ARTICLE IN PRESS
JID: ENBENV [m5GeSdc;May 24, 2023;20:8]

Energy and Built Environment xxx (xxxx) xxx

Contents lists available at ScienceDirect

Energy and Built Environment

journal homepage: http://www.keaipublishing.com/en/journals/energy-and-built-environment/

Evaluation of suitability of university ladder classroom environment on humans

Xin Liu[a], Xiu Geng[a], Kailiang Huang[a,*], Guohui Feng[a], He Zhao[b], Xiaotong Wang[a], Jianing He[a]

[a] *School of Municipal and Environment Engineering, Shenyang Jianzhu University, Shenyang 100168, China*
[b] *Jianke EET Co., Ltd., Beijing 100013, China*

A R T I C L E I N F O

Keywords:
Severe cold region
Suitability of environment on humans
Natural ventilation
Expert-entropy weight method
Evaluation system

A B S T R A C T

Evaluation of the suitability of university ladder classroom environment on humans is an effective approach to improve the quality of the indoor environment and protect human health. However, there are unresolved issues regarding the suitability of university ladder classroom environment for humans. For example, the design of enclosure structure and heating ventilation and air conditioning (HVAC) system is unreasonable, and the indoor air quality does not meet the required standard. In this study, the suitability of university ladder classroom environment on humans was considered the research object. The evaluation indices of indoor environment were selected from indoor air quality, indoor thermal and humid environments, light environment, and sound environment. And the health and comfort of users were taken as the evaluation indices of users. According to the results of expert investigations and case measurements, the index weight was determined by the expert-entropy weight method, and a complete evaluation system of indices was built. There were two first-level, six second-level, and fourteen third-level indices in the evaluation system. The evaluation indices of each level with the largest weight were indoor environment (0.5940), user health (0.2530), and indoor temperature (0.1175) respectively. By comparing the actual learning effect to the evaluation results, the applicability of the evaluation system was determined. The evaluation system of the suitability of university ladder classroom environment on humans is convenient for operators to identify the weak points between humans and the environment. The evaluation system is endowed with important theoretical and practical significance to realize the green development of colleges and universities and build an environment-friendly campus.

1. Introduction

Suitability of university ladder classroom environment on humans is achieved by the optimization of design schemes. Meanwhile, a hygienic, healthy, and comfortable artificial environment was basically created. By combining the rational design of the enclosure structure and HVAC system, the effect of energy saving was improved. According to the reports, *Modernization of Education 2035 in China and Implementation Plan for Accelerating Education Modernization*, at the end of 2021, there were 3012 colleges and universities in China. The number of colleges and universities was increased by 1.89% over the previous years [1]. The proportion of the increase in the number of university buildings is large. The importance of energy saving in public institutions was emphasized in *"The 13th Five-Year Plan" for Ecological and Environmental Protection*. The indoor comfort should be considered in the evaluation of the energy saving effect of public institutions. There is a close linkage relationship in the humans and the environment. However, regarding the suitability of university ladder classroom environment on humans, a comprehensive, quantitative, and targeted evaluation system has not been established.

Suitability of university ladder classroom environment on humans is affected by subjective and objective factors. The subjective evaluation of the suitability of university ladder classroom environment on humans is usually measured by sleep time, adverse symptoms, predicted mean vote (PMV), and predicted percentage dissatisfied (PPD) [2–7]. Objective evaluation is usually measured by indoor temperature, indoor humidity, indoor pollutant concentration, indoor noise, and indoor illumination [8–13].

In recent years, a variety of evaluation methods have been applied to the evaluation of the indoor environment in the ladder classrooms. The indoor environment has a key role in the work efficiency and comfort of teachers and students. Kraus et al. [14] subjectively evaluated the environmental quality of the classroom and compared indoor parameters such as the air acceptability, odor intensity, thermal comfort, humidity comfort, light comfort, and noise load before and after class. The students' performance, attention, and productivity were influenced

* Corresponding author.
E-mail address: huangkailiang_v@163.com (K. Huang).

https://doi.org/10.1016/j.enbenv.2023.05.003
Received 4 February 2023; Received in revised form 5 May 2023; Accepted 12 May 2023
Available online xxx

Please cite this article as: X. Liu, X. Geng, K. Huang et al., Evaluation of suitability of university ladder classroom environment on humans, Energy and Built Environment, https://doi.org/10.1016/j.enbenv.2023.05.003

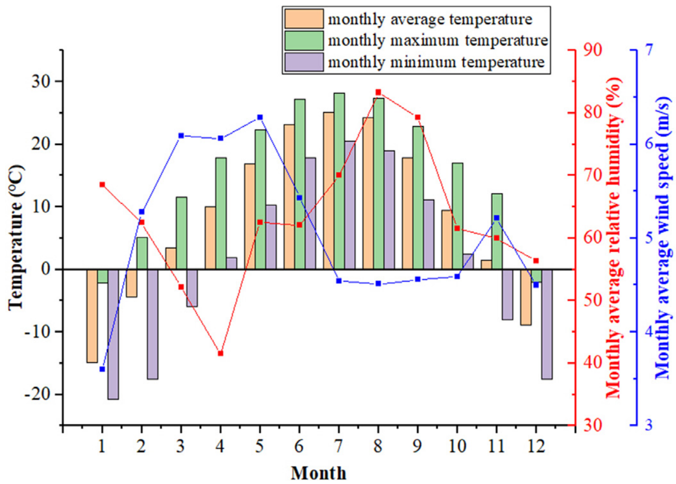

Fig. 1. Basic meteorological data in 2020.

by the air quality. Lee et al. [15] objectively measured the classroom temperature, relative humidity, wind speed, average radiation temperature, CO_2 concentration, equivalent sound pressure level, illuminance, household activities, and clothing insulation level. Combined with evaluation results of user learning (calculation, reading, comprehension, and typing), an empirical expression for the effect of an unsatisfactory indoor environmental quality on the learning performance loss was proposed. Sarbu et al. [16] developed a model for prediction of academic performance. The correlation coefficient for the air temperature, relative humidity, and CO_2 concentration was close to 0.999. The performance of the students was strongly influenced by indoor environmental conditions. Yuan et al. [17] established an indoor air quality evaluation model and management fuzzy comprehensive model. It was used to comprehensively evaluate the impact of various coexisting pollutants (such as formaldehyde and total volatile organic compounds) on the indoor environment. Norazman et al. [18] studied the indoor environment of classrooms by combining field and questionnaire surveys. The key influencing factors of the classroom indoor environment were cleanliness, air flow, and noise pollution. Dai et al. [19] used analytic hierarchy process-fuzzy comprehensive evaluation (AHP-FCE) and genetic algorithm-back propagation (GA-BP) neural network algorithm methods to assess smart learning environments in higher educational institutions.

Thus, a method to analyze the suitability of university ladder classroom environment on humans is required, combined with the linkage characteristics of humans and the environment. According to literature researches, field researches, and questionnaire surveys, the weights of evaluation indices were determined by the expert-entropy weight method. The complete evaluation system of indices was then formed. Based on the learning effect of students in university ladder classrooms, the correctness of the evaluation system of indices was demonstrated. Fourteen evaluation indices were included in the evaluation system. The indoor environment was improved by nine evaluation indices, the health of users was improved by five evaluation indices. The selection of indices is helpful for evaluation of the suitability of university ladder classroom

