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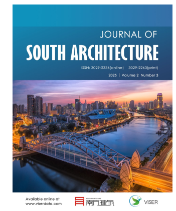

Design Strategy for Academic Building Clusters in Cold Regions Based on Outdoor Thermal Comfort

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ABSTRACT: This study, grounded in the regional characteristics of cold-climate urban and rural areas, refines the outdoor thermal comfort prediction index and analyzes the impact of academic building cluster configurations on thermal comfort, proposing design strategies for performance improvement. Based on measured thermal environment data from university campuses in cold regions, the study refines the outdoor thermal comfort prediction index and proposes cluster configuration strategies derived from simulation experiments. When the D/H ratio is 2.50, outdoor thermal comfort and spatial perception are optimal. Among various configurations, L-shaped and U-shaped enclosures offer the best balance between thermal comfort, energy efficiency, and spatial functionality. The evaluation index for outdoor thermal comfort needs to be adjusted according to regional characteristics. Designers can improve thermal comfort performance on cold-climate campuses by optimizing the configuration of academic building clusters.

KEY WORDS: buildings in cold regions; outdoor thermal comfort; academic building cluster configuration; UTCI

Introduction

Outdoor thermal comfort has a significant impact on livability and sustainability of cities [1]. Cities in cold regions experience extreme weather.University campuses are densely populated, and students and faculty members frequently engage in prolonged outdoor activities. They are highly susceptible to the cold climate [2]. Consequently, there is a substantial demand for a favorable outdoor climatic environment, which making it necessary to conduct targeted research on how the configuration of academic building clusters in universities affects outdoor thermal comfort.

In recent years, the continuous advancement of thermal environment simulation technologyenables designers to analyze the impact of urban form on outdoor thermal comfort performance through thermal simulations. Scholars at home and abroad have conducted extensive research on the correlation between urban forms and outdoor thermal comfort. Bajšanski, Miloševic, et al. conducted thermal environment simulations on the streets in downtown Novi Sad, and found that the buildings on both sides of the street could significantly affect outdoor thermal comfort by influencing solar exposure [3]. In 2017, Miloševic et al. simulated the impact of trees along streets on outdoor thermal comfort, and found that both the position of

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trees and the shape of their crowns have a significant effect on thermal comfort of the streets [4]. Meanwhile, Mackey et al. conducted simulations in three blocks in Singapore and concluded that the primary variable affecting outdoor thermal comfort in humid and hot regions is the mean radiant temperature [5], suggesting that outdoor thermal conditions can be improved by adjusting solar radiation exposure. However, existing studies on outdoor thermal comfort, both domestic and international, have largely focused on optimizing design strategies at the landscape level—such as the arrangement of vegetation and water features, and the selection of paving materials. For example, in 2010, CHEN Zhuolun proposed a regression relationship between vegetation design parameters and outdoor thermal comfort evaluation index based on the results of simulations [6]. Research by Hongbo et al. indicated that arranging buildings and vegetation in parallel to the prevailing wind direction contributes to improving the thermal comfort at pedestrian height [7]. In 2017, using a residential community in Guangzhou as a case study, LI Kunming conducted simulation analyses to examine the effects of landscape design parameters on outdoor thermal comfort in residential community of a humid and hot city [8]. However, these studies have not fully explored the potential of building cluster configurations to improve outdoor thermal comfort. Meanwhile, although lots of studies have been conducted to optimize the outdoor thermal comfort of urban spaces such as blocks, parks, and residential communities, very little attention has been paid to outdoor spaces in universities, particularly the academic buildings where daytime activities are concentrated. However, given the high density of students in and extensive use of outdoor spaces around academic buildings on university campuses, it would be beneficial to students' physical and mental well-being if outdoor thermal comfort could be improved by optimizing the form of the building cluster space [9].

In summary, there is significant potential for optimizing outdoor thermal comfort in urban areas.By applying simulation and analysis techniques, designers can improve outdoor thermal comfort in urban spaces by optimizing the configuration of building clusters [10]. Since the new millennium, universities have entered a phase of rapid construction and expansion. However, this growth has increasingly highlighted a contradiction between the extreme climatic conditions in cold regions and the need to optimize the physical environment of university campuses [11]. As academic buildings serve as the core zones of university campuses, meeting the outdoor thermal comfort needs of students and faculty around these building clusters—and thereby contributing to the creation of a sustainable campus—has become a shared focus among campus designers [12]. Using a university in Harbin as a case study, this paper aims to refine the UTCI index based on measured and survey data, and to explore the relationship between the spatial forms of building clusters and outdoor thermal comfort through simulations. Based on the findings, this paper proposes design strategies for academic building clusters in cold-region universities, providing a reference for similar campus planning and design practices.

