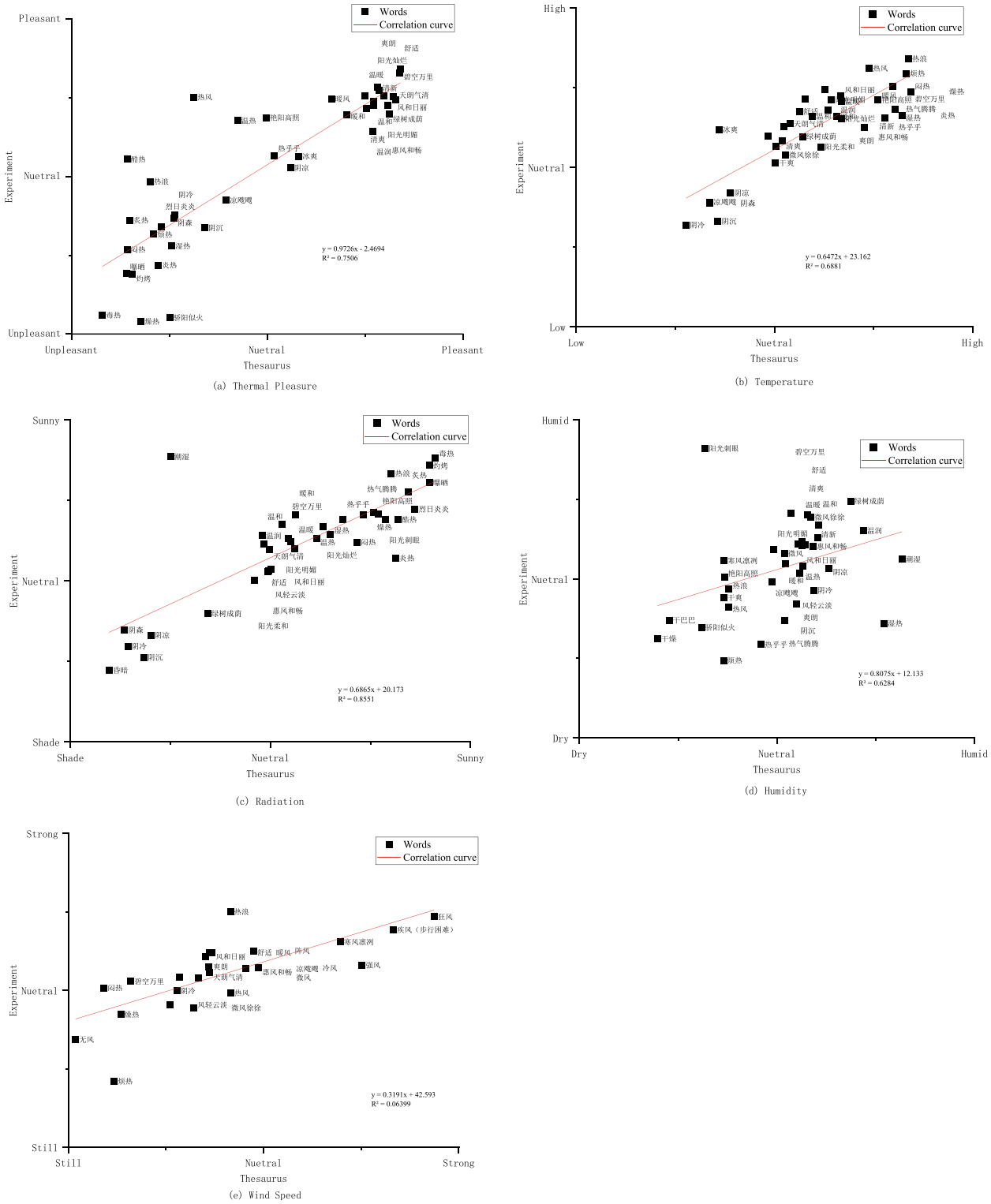


Fig. 10 Correlation analysis between thesaurus scores and experiment voted scores (**a**)–(**e**). **a** Thermal pleasure, **b** Temperature, **c** Radiation, **d** Humidity, **e** Wind speed