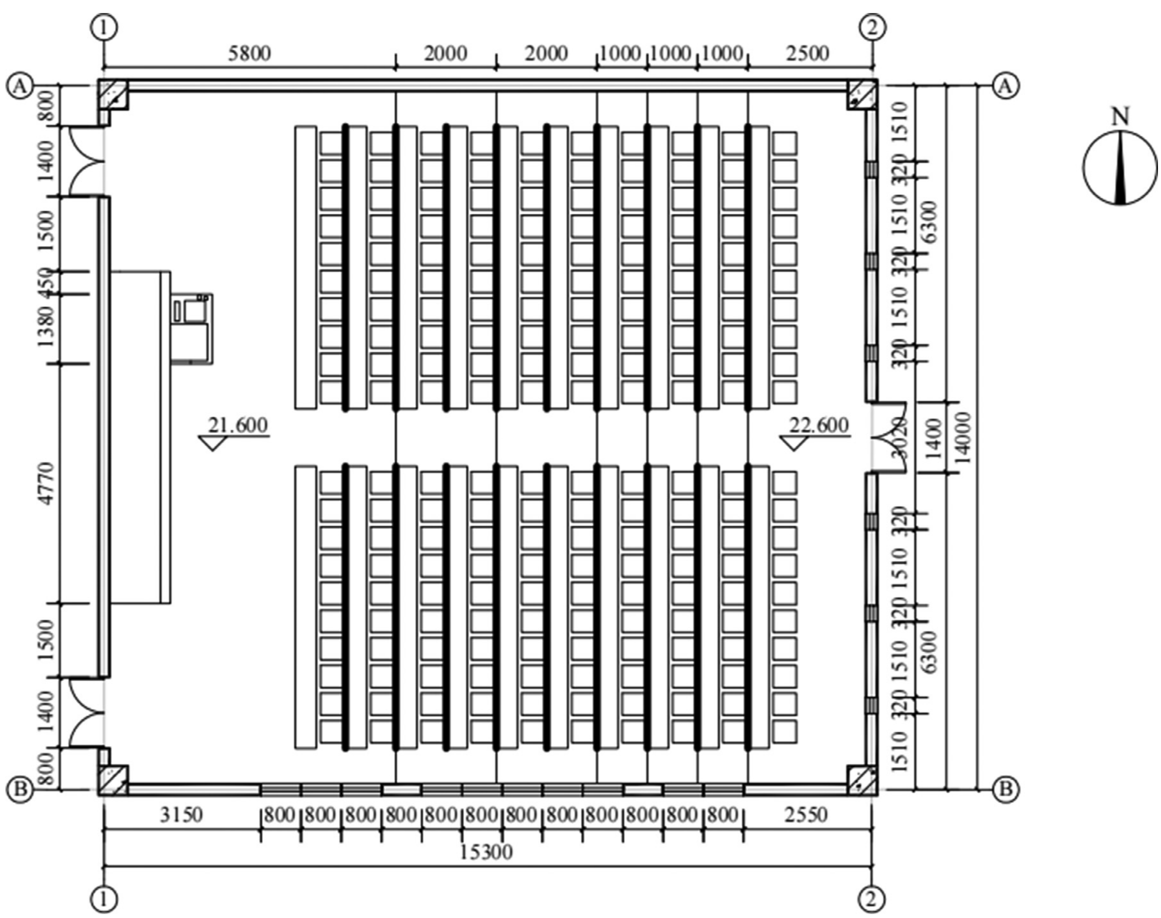

Fig. 2. The plan of the ladder classroom.

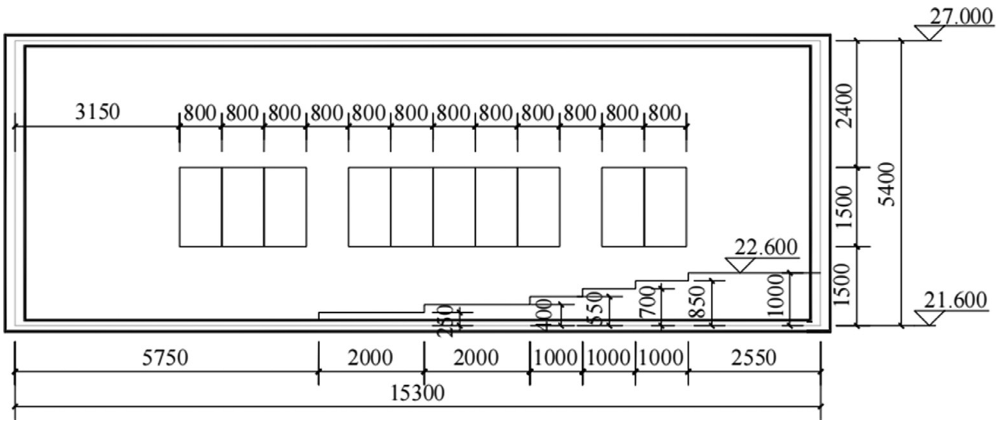

Fig. 3. The ladder classroom Ⓑ-Ⓑ axis sectional elevation.

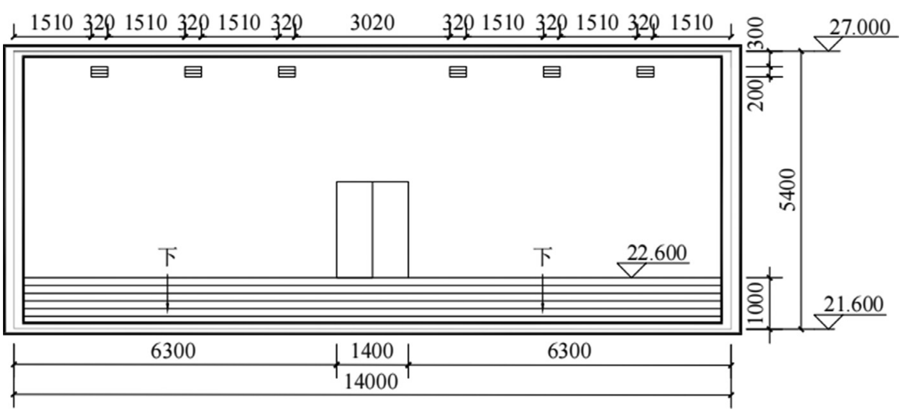

Fig. 4. The ladder classroom ②-② axis sectional elevation.

environment on humans. The evaluation results can be regarded as a valuable reference to improve the indoor environmental quality and human health.

2. Building overview

2.1. Climate parameters and challenges

Shenyang Jianzhu University is located in severe cold regions of China, with latitude and longitude of 41.7°N and 123.5°E respectively. The region is considered a temperate monsoon climate. Basic meteorological data in 2020 are shown in Fig. 1. The average temperature of Shenyang in 2020 was 8.62 °C. The coldest month was January. The monthly average temperature was -14.89 °C. The lowest temperature was -20.77 °C. The monthly average relative humidity was 68.54%.

2.2. Building overview

Fig. 2 shows the plan of the ladder classroom, with a building area of 214.2 m^2 and floor height of 5.4 m. Six steps were included in the ladder classroom. The height difference between two adjacent steps was 0.15 m. The classroom could accommodate 200 people, and the attendance rate was 84%. In winter, the central heating mode was employed, and the air was processed by fan coil units. In summer, fan coil units did not deliver cold air indoors. The design temperature in winter was 22 °C. The south exterior wall was equipped with 10 side hung windows, with a total window area of 6.4 m^2. In summer, the indoor air was regulated by a single-side ventilation system with a combined action of wind pressure and heat pressure (Figs. 3 and 4).

3. System for suitability of university ladder classroom environment on humans

3.1. Evaluation index screening method

The suitability of environment on humans can be improved by design of classroom enclosure, indoor layout, energy system, and health management. Considering the suitability of environment on humans, effective information was collected and integrated. The evaluation indices were selected from literature researches, field researches, and questionnaire surveys. The suitability of university ladder classroom environment on humans should be quantitatively analyzed under conditions of natural ventilation.

3.1.1. Literature research

Based on relevant industry norms, core journals, and above documents, papers on indoor environment problems and evaluation in the past 10 years were considered. The key factors, research methods, and results affecting the suitability of environment on humans were collected and integrated. The indoor CO_2 concentration, $PM_{2.5}$ concentration, formaldehyde concentration, temperature, relative humidity, noise, illumination, sleep time, heart rate, PMV, PPD were preliminarily determined as evaluation indices of the suitability of environment on humans.

3.1.2. Field research

In order to analyze the suitability of university ladder classroom environment on humans, 10% (4 rooms) of ladder classrooms were sampled. Indoor temperature and humidity, indoor pollutant concentration, indoor noise, and indoor illumination were monitored only during class hours throughout the year, and measured every 10 days. The data acquisition instruments are shown in Table 1. According to relevant standards

Table 1
Experimental data collection instruments and their parameters.

Device	Type	Measured parameters	Accuracy
Temperature and humidity light recording instrument	HOBOU12-012	Temperature	±0.35 °C
		Relative humidity	±2.5% RH
		Illumination	±2% lx
CO_2 detector	AZ77535	CO_2 concentration	±30 ppm±5%
Air quality detector	WP-6910	$PM_{2.5}$ concentration	0.1% μg/m^3
		Formaldehyde concentration	0.1% mg/m^3
Noise meter	AS824	Noise	±1.5 dB

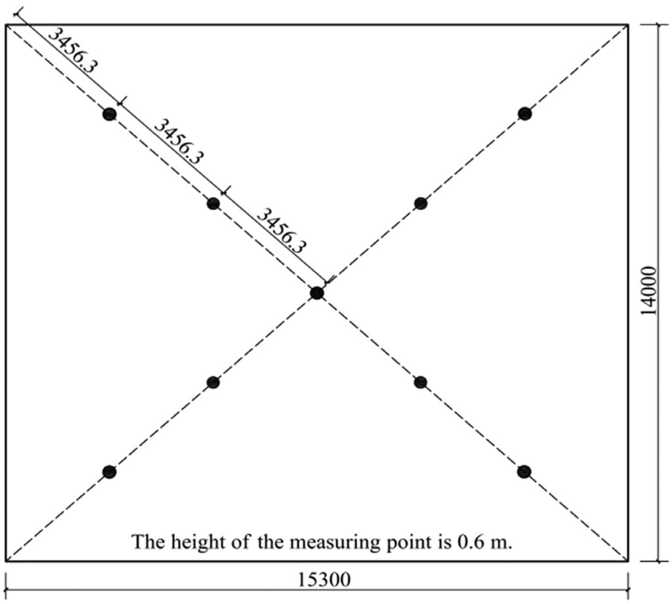

Fig. 5. Ladder classroom temperature and humidity measurement layout.