1 Field investigation and UTCI calculation and refinement

1.1 Field investigation

The field investigation was conducted in an open space of the Civil Engineering Building in Harbin Institute of Technology (Figure 1). During the investigation, physical environmental measurements and questionnaire surveys were employed to continuously record outdoor meteorological parameters and collect respondents' subjective perceptions of outdoor thermal comfort during the primary outdoor activity period (from 9:00 a.m. to 5:00 p.m.) over the period from October 9, 2017 to October 9, 2018.

Figure 1 Site of outdoor thermal comfort field measurement

The study utilized a weather station and a handheld anemometer to measure the physical environment within the space. The weather station wasinstalled on the roof of a two-story building within the site. The weather station automatically recorded data every 10 minutes for computing UTCI values (Table 1), including air temperature, relative humidity, wind speed measured at 10 m above ground, and black globe temperature. In addition, a portable handheld anemometer was used to record the wind speed at 1 m above ground during the administration of the questionnaires. This adjustment was necessary because the weather station's measurement height was significantly above the the human body's center of mass, which is more relevant for assessing perceived wind speed. However, such height differences have little impact on air temperature, humidity, and black globe temperature [13]. Thus, the instantaneous values of air temperature, humidity, and black globe temperature measured at the survey point can reliably represent the values perceived by the respondents.

Table 1 Sensor parameters used for field measurements

Meteorological parameter	Symbol	Sensor	Measurement range	Measurement Accuracy
Air temperature	T_a	SHT71	−40 to 100 ℃	≤0.4 ℃
Relative humidity	RH	SHT71	0 to 100% RH	±3% RH
Wind speed (10 m height)	V_{a10}	LC-CF3	0 to 60 m/s	±0.3 m/s
Wind speed (1 m height)	V_{a1}	LM-8000	0.4 to 30.0 m/s	≤20 m/s: ±3% F.S.;> 20m/s: ±4% F.S.
Black globe temperature	T_g	Pt100	−40 to 100 ℃	≤ 0.2 ℃

Figure 2 presents the questionnaire used tocollect the thermal comfort perceptions of university students. The questionnaire employs the ASHRAE 7-point thermal comfort scale [14], with respondents being students involved in outdoor activities at the survey site. A total of 1,019 valid responses were collected during the survey period (497 questionnaires were collected in the cold season, 308 collected in the transition season, and 214 in the hot season). In addition, only 1.3% of the valid responses involved high-intensity physical activity, as the vast majority of respondents were engaged in moderate or low-intensity activities.

Figure 2 Outdoor thermal comfort survey questionnaire

1.2 Calculation of UTCI

The Universal Thermal Climate Index (UTCI) is defined as the equivalent environmental temperature in a reference setting and is calculated based on air temperature (T_a), mean radiant temperature (T_{mrt}), relative humidity (RH), and wind speed at 10m above ground (V_{a10}) [15]. The values for air temperature, humidity, and wind speed are acquired through direct measurement, while T_{mrt} is computed based on these parameters. In the study, designers can calculate the UTCI using software, with its calculation expressed in Equation (1):

$$UTCI = f(T_a; T_{mrt}; V_a; RH) = T_a + Offset(T_a; T_{mrt}; V_a; RH) \quad (1)$$

In Equation (1), Ta denotes the air temperature,Tmrt represents the mean radiant temperature, V_a is the wind speed, and RH is the relative humidity.

The mean radiant temperature (T_{mrt}) represents the uniform temperature of a hypothetical enclosure and has a critical impact on the UTCI. In this study, the mean radiant temperature is calculated using Equation (2) according to the ISO 7726 standard.

$$T_{mrt} = \left[(T_g + 273)^4 + \frac{1.10 \times 10^8 V_a^{0.6}}{\varepsilon D^{0.4}}(T_g - T_a)\right]^{1/4} - 273 \quad (2)$$

In Equation (2), T_a is the air temperature, V_a is the wind speed, T_g is the black globe temperature, D is the diameter of the black globe (0.15 m in this study), and ε is the emissivity (with ε = 0.95 for the black globe).

Outdoor Thermal Comfort Survey Questionnaire

Time: ___________ Date: ______(DD)______(MM) Location: ___________

1. How long do you usually spend on outdoor activity each day?
   0~ 30 minutes / 31~ 60 minutes / 1~ 2 hours / More than 2 hours
2. What is the intensity of your outdoor activity?
   Exercise (light, e.g., walking) / Exercise (moderate, e.g., jogging, dancing) / Exercise (vigorous, e.g., running, high-intensity ball games) / Chatting (while sitting) / Chatting (while standing) / Relaxing / Playing chess / Looking after children or walking a dog / Dining outdoors
3. What are you wearing right now?
   Upper body: Short-sleeved shirt / Long-sleeved T-shirt / Light jacket / Pullover / Shirt / Sweater / Heavy coat / Down jacket
   Lower body: Shorts / Skirt / Long pants / Long skirt / Cotton pants
4. You prefer being in: Sunlight / Shade
5. How comfortable are you feeling right now?