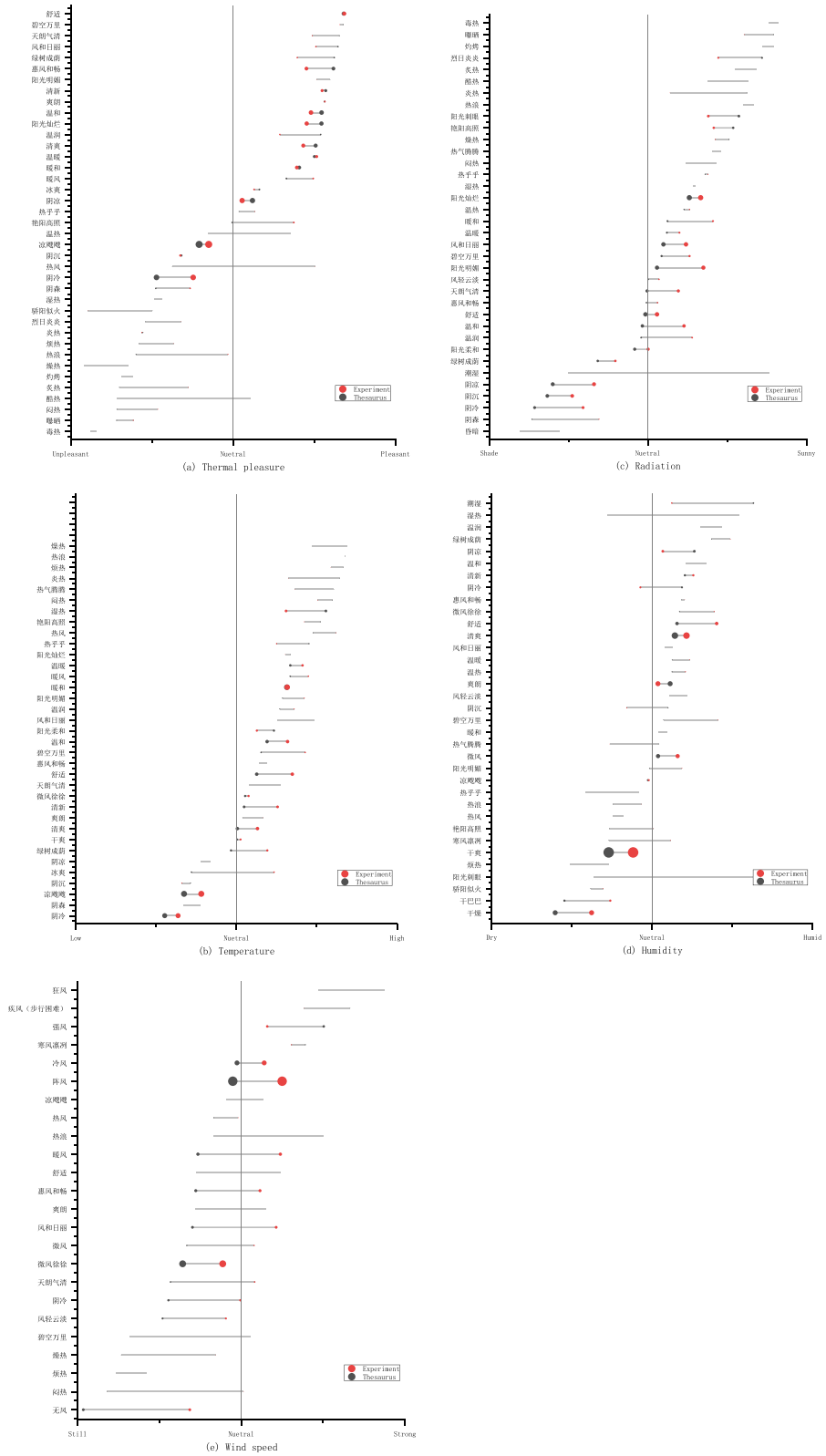


Fig. 11 Coordinates difference between thesaurus scores and experiment voted scores (**a**)–(**e**)

on the evaluation of thermal comfort (Fanger, P. O. (1970)); and a multidimensional semantic evaluation of thermal comfort was used to complement people's description of the environment they are located. The results showed that with equal TCV values the PET values were distributed in a wide range. Subjects ' words selected through the multidimensional semantic evaluation showed semantic similarity but were not identical. The findings meet de Dear et al.'s discussion in their study that 1-dimensional thermal comfort evaluation did not adequately reflect the outdoor thermal environment situation. Thus, multidimensional thermal comfort evaluation is needed (Liu et al., 2020).