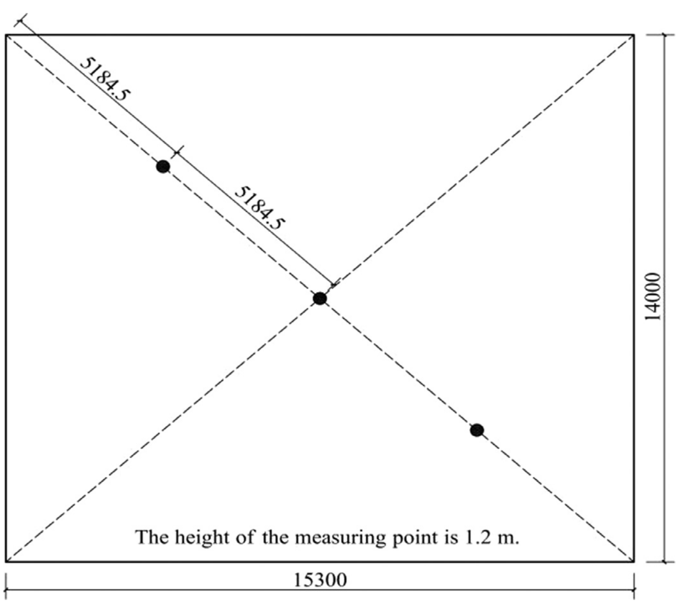

Fig. 6. Ladder classroom pollutant concentration measurement layout.

and specifications, the measurement position of each parameter was determined, as shown in Figs. 5–7. The height of indoor temperature and humidity measuring point was 0.6 m, indoor pollutant concentration and indoor noise measuring point was 1.2 m, indoor illumination measuring point was 0.75 m. The monthly average values of each parameter are shown in Figs. 8–10. 10% of the students in the class were sampled.

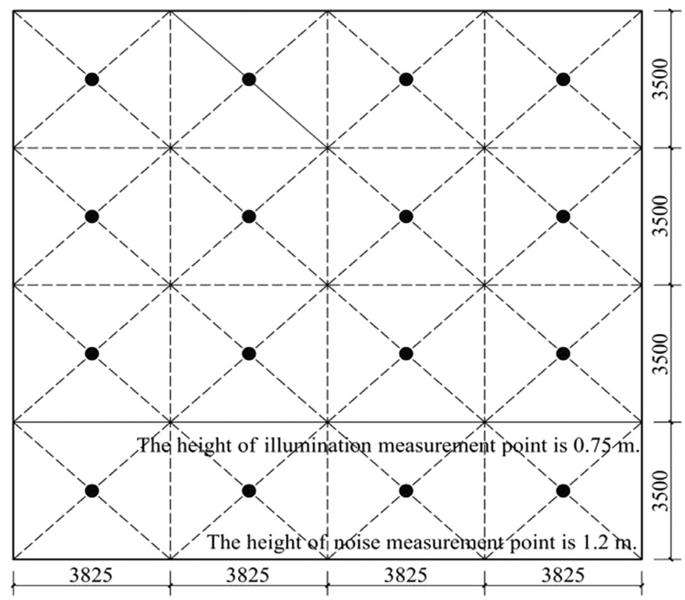

Fig. 7. Ladder classroom illumination and noise measurement layout.

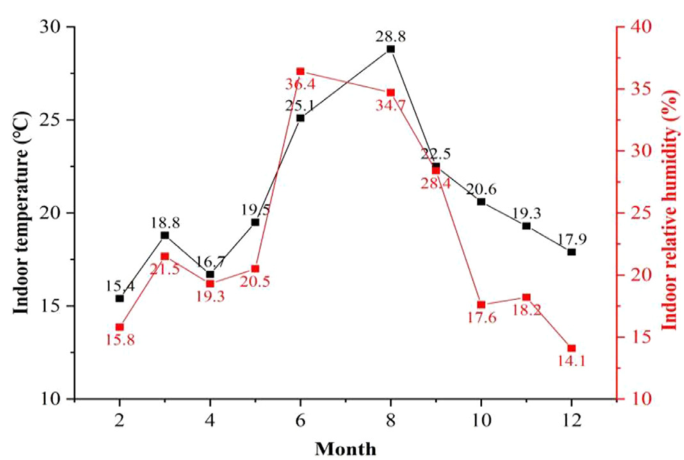

Fig. 8. Monthly average values of indoor temperature and humidity.

The survey results of students' sleep time, heart rate, adverse symptoms, PMV, and PPD are shown in Fig. 11. A strong support for the subsequent establishment of the indices system was provided by the survey results.

3.1.3. Questionnaire survey

Based on literature reviews and field studies, a subjective questionnaire on the indoor environment of ladder classrooms was developed. The research object was 178 teachers and students in ladder classrooms in Shenyang Jianzhu University. The results are shown in Figs. 12 and 13. The index system of the suitability of environment on humans was further modified by the results.

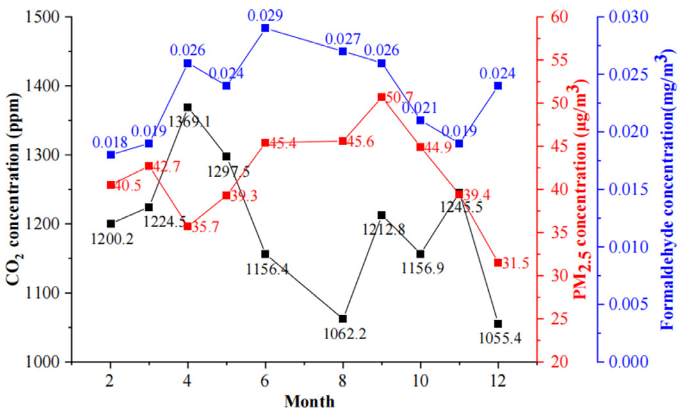

Fig. 9. Monthly average values of indoor pollutant concentration.

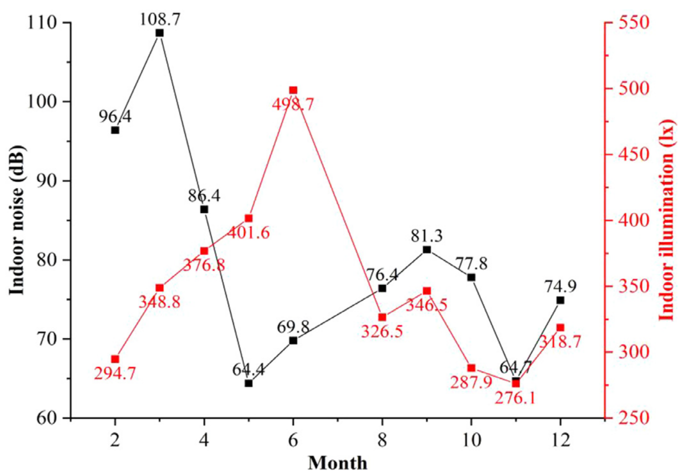

Fig. 10. Monthly average values of indoor noise and illumination.

3.2. Construction of the evaluation indices system

When the indoor environment and user health of university ladder classroom were analyzed, and the evaluation indices of the suitability of environment on humans were sorted out, then a complete evaluation indices system was established. There were two aspects covered in the evaluation index system, including 14 evaluation indices. The specific indices are shown in Fig. 14.

3.2.1. A: Indoor environment indices

Indoor environmental assessment was used to measure indoor air quality, indoor thermal and humid environments, indoor sound environment and indoor light environment. The key factors affecting indoor environmental quality were analyzed level by level, to propose targeted measures to improve the indoor environmental quality.

A1: Indoor air quality. Human metabolites are produced mainly from exhaled gas and skin metabolism. In a poorly ventilated environment, pollution of the indoor environment may be caused by human metabolites. The main output product of respiration is CO_2 [20]. Allergic dermatitis, asthma, and other diseases can be caused by excessive indoor $PM_{2.5}$ and formaldehyde concentrations. And the students' learning efficiency is affected by excessive indoor $PM_{2.5}$ and formaldehyde concentrations. The indoor CO_2 concentration (A11), indoor $PM_{2.5}$ concentration (A12), and indoor formaldehyde concentration (A13) were selected as indoor air quality evaluation indices for the ladder classroom.

A2: Indoor thermal and humid environments. Human physiological parameters and heat-moisture sensation are affected by heat-moisture environment. The indoor temperature and humidity should be in reasonable ranges to meet the needs of building use. The indoor temperature (A21) and indoor relative humidity (A22) were selected as indoor thermal and humid environments evaluation indices for the ladder classroom.

A3: Indoor sound environment. Most of the ladder classrooms in colleges and universities are ordinary teaching classrooms. According to *Environmental Quality Standard for Noise (GB/T 3096-2008)*, the noise in the ladder classrooms is relatively high [21]. The noises during class discussion and after class periods are significantly higher. The indoor noise compliance rate is defined as the ratio of the noise data volume within the standard range to the total data volume. The indoor noise (A31) and noise compliance rate (A32) were selected as indoor sound environment evaluation indices for the ladder classroom.

$$R_{noise} = \frac{N_{standard}}{N} \times 100\%, \quad (1)$$

where R_{noise} is the noise compliance rate [%], $N_{standard}$ is the amount of noise data within the standard range, and N is the total amount of noise data.