Uncomfortable	Neutral	Comfortable

6. How would you describe your current thermal sensation? (Use the scale below)

Cold	Cool	Slightly cool	Moderate	Slightly warm	Warm	Hot
−3	−2	−1	0	1	2	3

7. How would you like the following meteorological conditions to change?

Wind	Temperature	Relative humidity	Solar radiation
Stronger	Warmer	Wetter	Stronger
No change	No change	No change	No change
Weaker	Colder	Drier	Weaker

The study is based on the grading method that establishes a correspondence between TSV and UTCI,developed by De Dear et al. [16]. SPSS software (version 19.0) was used to compute the mean thermal sensation votes (MTSV) at 1 ℃ intervals of UTCI and to conduct regression analysis, thereby adjusting the UTCI scale to better reflect regional climatic characteristics.

1.3 UTCI refinement

A regression analysis was conducted on the UTCI and MTSV. Equations (3) and (4) respectively present the regression equations and the determination coefficients for the relationship between UTCI and MTSV across different seasons. It can be observed that the determination coefficient (R^2) for the UTCI regression equation in the cold season is lower than those for the hot and transition seasons. This indicates that the standard UTCI scale, although quite accurate for evaluating outdoor thermal comfort in cold-region universities, exhibits a non-negligible deviation when used to predict outdoor thermal comfort under certain levels of cold stress. Hot and transition seasons: (3) Cold season: (4)

Since the UTCI scale is divided into 10 thermal comfort categories, whereas the TSV in the questionnaires is based on a 7-point scale while the average TSV aligns with a 10-point scale [17], the graded TSV values are substituted into Equations (3) and (4) to compute a 10-level UTCI scale for university students. This revised scale is presented alongside the original scale in Table 2. It can be seen that the discomfort category of "extreme cold" for cold-region university students corresponds to values below

- 25 ℃, which is 15 ℃ above the original threshold, indicating that the original scale does not accurately assess outdoor thermal comfort under extreme cold stress for these students.

Table 2 UTCI scale for students at cold-region universities

Thermal comfort category	Original UTCI Scale/℃	UTCI scale for cold-region University students/℃
Extreme Cold	< −40	< −25
Very Strong Cold	−40 to −27	−25 to −18
Strong Cold	−27 to −13	−18 to −11
Cold	−13 to 0	−11 to −4
Slight Cold	0 to 9	−4 to 3.5
No Thermal Discomfort	9 to 26	3.5 to 21
Heat	26 to 32	21 to 33
Strong Heat	32 to 38	33 to 39
Very Strong Heat	38 to 46	39 to 45
Extreme Heat	> 46	> 45

2 Outdoor thermal comfort simulation for academic building cluster

2.1 Typical model and boundary conditions

In an instructional center zone, a cluster of buildings composed of a main academic building or auditorium, several similar single academic buildings, and a library is defined as an academic building cluster [18]. The factors influencing the outdoor thermal comfort of cold-region academic building cluster space forms mainly include spatial scale, building orientation, and enclosure configuration [19]. Survey results from 80 cold-region university campuses indicate that the central courtyard layout is the predominant configuration, accounting for 74% of cases, and the D/H ratio for the building clusters generally ranges between 1 and 2.5. Currently, academic buildings in cold-region universities are mostly multistory structures. Moreover, even within the same layout type, the orientation of academic buildings is influenced by the central landscape, topographic constraints, and functional requirements. Based on the survey, this study selected multistory academic buildings with a central courtyard layout as a typical form. The established typical model is shown in Figure 3. In this model, the cluster occupies an area with a length of 318m and a width of 270m, covering 85,860 m^2, and has a floor area ratio ranging from 1.27 to 1.88.