3) de Dear established a 6-dimensional semantic evaluation framework, including 'Thermal Intensity' dimension which is well established in pain research and refers to stimulus strength (Green & Schoen, 2007; Melzack & Casey, 1968), which encompasses both the effects of heat intensity and cold intensity. For example, the word 'feverish' scored 78.71 for temperature dimension and 78.56 for thermal intensity dimension, indicating that individuals perceive a higher temperature and more pronounced heat stimulation in a 'feverish' environment. Conversely, the word 'arctic' scored 9.70 for temperature and 76.12 for the thermal intensity dimension, signifying that individuals perceive a lower temperature and more pronounced cold stimulation in an 'arctic' environment.

   Although such descriptions are more scientifically accurate, practical experiments in the Chinese context revealed that, despite a 30-min explanation to participants without a professional background, the thermal intensity dimension still led to misunderstandings. Therefore, this study adopted a 5-dimensional approach, which may not yield as comprehensive results as de Dear et al.'s method but is easier for non-specialist participants to understand. In future studies, efforts can be made to recruit more professionals and enhance explanations to ensure a better understanding of the thermal intensity dimension. Additionally, we found that the 5-dimensional semantic evaluation approach could serve as a supplement to existing thermal comfort evaluations, making it more accessible to non-specialist participants and providing another option for expanding the research samples.

4) Both studies conducted word validation and field experiments in the semantic thesaurus, correlating the scores of words in the thesaurus across multiple dimensions with participants' subjective evaluations in the field. The analysis results showed a good correlation between the scores of selected words in both stages (de Dear et al. obtained 480 samples with R^2 greater than 0.65 for all six 6 dimensions, while this study obtained 340 samples with R^2 greater than 0.62 for all five dimensions). Both of which validated the applicability of the multi-dimensional thermal comfort assessment. Although this study had a smaller sample size compared to de Dear et al., and slightly lower correlation, future research with an expanded sample size is expected to refine the thermal comfort thesaurus and enhance its effectiveness.

5) The thesaurus of thermal comfort evaluation in this study was established by non-professional questionnaire survey and internet survey, professional modification and word score assignment, thus the Chinese words can be used under different thermal environments. But the validation field experiment duration was just 3 days in Spring in Shenyang city, and if the experiment were taken in hot summer or cold winter, more negative words may be chosen by people. The participants are all young college students in this experiment, so the validation under different seasons of various environments by more participant samples are needed.

5 Conclusion

1) In the first stage, this study constructed a multidimensional semantic Chinese thesaurus for evaluating thermal comfort with 63 words, and obtained the scores of each word in 5-dimensions. In the second stage, people choose the words to evaluate the thermal environment on site, the scores in the 5-dimensions are voted based on how they feel right at the questionnaire survey time. The thermal pleasure, temperature, radiation and wind speed showed a good correlation, which validated the effectiveness of established thesaurus.

2) Some words described the information of all 5 thermal comfort items, and some of the words only described information in some of the dimensions. For example, the Chinese word '闷热' described 5 dimensions: thermal pleasure (14.19), temperature (79.90), radiation (71.60), humidity (54.54), wind speed (9.11). For the Chinese word '冰爽', it only described 3 thermal comfort items: Thermal pleasure (58.11), Temperature (36.04) and Humidity (51.06).

3) With a TCV score of 71, the PET range varied between 10.1 and 20.4, revealing that the traditional method of thermal comfort index cannot reflect people's feelings completely. As for the language descriptions, the words number used to describe thermal

pleasure, temperature, radiation, humidity, and wind speed are 3, 8, 8, 9 and 4 respectively. These results showed that relying solely on thermal comfort votes does not allow for a thorough and systematic representation of individuals' perceptions of the outdoor thermal environment, and it is therefore crucial to conduct a semantic evaluation of thermal comfort.

Despite the online survey's coverage of other areas during the initial stage, the participants of this study are young college students residing in a severely cold region, and the field experiment was carried out in spring for only 3 days, thus the sample size and representativeness has its limitations, and more study related to different people, season and various thermal environment needs to be expanded.

Authors' contributions

Tianyu Xi: supervision, methodology, draft review and funding acquisition; Ming Wang: supervision, methodology, project administration and, original draft preparation revision and revision; Enjia Cao: project administration and draft review; Jin Li: draft review and revision; Yong Wang: draft review and revision. Leping Lu: draft review and revision. Xingyu Zhang. The author(s) read and approved the final manuscript.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 26 October 2023 Accepted: 2 February 2024
Published online: 06 March 2024

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