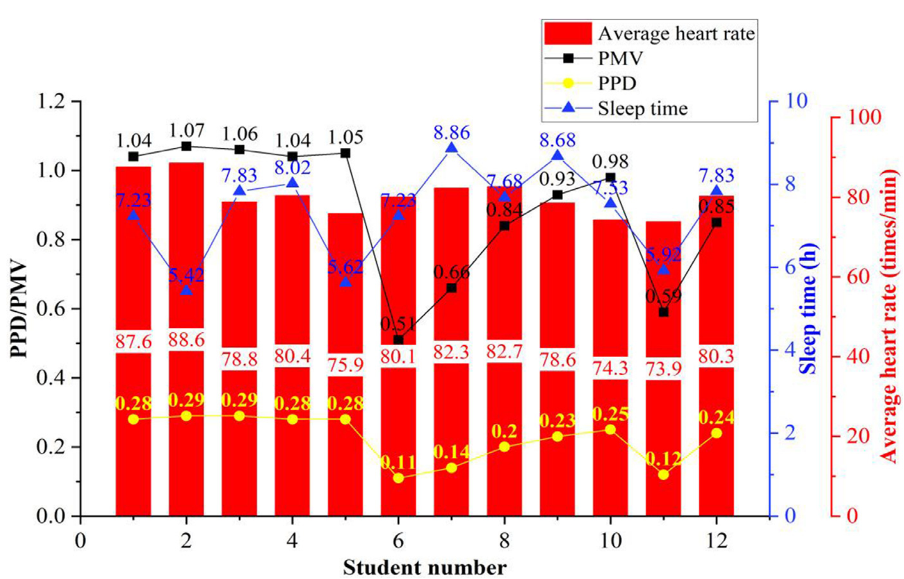

Fig. 11. Test data of sampled students.

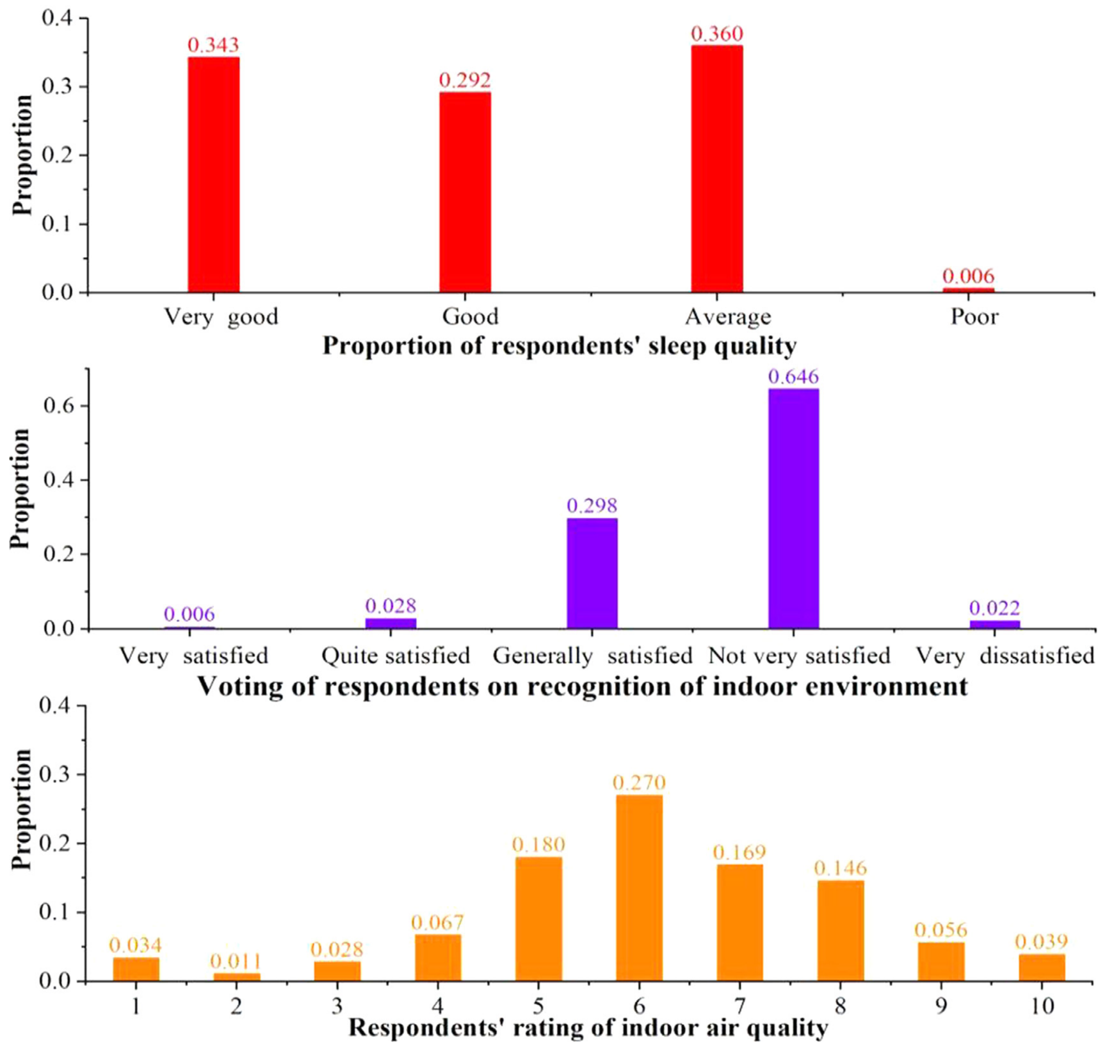

Fig. 12. Questionnaire survey data of respondents.

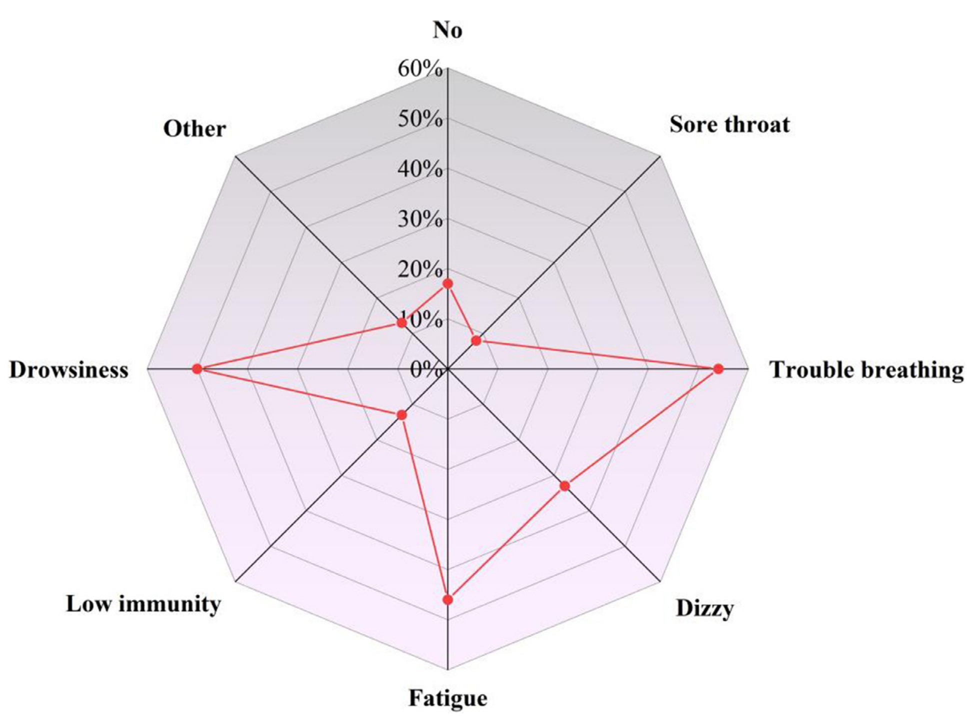

Fig. 13. Adverse symptoms of indoor personnel.

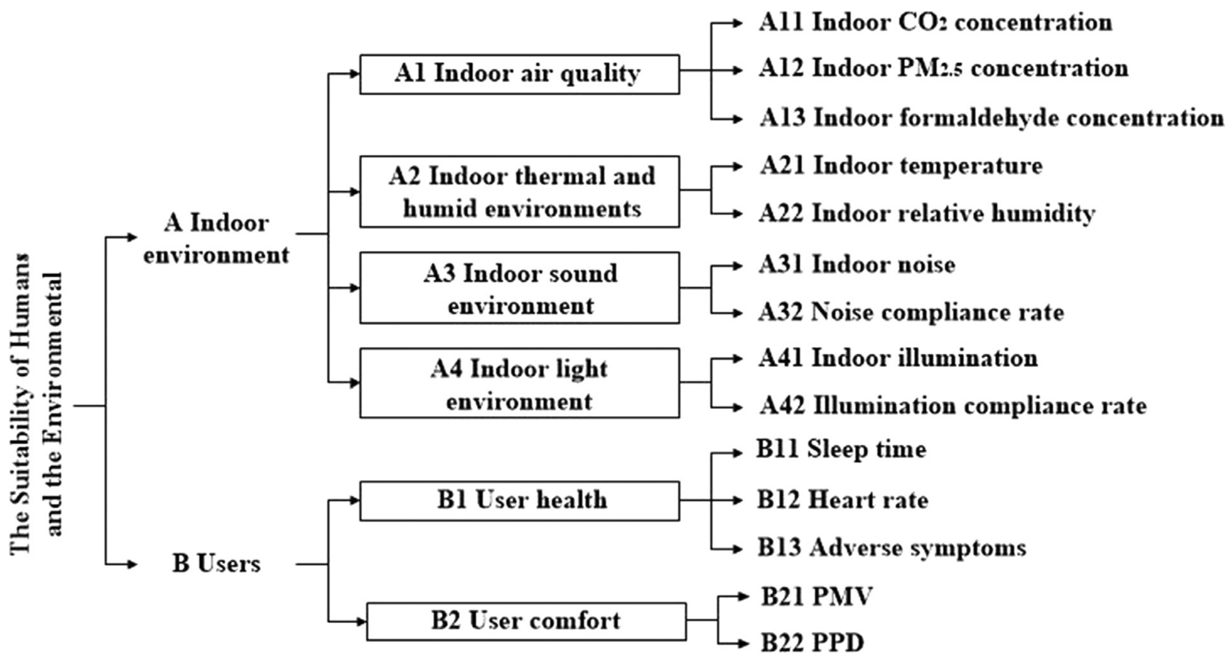

Fig. 14. Evaluation index system.