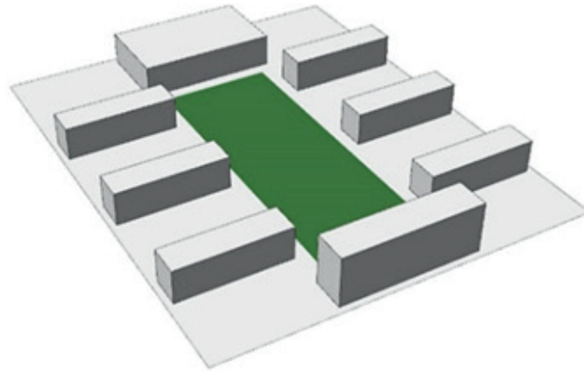
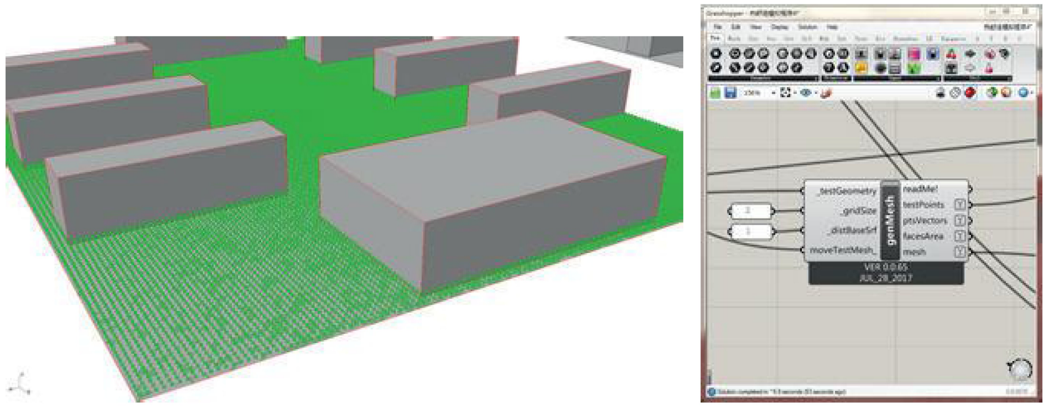


Figure 3 Typical model of academic building cluster in a cold-region university

Existing studies have shown that the climatic conditions during the transitional and summer seasons in Harbin are more conducive to outdoor activities, whereas outdoor thermal comfort in winter is relatively poor [20]. Therefore, the simulations were conducted during the primary outdoor activity period (9:00—17:00) of the coldest week (January 18 to January 24) by analyzing, for different building cluster space forms, the average UTCI per unit time (1 h) and the the percentage of area above the "extreme cold" discomfort threshold in order to compare the effects of different configurations on outdoor thermal comfort.

The experiment employed Ladybug & Honeybee 0.0.65—a simulation software based on a Python computation kernel that integrates Daysim, Radiance, and EnergyPlus—as the analysis tool. This software systematically processes meteorological data to generate bioclimatic maps and perform simulations of solar exposure, energy consumption, and outdoor thermal comfort, among other functions.

In the area analyzed through the simulation, the grid was established at a height of 1 meter above the ground, with each grid cell measuring 2 meters by 2 meters. The area measures85,860 m^2 (318 m in length and 270 m in width), yielding a total of 21,465 grid cells, all of which met quality requirements (see Figure 4). The simulation calls for the use of dry-bulb temperature, relative humidity, wind speed, direct radiation, diffuse radiation, and infrared radiation values from the EnergyPlus meteorological data file for Harbin. The default input for human body posture is set to 0, and the body position is assumed to be flush with the test plane.



a) Grid discretization of the 3D model b) Grid settings in grasshopper

Figure 4 Grid setup and discretization of the 3D model

2.2 Optimization of building spacing

Based on case study surveys, it is concluded that the building spacing D/H ratio for academic buildings in cold-region universities mostly ranges from 1 to 2.5. Therefore, the study examines four cases with D/H values spanning from 1.05 to 2.50. Since multi-story academic buildings imply that a D/H ratio of 1 would result in a spacing (D) less than 25 m, and according to the regulations for primary and secondary school buildings [21], the experiment adopts a minimum spacing of 25 m (i.e., D/H = 1.05).

Table 3 Outdoor thermal comfort in cluster spaces at different D/H ratios

D/H ratio	Average UTCI/℃	Average percentage of area not experiencing "extreme cold" per unit time
2.50	−27.53	22.14%
2.00	−28.02	16.92%
1.50	−28.09	15.81%
1.05	−28.09	15.54%

Table 3 presents the outdoor thermal comfort values of cluster spaces at different D/H ratios. Under the conditions of extreme cold, when D/H = 1.05 the average UTCI reaches a minimum of - 28.09 ℃ and the percentage of area not reaching thethreshold of "extreme cold" discomfort is only 15.54%; whereas when D/H = 2.50 the average UTCI is highest at - 27.53 ℃, 0.54 ℃ higher than that for D/H = 1.05, and the percentage of area is highest at 22.14%, 6.6% greater than that for D/H = 1.05. In other words, the outdoor thermal environment is more comfortable at a spacing of D/H = 2.50, and least comfortable when D/H = 1.05.

Figure 5 illustrates the temporal variation of outdoor thermal comfort performances of cluster spaces at different D/H ratios. It can be observed that, when building spacing D/H = 2.50, the outdoor UTCI in the cold-region academic building cluster space during the midday peak activity period is 1.21 ℃ higher than that for D/H = 1.05, and the area under thermal discomfort is reduced by 20.05%. This difference arises because, under the conditions of extreme cold,a D/H ratio of 2.50 results in a more open outdoor space with ample solar exposure, whereas when D/H= 1.05 the outdoor space is largely covered by building shadows; in addition, the "narrow canyon effect" further intensifies outdoor thermal discomfort in the winter for the building cluster.