A4: Indoor light environment. The students' visual acuity is greatly affected by indoor illumination. Considering *Standard for Lighting Design of Buildings (GB 50034-2013)* and *Standard for Daylighting Design of Buildings (GB/T 50033-2013)*, the color rendering indices of most rooms in the campus buildings are low [22,23]. The indoor illumination compliance rate is defined as the ratio of the illumination data volume to the total data volume within the standard range. The indoor illumination (A41) and illumination compliance rate (A42) were selected as light environment evaluation indices for the ladder classroom.

$$R_{illu\min ation} = \frac{M_{s\tan dard}}{M} \times 100\%, \tag{2}$$

where $R_{\text{illumination}}$ is the illumination compliance rate [%], M_{standard} is the amount of illumination data within the standard range, and M is the total amount of illumination data.

3.2.2. B: User indices

B1: User health. The students' listening effect and physical health are affected by the quality of sleep. And sleep quality is closely related to sleep time. Heart rate variability is the main index of autonomic nervous system function evaluation, and human health is reflected by heart rate. People who stay indoors for a long time are likely to have adverse symptoms due to pollutants. The rate of adverse symptoms is defined as the ratio of the number of people with adverse indoor symptoms to the total number of people. Sleep time (B11), heart rate (B12), and adverse symptoms (B13) were selected as health evaluation indices for users of the ladder classroom.

B2: User comfort. The PMV is based on the human thermal balance and subjective thermal sensation level of psychophysiology as a starting point and accounts for numerous relevant factors of human thermal comfort. The proportion of people who feel too warm or too cold is predicted by the PPD [20]. The PMV (B21) and PPD (B22) were used as indices to evaluate the user comfort.

$$PMV = [0.303\exp(-0.036M) + 0.0275]T_L, \tag{3}$$

where M is the body's metabolic rate [W/s] and T_L is the difference between the human body heat production and heat dissipation.

$$PPD = 100 - 95\exp\left[-\left(0.3353 \div PMV^4 + 0.2179PMV^2\right)\right]. \tag{4}$$

Table 2
Classification standard of adverse symptoms

Grade	Placement basis	Explanation
Level I	General symptoms	Fatigue Head weight Headache Distracted attention Nausea/dizziness
Level II	Symptoms of mucous membranes	Cough Dry throat Nasal tingling/nasal congestion/runny nose Itchy eyes
Level III	Skin symptoms	Facial redness Itchy scalp Hand rashes

3.3. Quantitative standards for qualitative indices

The scoring of experts in relevant fields was used as original data of qualitative indices. According to the evaluation points of qualitative indices, adverse human body symptoms are divided into three categories: I, II, and III [24], assigned according to levels of 1, 0.7, and 0.4, respectively. The specific grading basis and standard of indices are listed in Table 2.

4. Establishment of the evaluation system for the suitability of environmenton humans

4.1. Determination method of evaluation index weight

The comprehensive evaluation methods were divided into two categories: subjective and objective. The evaluation index weight was determined using the expert scoring method [25] and entropy weight method [26]. Based on the expert scoring method, after several rounds of consultation and result feedback, the discrete evaluation results were gradually converged, and the evaluation results with a higher feasibility were finally obtained. High accuracy and small sample size are the characteristics of entropy weight method. The characteristics of subjective and ob-

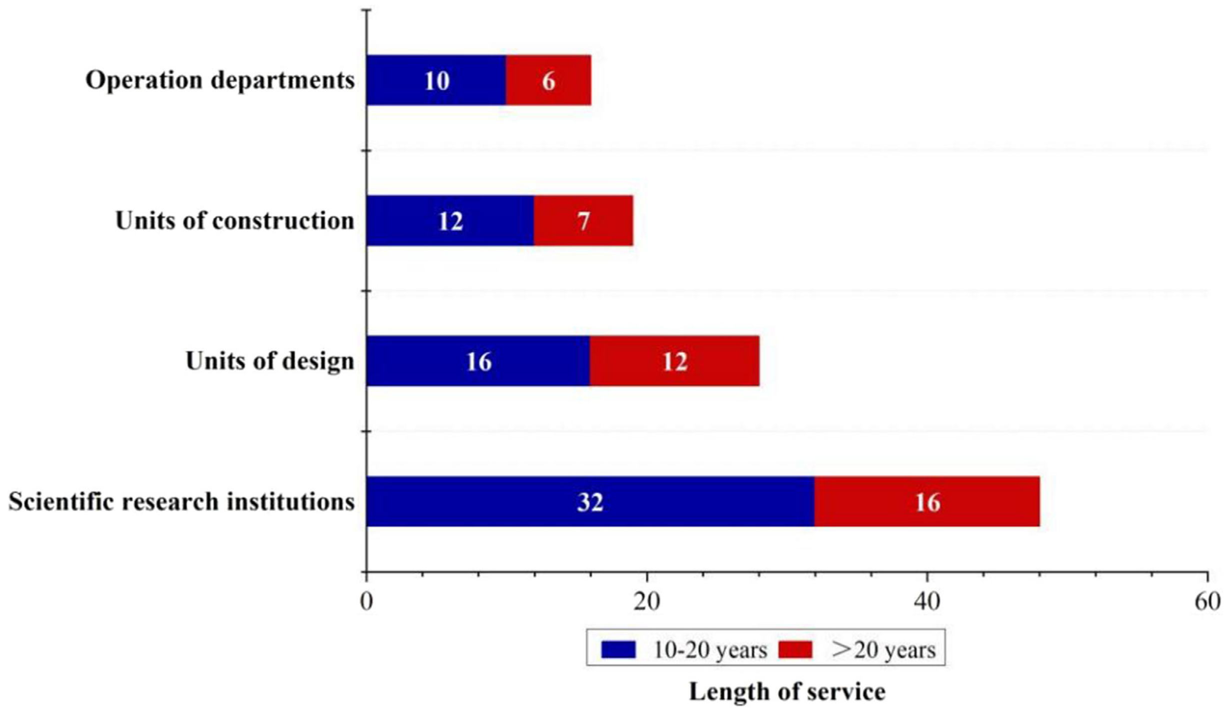

Fig. 15. Statistics on the number of questionnaire experts.

jective empowerments were integrated by the method of additive combination empowerment. The problems of the single empowerment method were overcome by the combination empowerment method. The empowerment results using the additive combination method were more real and reliable.

4.1.1. Expert scoring method

According to the three levels evaluation indices covered by the evaluation index system, the importance of a certain level for a certain factor at the next level was judged step by step. To obtain the subjective weight of evaluation indices, the index weight questionnaire was distributed to experts with different working years engaged in scientific research institutions, design units, construction units, and operation departerments. Fig. 15 illustrates the statistics of the number of experts in the questionnaire survey. The number of experts with a length of service larger than 20 years accounted for the smallest proportion in different industry types. The numbers of research experts in each industry decreased with the increase in the length of service. The final weight distribution of the expert scoring method is presented in Table 3.

4.1.2. Entropy weight method

The ladder classrooms of universities in severe cold regions were selected as evaluation objects to carry out field research on the suitability of environment on humans and the measured data of various evaluation indices were obtained. Based on the theory of the entropy weight method, the measured data were standardized, and the entropy weight vector, difference coefficient, and weight of each evaluation index were calculated. The relative weight and final weight of each index could be obtained by adding the lower index weight and pushing it up layer by layer, as shown in Table 4. The initial matrix is X.

$$X = \begin{pmatrix} x_{11} & x_{21} & x_{31} & \cdots & x_{m1} \\ x_{12} & x_{22} & x_{32} & \cdots & x_{m2} \\ x_{13} & x_{23} & x_{33} & \cdots & x_{m3} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ x_{1n} & x_{2n} & x_{3n} & \cdots & x_{mn} \end{pmatrix}.$$

The entropy weight is calculated as follows. The matrix standardization is expressed by

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, \tag{5}$$

where y_{ij} is the index j of the object i standardized index value and x_{ij} is the index j of the object i standardized index value.

The entropy weight vector of the index set is

$$Ej = -k \sum_{i=1}^{m} f_{ij} \ln\left(f_{ij}\right). \tag{6}$$

The difference coefficient of indices is

$$g_i = 1 - E_j. \tag{7}$$

The entropy weight of indices is

$$B_j = \frac{1 - E_j}{n - \sum_{i=1}^{n} E_{ij}}. \tag{8}$$

4.1.3. Expert-entropy weight method

To address the limitations of the subjective empowerment method and objective empowerment method, the weight calculation results of the two methods were integrated. The principle of the additive combination empowerment method is as follows.

$$W_{com} = a \times W_{sub} + (1 - a)W_{obj}, \tag{9}$$

where W_{com} is the comprehensive weight, a is the combination coefficient of 0 to 1, considered as 0.5, and W_{sub} and W_{obj} are subjective and objective weighting attribute weights, respectively.