In summary, to achieve optimal outdoor thermal comfort for academic building clusters in cold-region universities, the cluster spacing D/Hshould ideally approach 2.50. This spacing retains sufficient solar exposure in winter; although it reduces shaded areas in summer, the reduced summer shading can be mitigated by planting broad-canopy deciduous trees and arranging them in the direction of prevailing summer wind to facilitate ventilation and cooling. Furthermore, when the cluster spacing D/H = 2.50, the outdoor space is larger. To enhance the spatial hierarchy of the outdoor area, differentiated paving, increased landscape diversity, and the incorporation of landscape features should be implemented.

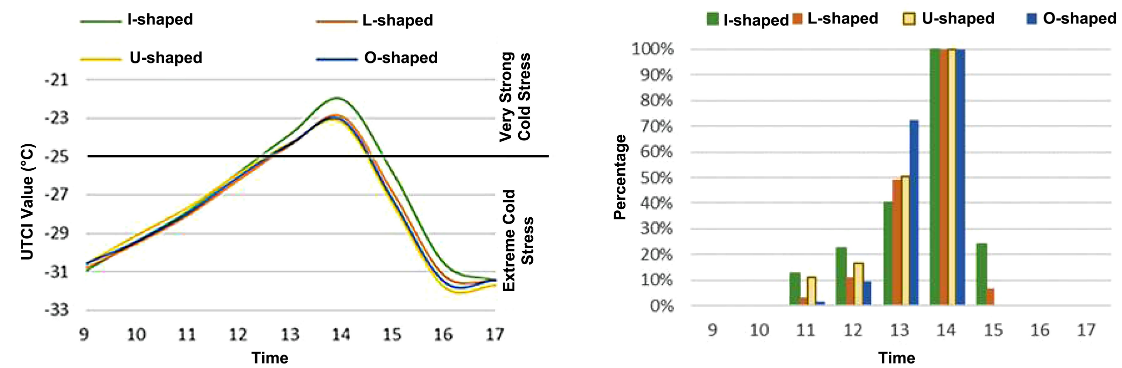


Figure 5 Temporal variation of outdoor thermal comfort in cluster spaces at different D/H ratios

2.3 Selection of building orientation

Based on survey results, the orientation of teaching buildings is mainly influenced by three objective factors—functional requirements, orientation of the central landscape, and topographic constraints. Therefore, the study conducted simulations for four primary orientations of the building mass (due south, due east, southeast, and southwest). Table 4 presents the outdoor thermal comfort performances of cluster spaces with different building orientations. It can be observed that among all orientations, the due east orientation exhibits the highest average UTCI during the coldest week at - 25.76 ℃, and its percentage of area not reaching the threshold of "extreme cold" discomfort is the highest at 44.03%; this was followed by the southwest orientation. In contrast, for the due south orientation the average outdoor UTCI during the coldest week is the lowest at - 27.53 ℃, which is 1.77 ℃ lower than that for the due east orientation; its area percentage is the lowest at 22.14%, 21.89% lower than that of the due east orientation. Evidently, during the cold season the cluster with buildings facing due east offers the most comfortable outdoor thermal environment, while that with the due south orientation is the least comfortable.

Table 4 Outdoor thermal comfort in cluster spaces with different building orientations

Building orientation	Average UTCI/℃	Average percentage of area not experiencing "extreme cold" per unit time
Due south	−27.53	22.14%
Due east	−25.76	44.03%
South east	−27.00	30.56%
South west	−25.87	38.80%

Figure 6 shows the temporal variation of outdoor thermal comfort performances of cluster spaces with different building orientations. It is evident that during the peak period of outdoor activities of faculty and students (9:00—17:00), when the academic building cluster is oriented due east or southwest, the outdoor area where discomfort is experienced is reduced by over 66% compared to the due south orientation, and the UTCI is increased by more than 5 ℃.

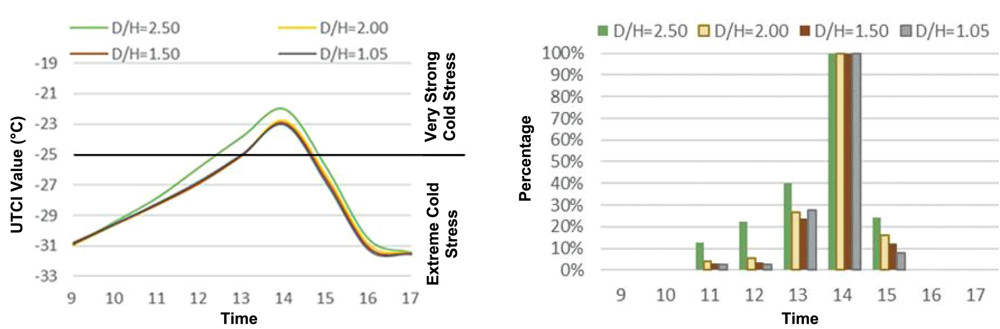


Figure 6 Temporal variation of outdoor thermal comfort of cluster spaces with different building orientations

This is because the lower solar elevation in winter results in a smaller perpendicular projection area of the east- and southwest-facing facades relative to the direction of sunshine, thereby reducing the area of outdoor shadow zones. Moreover, the dominant winter wind in Harbin (southwest wind) is perpendicular to the long side of academic buildings facing southwest, which further improves the outdoor thermal comfort in winter.

In addition, good natural lighting in classrooms is a prerequisite for fulfilling educational functions. Therefore, the natural lighting performance for classrooms should also be considered when outdoor thermal comfort is evaluated. Although academic buildings facing due east offers a more comfortable outdoor thermal environment, the number of south-facing classrooms with optimal natural lighting is relatively small, whereas the southwest orientation effectively balances a comfortable outdoor thermal environment with adequate classroom daylighting, thereby meeting both functional requirements and outdoor space quality standards. This makes the southwest orientation a preferable choice.

2.4 Selection of enclosure configurations

Survey findings indicate that the basic enclosure configuration of academic building clusters in cold-region universitiesis categorized into four types: I-shaped, L-shaped, U-shaped, and O-shaped enclosures (see Figure 7). By adapting the four basic configurations to fit specific local conditions or design needs, a variety of cluster space types can be developed for universities in cold regions.

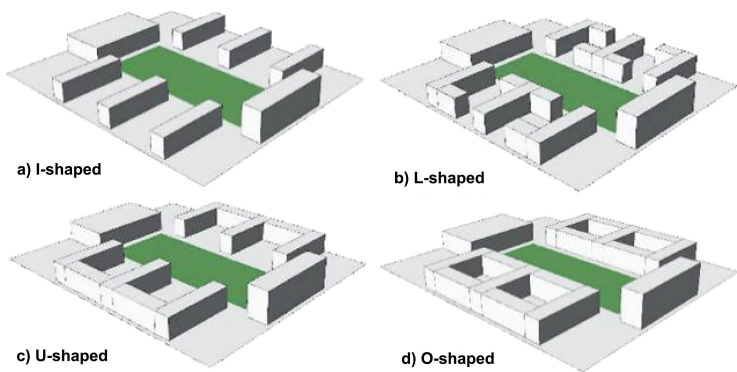


Figure 7 Academic building clusters with different enclosure configurations

The outdoor thermal comfort performance of cluster spaces with different enclosure configurations is shown in Table 5. It can be seen that the O-shaped enclosure exhibits the lowest average UTCI during the coldest week (−27.97 ℃); the highest is achieved by the I-shaped configuration (−27.53 ℃), which is 0.44 ℃ higher than the O-shaped arrangement. In addition, the O-shaped enclosure has the lowest percentage of areabelow the threshold of "extreme cold" discomfort (18.93%), whereas the I-shaped arrangement has the highest at 22.14%, 3.21% higher than that of the O-shaped one.

Table 5 Outdoor thermal comfort of group spaces in different enclosure configurations

Enclosure configuration	Average UTCI/℃	Average percentage of area not experiencing "extreme cold" per unit time (1 h)
I-shaped	−27.53	22.14%
L-shaped	−27.96	19.75%
U-shaped	−27.64	20.32%
O-shaped	−27.97	18.93%

Figure 8 displays the temporal variation of outdoor thermal comfort performances of cluster spaces with different enclosure configurations. From the figure, during the peak outdoor activity period in the morning (9:00—12:30), the greatest percentage of area not reaching the threshold of "extreme cold" discomfort occurs for the I-shaped enclosure, followed by the U-shaped arrangement, with the O-shaped configuration having the lowest; at 12:00, the percentage difference reaches a maximum of 13.19%. During the peak period in the afternoon (12:30—17:00), the average UTCI is the highest for the I-shaped enclosure and the lowest for the U-shaped enclosure, with a maximum average difference of 1.22 ℃ at 14:00; apart from 13:00 when the O-shaped configuration exhibits the highest percentage, the I-shaped enclosure consistently shows the highest area percentage at other hours.

When designing academic building clusters in cold regions, how to reduce building energy consumption is also an important aspect. This study introduces the form factor as a parameter to compare the energy consumption levels of academic buildings with different enclosure configurations in cold regions. Within a given range, a smaller form factor indicates higher energy efficiency. To apply this concept to the cluster space, the study defines the cluster's form factor as S_a(S_a= total buildingenvelope area F_a/ total building volume V_a).