According to the survey and calculation results, the evaluation indices of the suitability of environment on humans calculated by the expert-entropy weight method are listed in Table 5.

4.2. Construction of a comprehensive evaluation system

4.2.1. Index score interval

According to the evaluation indices and corresponding weights, the overall evaluation system of the suitability of university ladder class-

Table 3
Evaluation index weight of the expert scoring method.

The first level indices	Relative weight of the first level indices	The second level indices	Relative weight of the second level indices	Final weight of the second level indices	The third level indices	Relative weight of the third level indices	Final weight of the third level indices
A Indoor environment	0.5	A1 Indoor air quality	0.300	0.150	A11 Indoor CO_2 concentration	0.597	0.090
					A12 Indoor $PM_{2.5}$ concentration	0.200	0.030
					A13 Indoor formaldehyde concentration	0.203	0.030
		A2 Indoor thermal and humid environments	0.388	0.194	A21 Indoor temperature	0.555	0.108
					A22 Indoor relative humidity	0.445	0.086
		A3 Indoor sound environment	0.168	0.084	A31 Indoor noise	0.467	0.039
					A32 Noise compliance rate	0.533	0.045
		A4 Indoor light environment	0.144	0.072	A41 Indoor illumination	0.405	0.029
					A42 Illumination compliance rate	0.595	0.043
B Users	0.5	B1 User health	0.796	0.398	B11 Sleep time	0.253	0.101
					B12 Heart rate	0.254	0.101
					B13 Adverse symptoms	0.493	0.196
		B2 User comfort	0.204	0.102	B21 PMV	0.628	0.064
					B22 PPD	0.372	0.038

Table 4
Evaluation index weight of the entropy weight method.

The first level indices	Relative weight of the first level indices	The second level indices	Relative weight of the second level indices	Final weight of the second level indices	The third level indices	Relative weight of the third level indices	Final weight of the third level indices
A Indoor environment	0.688	A1 Indoor air quality	0.219	0.151	A11 Indoor CO_2 concentration	0.325	0.049
					A12 Indoor $PM_{2.5}$ concentration	0.417	0.063
					A13 Indoor formaldehyde concentration	0.258	0.039
		A2 Indoor thermal and humid environments	0.323	0.222	A21 Indoor temperature	0.572	0.127
					A22 Indoor relative humidity	0.428	0.095
		A3 Indoor sound environment	0.116	0.080	A31 Indoor noise	0.475	0.038
					A32 Noise compliance rate	0.525	0.042
		A4 Indoor light environment	0.342	0.235	A41 Indoor illumination	0.821	0.193
					A42 Illumination compliance rate	0.179	0.042
B Users	0.312	B1 User health	0.346	0.108	B11 Sleep time	0.491	0.053
					B12 Heart rate	0.407	0.044
					B13 Adverse symptoms	0.102	0.011
		B2 User comfort	0.654	0.204	B21 PMV	0.534	0.109
					B22 PPD	0.466	0.095

room environment on humans was constructed. The scoring interval of each index was determined by the relevant national indoor environmental standards and actual research situation. The scoring interval of each index was divided into four levels: A, B, C, and D, and different scores were assigned to each interval. The scoring interval and assignment of indices are listed in Table 6.

A: Indoor environment evaluation index.

(1) Score interval of indoor CO_2 concentration index

The CO_2 concentration limit of Hygienic Standard for Carbon Dioxide in *Indoor Air (GB/T 17094-1997)* is 1000 ppm [27]. The CO_2 concentration in the outdoor environment is generally 350-450 ppm, while a 350-1000-ppm air is relatively fresh. Therefore, 350, 450, and 1000 ppm were used as limits of indoor CO_2 concentration.

(2) Score interval of indoor $PM_{2.5}$ concentration index

The World Health Organization has set the standard value of $PM_{2.5}$ concentration to below 10 μg/m^3, transition target 1 to below 75 μg/m^3, transition target 2 to below 50 μg/m^3, and transition target 3 to below 37.5 μg/m^3. 37.5, 50, and 75 μg/m^3 were used as limits of indoor $PM_{2.5}$ concentration.

(3) Score interval of indoor formaldehyde concentration index

Table 5
Evaluation index weight of the expert-entropy weight method.

The first level indices	Relative weight of the first level indices	The second level indices	Relative weight of the second level indices	Final weight of the second level indices	The third level indices	Relative weight of the third level indices	Final weight of the third level indices
A Indoor environment	0.594	A1 Indoor air quality	0.2534	0.1505	A11 Indoor CO_2 concentration	0.4618	0.0695
					A12 Indoor $PM_{2.5}$ concentration	0.3090	0.0465
					A13 Indoor formaldehyde concentration	0.2292	0.0345
		A2 Indoor thermal and humid environments	0.3502	0.2080	A21 Indoor temperature	0.5649	0.1175
					A22 Indoor relative humidity	0.4351	0.0905
		A3 Indoor sound environment	0.1380	0.0820	A31 Indoor noise	0.4695	0.0385
					A32 Noise compliance rate	0.5305	0.0435
		A4 Indoor light environment	0.2584	0.1535	A41 Indoor illumination	0.7231	0.1110
					A42 Illumination compliance rate	0.2769	0.0425
B Users	0.406	B1 User health	0.6232	0.2530	B11 Sleep time	0.3043	0.0770
					B12 Heart rate	0.2866	0.0725
					B13 Adverse symptoms	0.4091	0.1035
		B2 User comfort	0.3768	0.1530	B21 PMV	0.5654	0.0865
					B22 PPD	0.4346	0.0665

Table 6
Scoring interval and assignment of indices.

Grade	Scoring interval	Assignment (points)	Explanation
A	[80, 100]	100	Very good
B	[70, 80)	80	Better
C	[60, 70)	60	General
D	[0, 60)	40	Poor

Based on *Indoor Air Quality Standard (GB/T 18883-2002)*, doors and windows are closed for 12 h before detection, and the formaldehyde concentration is below 0.1 mg/m^3 [28]. According to *Standard for Indoor Environmental Pollution Control of Civil Building Engineering (GB 50325-2020)*, the formaldehyde content of class-I civil buildings is lower than 0.07 mg/m^3, and that of class-II civil buildings is lower than 0.08 mg/m^3 [29]. Therefore, 0.07, 0.08, and 0.1 mg/m^3 were used as limits of indoor formaldehyde concentration.

(4) Score interval of indoor temperature and humidity index

According to *Indoor Air Quality Standard (GB/T 18883-2002)*, the air conditioning temperature in summer is marked at 22-28 °C, while the marked value of relative humidity is 40-80%. The marked value of heating temperature in winter is 16-24 °C, while the marked value of relative humidity is 30–60% [28]. According to *Design Code for Heating Ventilation and Air Conditioning of Civil Buildings (GB 50736-2012)*, the temperature and humidity calculation parameters of the specified long-term stay area are listed in Table 7 [30]. According to the two standards, 22, 24, 26, and 28 °C were used as limits of summer temperature, while 40%, 50%, 60%, and 70% were used as limits of summer relative humidity. 16, 18, 22, and 24 °C were used as limits of winter temperature, while 30%, 45%, and 70% were used as limits of winter relative humidity.

Table 8
Standard limit of noise.

Building type	Location	Allowed noise level (dB)
Campus buildings	Ordinary classrooms, laboratories, computer rooms, music classrooms	45
	Teachers' offices, lounges, meeting rooms	45
	Voice classrooms, reading rooms	40
	Dance classrooms, gyms	50

(5) Score interval of indoor noise index

According to *Environmental Quality Standard for Noise (GB/T 3096-2008)*, the daytime and nighttime noise limits in the education area are 55 and 45 dB, respectively [21]. According to *Code for Design of Sound Insulation of Civil Buildings (GB 50118-2010)*, the noise limits for various main functional rooms of campus buildings are listed in Table 8 [31]. The high-limit standard values are 5 dB higher than the low-limit standard values. In combination with the noise limit in the standard, the noise requirement of buildings and rooms is basically higher than 40

Table 7
Indoor calculation parameters of temperature and relative humidity in a long-term stay area

Parameter	Grade of thermal comfort	Temperature (°C)	Relative humidity (%)
Summer	Level I	24-26	40-70
	Level II	27-28	≤70
Winter	Level I	22-24	≥30
	Level II	18-22	—

Table 9
Classification of PMV.

Thermal comfort	Cold	Cool	Chilly	Moderate	Micro warm	Warm	Heat
Value	-3	-2	-1	0	1	2	3

Table 10
PMV and PPD values for different thermal comfort levels.

Grade of thermal comfort	PMV	PPD
Level I	-0.5≤PMV≤0.5	≤10%
Level II	-1≤PMV<-0.5, 1≤PMV<0.5	≤27%

dB. Therefore, a noise below 40 dB was classified as "very good" interval, while 5 dB as an added value.

(6) Score interval of noise compliance rate index

The allowable noise range of the ladder classroom was 40-55 dB. 25%, 50%, and 75% were used as limits of indoor noise compliance rate.