Under the premise that the building enclosure area remains constant (60 m × 60 m), Table 6 shows the cluster's form factors for different enclosure configurations, with the enclosure interface parameters arranged from smallest to largest from top to bottom. It can thus be seen that, while maintaining the same enclosure area,the cluster form factor is inversely proportional to the enclosure degree; hence, the U-shaped and O-shaped enclosures are more energy efficient.

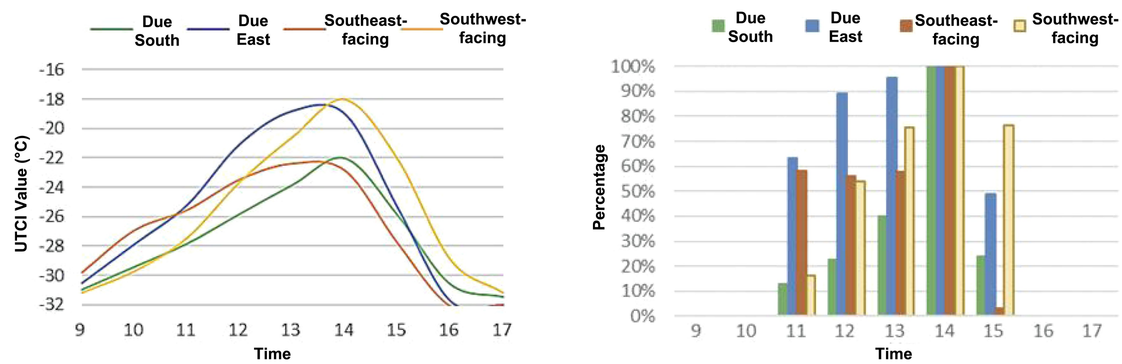
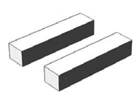
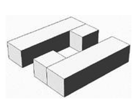
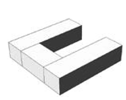
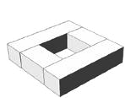


Figure 8 Temporal variation of outdoor thermal comfort of cluster spaces with different enclosure configurations

Table 6 Form factor of the four basic enclosure configurations of academic buildings

Enclosure configuration	Illustration	Total building envelope area F_a(m^2)	Total building volume V_a(m^3)	Enclosure area A (m^2)	Cluster form factor S_a
I-shaped		11,808	51,840	3,600	0.228
L-shaped		19,872	93,312	3,600	0.213
U-shaped		19,008	93,312	3,600	0.204
O-shaped		26,208	134,784	3,600	0.194

It can be observed that the I-shaped enclosure balances both classroom daylighting needs and winter outdoor thermal comfort, which makes it the most common layoutfor academic buildings in cold-region universities. However, its higher form factor also leads to increased energy consumption. Additionally, a lower degree of enclosure significantly weakens spatial cohesion. To ensure the outdoor space meets diverse functional requirements, landscape features should be used to separate different outdoor areas. By effectively blocking external cold winds and minimizing heat loss from building clusters, L-shaped and U-shaped enclosures reduce energy consumption and create a sheltered, low-wind environment that enhances outdoor thermal comfort during the cold season. In contrast, while the O-shaped enclosure configuration offers superior wind protection and thermal insulation, it reduces sunlight exposure and creates larger shadow zones in winter.

Conclusion

Using Harbin—a typical cold-region city—as a case study, this research localized UTCI, the outdoor thermal comfort evaluation index, through field measurements. Based on the revised UTCI stress categories, simulation analyses were conducted on models of typical academic building clusters in cold-region universities. The study examined the relationship between outdoor thermal comfort and various design parameters, thereby providing guidance for optimizing the thermal environment in these clusters. The main conclusions are as follows:

(1) The range of "extreme cold" discomfort in the original evaluation scale is 15 ℃ higher than the stress range experienced by students in cold-region universities, indicating that the original scale substantially overestimates students' tolerance to extreme cold. This demonstrates that the original UTCI scale inevitably fails to account for regional differences in outdoor thermal comfort evaluation.

(2) In terms of spacing selection, the front-to-back building spacing should ideally achieve a D/H ratio of 2.50, and avoid the condition of D/H = 1.05. This is because an academic building cluster space with D/H = 2.50 features a more open spatial perception and receives more sunlight in winter, thereby providing a more comfortable outdoor thermal environment. However, more open outdoor spaces may have fewer shaded areas in summer. This can be addressed by planting vegetation to enhance natural shading.