(7) Score interval of indoor illumination index

In the *Standard for Lighting Design of Buildings (GB 50034-2013),* the illumination of the classrooms is required to be 300 lx, and 300 lx is used as a boundary [22]. Based on the field survey results, it was generally acceptable for personnel whose illuminance was 200-300 lx. This range was considered as "general" interval. When the indoor illumination was 300-400 lx, it met the standard requirements and was classified as "very good" interval. 400-500 lx were classified as "better" interval, while other areas with low or high illuminances were classified as "poor" interval.

(8) Score interval of illumination compliance rate index

The allowable illuminance range of the ladder classroom was 300-500 lx. 25%, 50%, and 75% were used as limits of indoor noise compliance rate.

B: User evaluation index.

(1) Score interval of sleep time index

According to the recommendations of American Sleep Medical Association and Sleep Research Society on adult sleep time, young people should generally sleep for 6 to 8 h. If the sleep time is too long (more than 10 h), the amount of blood returning to the heart is reduced, which easily leads to an insufficient blood supply to the brain. Too small sleep time (less than 6 h) leads to a decline in daytime mental state. Therefore, 6, 8, and 10 h were used for interval division.

(2) Score interval of heart rate index

The normal range of adult heart rate is 60 to 100 times/min. Heart rate over 100 times/min is called tachycardia, and heart rate below 60 times/min is called bradycardia. Physiological bradycardia is generally characterized by values between 50 and 60 times/min. Pathological bradycardia is generally characterized by values below 50 times/min. Therefore, 50, 60, and 100 times/min were used for interval division.

(3) Score interval of adverse symptom index

The qualifying standard was set at 60%. The rate of adverse symptoms is less than 10%, indicating that people have a very good adaptability to the indoor environment. The rate of adverse symptoms is 10%-30%, indicating that people have a better adaptability to the environment. This was used as a scoring standard to divide the scoring range.

(4) Score interval of PMV index

The International Organization for Standardization states that the recommended PMV is [-0.5, 0.5]. The thermal comfort level of PMV is presented in Table 9 [20]. According to *Design Code for Heating Ventilation and Air Conditioning of Civil Buildings (GB 50736-2012)*, PMV and PPD values corresponding to different thermal comfort levels are listed in Table 10 [30]. The PMV score interval was defined by boundaries of -2.5, -1, -0.5, 0.5, 1, and 2.5.

(5) Score interval of PPD index

The qualification standard was set at 60%. The PPD index is less than 10%, indicating that the thermal sensation satisfaction of personnel is very good. The PPD index is 10%-27%, indicating that the thermal sensation satisfaction of personnel is better. This was used as a scoring standard to divide the scoring range.

Table 11
Complete evaluation scoring system

Weight	Scoring interval Index item	A Very good (100 points)	B Better (80 points)	C General (60 points)	D Poor (40 points)
0.0695	Indoor CO_2 concentration (ppm)	(0, 350)	[350, 450)	[450, 1000)	[1000, 100000)
0.0465	Indoor $PM_{2.5}$ concentration (μg/m^3)	(0, 37.5)	[37.5, 50)	[50, 75)	[75, 100000)
0.0345	Indoor formaldehyde concentration (mg/m^3)	(0, 0.07)	[0.07, 0.08)	[0.08, 0.1)	[0.1, 100000)
0.1175	Summer indoor temperature (°C)	[24, 26)	[22, 24)	[26, 28)	(-100, 22)∪[28, +100)
	Winner indoor temperature (°C)	[22, 24)	[18, 22)	[16, 18)	(-100, 16)∪[24, 100)
0.0905	Summer indoor relative humidity (%)	[50, 60)	[40, 50)	[60, 70)	(0, 40)∪[70, 100)
	Winner indoor relative humidity (%)	[30, 45)	[45, 60)	[60, 100)	[0, 30)
0.0385	Indoor noise (dB)	[0, 40)	[40, 45)	[45, 50)	[50, 100000)
0.0435	Noise compliance rate (%)	[0.75, 1]	[0.50, 0.75)	[0.25, 0.50)	[0, 0.25)
0.1110	Indoor illumination (lx)	[300, 400)	[400, 500)	[200, 300)	(0, 200)∪[500, 100000)
0.0425	Illumination compliance rate (%)	[0.75, 1]	[0.50, 0.75)	[0.25, 0.50)	[0, 0.25)
0.0770	Sleep time (h)	[6, 8)	[8, 10)	[10, 24)	(0, 6)
0.0725	Heart rate (Times/min)	(60, 100)	[50, 60)	[100, 100000)	(0, 50)
0.1035	Adverse symptoms	[0, 0.1]	(0.1, 0.3]	[0.3, 0.6)	[0.6, 1]
0.0865	PPM	[-0.5, 0.5]	[-1, -0.5)∪(0.5, 1]	(-1, -2.5]∪(1, 2.5]	(-3, -2.5)∪[2.5, 3)
0.0665	PPD	[0, 0.1]	(0.1, 0.27]	[0.27, 0.6)	[0.6, 1]

Table 12
Scores of indoor environment indices.

Order number	Index item	Targeted value	Grading level	Weight	Weighted score
1	Indoor CO_2 concentration (ppm)	1238	D Poor (40 points)	0.0695	2.78
2	Indoor $PM_{2.5}$ concentration (μg/m^3)	34.125	A Very good (100 points)	0.0465	4.65
3	Indoor formaldehyde concentration (mg/m^3)	0.02	A Very good (100 points)	0.0345	3.45
4	Indoor temperature (°C)	27.4	C General(60 points)	0.1175	7.05
5	Indoor relative humidity (%)	63.1	C General(60 points)	0.0905	5.43
6	Indoor noise (dB)	85.2	D Poor (40 points)	0.0385	1.54
7	Noise compliance rate (%)	0.222	D Poor (40 points)	0.0435	1.74
8	Indoor illumination (lx)	517.5	D Poor (40 points)	0.1110	4.44
9	Illumination compliance rate (%)	0.556	B Better (80 points)	0.0425	3.40
Total	——	——	——	0.5940	34.48

Table 13
Scores of user indices.

Order number	Index item	Targeted value	Grading level	Weight	Weighted score
1	Sleep time (h)	6.25	A Very good (100 points)	0.0770	7.70
2	Heart rate (Times/min)	83.7	A Very good (100 points)	0.0725	7.25
3	Adverse symptoms	0.8254	D Poor (40 points)	0.1035	4.14
4	PMV	0.68	B Better (80 points)	0.0865	6.92
5	PPD	0.174	B Better (80 points)	0.0665	5.32
Total	——	——	——	0.4060	31.33

4.2.2. *Total scoring method*

The total score of the assessment of the suitability of university ladder classroom environment on humans is calculated according to

$$Q = \sum_{i=1}^{2} w_i Q_i, \tag{10}$$

where Q is the total score, Q_i are the scores of indices A and B with $i = 1$ and 2, respectively, and w_i are the weights of the two types of index scoring items with $i = 1$ and 2, respectively.

According to the actual research and national standard limit requirements, the scoring intervals of various indices in different situations were divided. The complete evaluation scoring system is presented in Table 11. The constructed grading system was used for the comprehensive grading of university ladder classrooms across the country.

5. Results and discussion

5.1. *Calculation of evaluation indices*

5.1.1. *Indoor environment metric item score*

The scores of indoor environment indices are listed in Table 12. The full index score was 59.4 points, and the indoor environment index score was 34.48 points. The instance score was low, while the indoor environment level was poor. The indoor CO_2 concentration, noise, noise compliance rate, and illumination were in the "poor" interval, the indoor temperature and relative humidity reached the passing level, the indoor illumination compliance rate was in the "better" interval, and the indoor $PM_{2.5}$ and formaldehyde concentrations were in the "very good" interval.

5.1.2. *User metric item score*

The scores of user indices are listed in Table 13. The full score of the index was 40.6 points, and the user index score was 31.33 points. The instance score was low. The index value of adverse symptoms was 0.8254, while the number of users with fatigue, heavy head, and difficulty in concentration during class was relatively high. The sleep time, heart rate, PMV, and PPD were at a high level.

The total score was 65.81 points, belonging to the C-level interval. The suitability of university ladder classroom environment on humans was poor. Because the teaching building was built earlier, there were numerous existing problems in the indoor environment, and the suitability of environment on humans could be largely improved.

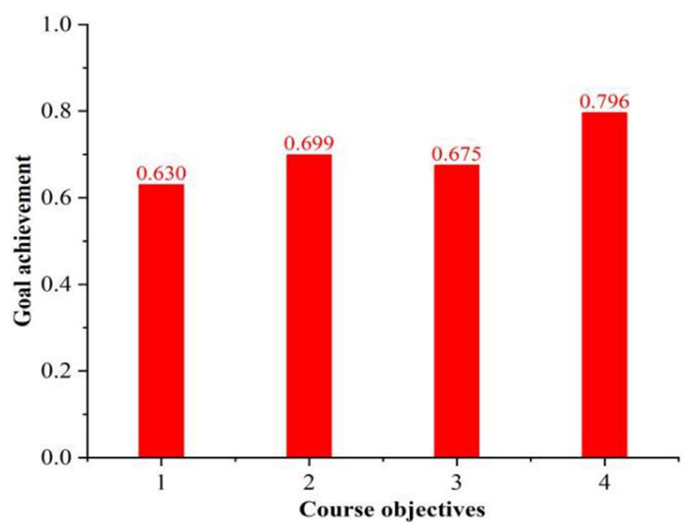

Fig. 16. Course goal achievements of the surveyed students.