(3) When choosing the orientation for a cluster of academic buildings, the arrangement should be such that the angle between the direction of the sun's rays and the direction of the building openings is kept as small as possible, and the angle between the prevailing wind direction and the building openings is kept as close to 90° as possible. In addition, when planning the orientation of academic building clusters in cold regions, designers should consider both the outdoor thermal comfort and the natural daylight available for classrooms. It is not advisable to arrange the academic buildings so that they face east or west.

(4) When selecting the enclosure configuration for academic building clusters in cold-region universities, the study considered outdoor thermal comfort, energy-saving requirements, and spatial needs.We examined the advantages and disadvantages of four common enclosure configurations and ultimately recommended that L-shaped and U-shaped enclosures are the most optimal choices.

Sources of Figures and Tables

All figures and tables are derived from Reference Item [12].

References

[1] CHEN L, NG E. Outdoor Thermal Comfort and Outdoor Activities: A Review of Research in the Past Decade[J]. Cities. 2012; 29: 118-125.

[2] CHEN Yi. Study on the Outdoor Thermal Environment of Tianjin University in Summer[D]. Tianjin: Tianjin University, 2013.

[3] Bajšanski I V, Miloševic D D, Savic S M. Evaluation and Improvement of Outdoor Thermal Comfort in Urban Areas on Extreme Temperature Days: Applications of Automatic Algorithms [J]. Building and Environment, 2015; 94(2): 632-643.

[4] Miloševi D D, Bajšanski I V, Savic S M. Influence of Changing Trees Locations on Thermal Comfort on Street Parking Lot and Footways[J]. Urban Forestry & Urban Greening, 2017; 23: 113-124.

[5] MACKEY C,GALANOS T, NORFORD L,et al. Wind, Sun, Surface Temperature, and Heat Island: Critical Variables for High-Resolution Outdoor Thermal Comfort[C]. In the 15th IBPSA Conference San Francisco, CA, USA, August 7-9, 2017.

[6] CHEN Zhuolun. Study on the Impact of Greening System on the Outdoor Thermal Environment of Building Groups in Damp and Hot Areas[D].Guangzhou: South China University of Technology, 2010.

[7] HONG B, LIN B. Numerical Studies of the Outdoor Wind Environment and Thermal Comfort at Pedestrian Level in Housing Blocks with Different Building Layout Patterns and Trees Arrangement[J]. Renewable Energy, 2015(73): 18-27.

[8] LI Kunming. Thermal Environment Comfort Evaluation and Optimization Design of Urban Residential Areas in Hot and Humid Regions[D]. Guangzhou: South China University of Technology,

2017.

[9] WANG Yan. Research on the Optimization Design Strategy of Integrated Teaching Buildings in Ordinary Universities[D]. Xi'an: Xi'an University of Architecture and Technology, 2010.

[10] XIE Y,HUANG T, LI J, et al. Evaluation of a Multi-nodal Thermal Regulation Model for Assessment of Outdoor Thermal Comfort: Sensitivity to Wind Speed and Solar Radiation [J]. Building and Environment, 2018; 132: 45-56.

[11] ZHANG Yue. Architectural Design of Campus Teaching Area in Cold University [D]. Harbin: Harbin Institute of Technology, 2014.

[12] ZHI Dongyi. Study on the Group Design Strategy of Teaching Buildings in Cold Colleges Based on Outdoor Thermal Comfort [D]. Harbin: Harbin Institute of Technology, 2019.

[13] MAYER H, Höppe P. Thermal Comfort of Man in Different Urban Environments [J]. Theoretical and Applied Climatology, 1987 (38): 43-49.

[14] ASHRAE, ASHRAE Standard 55-2013 [S]: Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta, USA.2013.

[15] BRODE. P, FIALA. D, BLAZEJCZYK. K, et al. Calculating UTCI equivalent temperature // Castellani J W, Endrusick T L[C]. Proceedings of the 13th International Conference on Environment Ergonomics, Boston. MA, 2009.

[16] DE R J, FOUNTAIN M E. Field Experiments on Occupant Comfort and Office Thermal Environments in a hot-humid climate [J]. ASHRAE Transactions, 1994(100): 457-474.

[17] LAI D, GUO D, HUO Y. Studies of Outdoor Thermal Comfort in Northern China. Building and Environment[J]. Building and Environment, 2014(77): 110-118.

[18] MAI Heng. Research on the Group Structure Design of Campus Teaching Areas of Newly Built Universities in China[D]. Guangzhou: South China University of Technology, 2012.

[19] LIU Kexin. Research on the Enclosed External Space Environment Design of Cold Campus[D].Harbin: Harbin Institute of Technology, 2013.

[20] CHEN Xin. Study on the Dynamic Change and Prediction Methods of Thermal Comfort of Outdoor People in Harbin[D]. Harbin:Harbin Institute of Technology, 2017.

[21] GB 50099-2011, Code for Architectural Design of Primary and Secondary schools [S].