5.2. *Analysis of evaluation results*

The indoor environment had an important role in human health and learning efficiency. The learning results of 168 interviewed students covered two parts: final examination and process assessment. The results of course goal achievements of the surveyed students are shown in Fig. 13. The achievement degrees of course goals 1, 2, 3, and 4 were 0.630, 0.699, 0.657, and 0.796, respectively, while the total achievement degree of course goals was 0.6955.

The relative error of the evaluation system for the suitability of environment on humans used in the university ladder classroom was 5.38%. The constructed scoring system was used for comprehensive scoring of the university ladder classrooms across the country (Fig. 16).

6. Conclusions

Based on the interaction characteristics of humans and the environment in university ladder classrooms, an evaluation system of the suitability of university ladder classroom environment on humans was established. The weak links in the interaction process of humans and the environment were analyzed. Two first-level, six second-level, and fourteen third-level indices were included in the evaluation system. Effective ways to improve the suitability of environment on humans were provided by the evaluation system. The following conclusions were summarized.

(1) Based on the results of literature researches, field researches, and questionnaire surveys, the evaluation system of the suitability of university ladder classroom environment on humans was established. Indoor environment and users were covered in the evaluation system, and there were 13 quantitative and 1 qualitative indices. The suitability of university ladder classroom environment on humans could be measured by the evaluation results. In the meantime, a reference to improve the indoor environmental quality and human health was provided.
(2) Combined with the survey results of industry experts and measured data of typical cases, the weights of evaluation indices were determined by the expert scoring and entropy weight methods. The results were revised by the linear recombination method. Among the first-level indices, the weight of indoor environment was the largest, with a value of 0.5490, and the weight of user was the smallest, with a value of 0.4060. Among the second-level indices, the weight of user health was the largest, with a value of 0.2530, and the weight of indoor sound environment was the smallest , with a value of 0.0820. Among the third-level indices, the weight of the indoor temperature was the largest, with a value of 0.1175, and the weight of formaldehyde concentration was the smallest, with a value of 0.0345.
(3) The evaluation system of the suitability of environment on humans was applied to the university ladder classroom. The indoor environment index score was 34.48 points, and the user index score was 31.33 points. The total score was 65.81 points. The total point belonged to the “general” interval. The suitability of university ladder classroom environment on humans was poor. The relative error value between the evaluation results and the course goal achievements in the university ladder classroom classroom was 5.38%. Therefore, the constructed evaluation system could be used to comprehensively score the ladder classrooms of colleges and universities nationwide.

Conflicts of 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.

CRediT authorship contribution statement

Xin Liu: Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Xiu Geng:** Data curation, Writing – original draft. **Kailiang Huang:** Validation, Resources, Project administration. **Guohui Feng:** Supervision. **He Zhao:** Investigation. **Xiaotong Wang:** Formal analysis. **Jianing He:** Formal analysis.

Acknowledgment

Thanks to the financial support provided by the Key Project of Education Department of Liaoning Province (project number LJKZ0577) and reviewer’s advice and comments.

References

[1] Liu J. Neoliberal trends of higher education reforms in China, Japan, and Korea: catch-up and self-reorientation. Discourses of Globalisation and Higher Education Reforms, 2022: 133-147.
[2] J Gao, P Wargocki, Y. Wang, Ventilation system type, classroom environmental quality and pupils’ perceptions and symptoms, Build. Environ. 75 (2014) 46–57.
[3] Z Shi, Q Liu, Z Zhang, et al., Thermal comfort in the design classroom for architecture in the cold area of China, Sustainability 14 (14) (2022) 8307.
[4] A L Pertiwi, L H Sari, A. Munir, Evaluation of air quality and thermal comfort in classroom, 881, IOP Publishing, 2021.
[5] H Liu, X Ma, Z Zhang, et al., Study on the relationship between thermal comfort and learning efficiency of different classroom-types in transitional seasons in the hot summer and cold winter zone of China, Energies 14 (19) (2021) 6338.
[6] C M Rodríguez, M C Coronado, J M Medina, Thermal comfort in educational buildings: the classroom-comfort-data method applied to schools in Bogotá, Colombia, Build. Environ. 194 (2021) 107682.
[7] Z Fang, S Zhang, Y Cheng, et al., Field study on adaptive thermal comfort in typical air conditioned classrooms, Build. Environ. 133 (2018) 73–82.
[8] F Leccese, M Rocca, G Salvadori, et al., Towards a holistic approach to indoor environmental quality assessment: Weighting schemes to combine effects of multiple environmental factors, Energy Build. 245 (2021) 111056.
[9] W P Akanmu, S S Nunayon, U C Eboson, Indoor environmental quality (IEQ) assessment of Nigerian university libraries: a pilot study, Energy Built Environ. 2 (3) (2021) 302–314.
[10] D Yang, C M Mak, Relationships between indoor environmental quality and environmental factors in university classrooms, Build. Environ. 186 (2020) 107331.
[11] A J Aguilar, M L de la Hoz-Torres, M Martínez-Aires, et al., Monitoring and assessment of indoor environmental conditions after the implementation of COVID-19-based ventilation strategies in an educational building in southern Spain, Sensors 21 (21) (2021) 7223.
[12] F Aliakbari, S T Moghadam, P. Lombardi, Indoor air and light quality assessment in a university campus classroom, J. Sustain. Archit. Civ. Eng. 30 (1) (2022) 163–182.
[13] Babaoğlu Ü T, Öğütçü H, Erdoğdu M, et al. Assessment of indoor air quality in schools from Anatolia, Turkey, Turk.. 2022.
[14] M Kraus, P. Nováková, Assessment of indoor air quality in university classrooms, in: Proceedings of the MATEC Web of Conferences, 279, EDP Sciences, 2019, p. 03012.
[15] M C Lee, K W Mui, L T Wong, et al., Student learning performance and indoor environmental quality (IEQ) in air-conditioned university teaching rooms, Build. Environ. 49 (2012) 238–244.
[16] I Sarbu, C. Pacurar, Experimental and numerical research to assess indoor environment quality and schoolwork performance in university classrooms, Build. Environ. 93 (2015) 141–154.
[17] Jing Yuan, Zhi Chen, Lexuan Zhong, Baozhen Wang, Indoor air quality management based on fuzzy risk assessment and its case study, Sustain. Cities Soc. 50 (2019) 1–9.
[18] N Norazman, A I Che Ani, W N W Ismail, et al., Indoor environmental quality towards classrooms’ comforts level: case study at Malaysian secondary school building, Appl. Sci. 11 (13) (2021) 5866.
[19] Zhicheng Dai, Assessment of smart learning environments in higher educational institutions: a study using AHP-FCE and GA-BP methods, IEEE Access 9 (2021) 35487–35500.
[20] Yingxin Zhu, et al., Built Environment, China Architecture and Building Press, Beijing, 2016 (in Chinese).
[21] Ministry of Ecology and Environment of People’s Republic of ChinaEnvironmental Quality Standard for Noise, China Environmental Press, Beijing, 2008 (GB/T 3096-2008)(in Chinese).
[22] Ministry of Housing and Urban-Rural Development of People’s Republic of China-Standard for Lighting Design of Buildings, China Architecture and Building Press, Beijing, 2013 (GB 50034-2013)(in Chinese).
[23] Ministry of Housing and Urban-Rural Development of People’s Republic of ChinaStandard for Daylighting Design of Buildings, China Architecture and Building Press, Beijing, 2013 (GB 50033-2013)(in Chinese).
[24] Y Wu, S Zhang, H Liu, et al., Thermal sensation, sick building syndrome symptoms, and physiological responses of occupants in environments with vertical air temperature differences, J. Therm. Biol. (2022) 103276.
[25] W Li, W Liang, L Zhang, et al., Performance assessment system of health, safety and environment based on experts’ weights and fuzzy comprehensive evaluation, J. Loss Prev. Process Ind. 35 (2015) 95–103.
[26] J Zhao, G Ji, Y Tian, et al., Environmental vulnerability assessment for mainland China based on entropy method, Ecol. Indic. 91 (2018) 410–422.
[27] The State Bureau of Quality and Technical SupervisionHygienic Standard for Carbon Dioxide in Indoor Air, China Architecture and Building Press, Beijing, 1997 (GB/T 17094-1997)(in Chinese).
[28] General Administration of Quality SupervisionInspection and Quarantine of the People’s Republic of China. Indoor air quality standard, China Architecture and Building Press, Beijing, 2002 (GB/T 18883-2002)(in Chinese).
[29] Ministry of Housing and Urban-Rural Development of People’s Republic of ChinaStandard for Indoor Environmental Pollution Control of Civil Building Engineering, China Construction Press, 2020 (GB 50325-2020)(in Chinese).
[30] Ministry of Housing and Urban-Rural Development of People’s Republic of ChinaDesign Code for Heating Ventilation and Air Conditioning of Civil Buildings, China Architecture and Building Press, 2012 (GB 50736-2012)(in Chinese).
[31] Ministry of Housing and Urban-Rural Development of People’s Republic of China-Code for Design of Sound Insulation of Civil Buildings, China Architecture and Building Press, 2010 (GB 50118-2010)(in Chinese).