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Green BIM-based study on the green performance of university buildings in northern China

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Abstract

Background: Energy-efficient university campuses will play a vital role in the development of future sustainable cities, and will be important for achieving the Chinese carbon-neutrality goals. It is, therefore, necessary to develop new decision-making tools for evaluating the sustainability of campus buildings. Since university campuses typically comprise a broad variety of building types, standardized evaluation methods and tools, such as Green BIM, are needed. Green BIM (Building Information Modeling) emphasizes the importance and role of BIM technology in the design and construction of green buildings, providing a standardized framework for the decision-making process, and methods for improving the green performance of buildings.

Methods: This study develops a method based on the Green BIM framework, using BIM architecture to analyse building performance, and the *Assessment Standard for Green Building* (GB/T 50378-2019) standard to establish benchmark values for evaluation, and project objectives. The method is evaluated on three examples of the most representative university buildings in northern China. The goal is to understand common denominators and differences between different types of campus buildings, in terms of green building indicators, that are important to consider in the early design stages of campus building complexes.

Results: In this study, a library is used as a case study to demonstrate the tools for evaluating green performance. The study optimizes green performance from five aspects: surrounding environment, function layout, envelope performance and system transformation, and management measures improvement. The results show that this optimization scheme can achieve reductions of the annual loads of about 47.4%, in line with the national energy efficiency standards for public buildings. In particular, the heating load was reduced by 59.1%, and the cooling load reduced by 21.5%.

Conclusion: A comprehensive approach, combining the aspects of planning, building design, system design, energy management, and energy conservation planning, is required to improve the green performance of university buildings to meet the goals. In the future, it will be further necessary to perform data mining of energy consumption patterns, and continue energy retrofitting of existing buildings and energy systems, to achieve the goal of green and low-carbon campuses.

Keywords: Green BIM, Northern China, University building, Green performance, Design strategy

Background

Energy-efficient university campuses will play a vital role in the development of future sustainable cities, and will be important for achieving the Chinese carbon-neutrality

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goals. A university campus is a community that has a well-defined geographical scope and spatial scale, and serves a variety of functions, such as teaching, scientific research, and accommodation. As such, the university campus possesses urban characteristics and diverse building types, and the development of green university campuses will play a leading role in the green urban construction in China, which is now facing the ecological and energy pressure of increased urbanization [1]. As a major component of the natural environment in cities, the university campus will effectively regulate the microclimate and ecological function of cities by maintaining natural ecology on a large scale [2].

The earliest mentions of the terms "green campus", "ecological campus", and "sustainable campus" in the research literature can be traced back to the 1970s, with a very limited number of studies produced between 1970 and 1990. This number has gradually increased since the mid-1990s, with a surge in the number of relevant published studies since 2000. This topic has attracted considerable attention from the academic research community in recent years, and American scholars, in particular, have paid more attention to the topic of green campus in the recent 20 years [3]. These studies can be divided into three categories, based on their respective research focus. The first category focuses on the overall characteristics and contents of green campuses. In the book *The Green Campus: Meeting the Challenge of Environmental Sustainability*, Walter Simpson analyses excellent environmental programs in campuses worldwide and in the United States, providing guidance and inspiration for campus leaders, to promote sustainable development of institutions of higher education [4]. The second category concerns research on green campus evaluation systems. The relevant international standards mainly include LEED for school in the United States, BREEAM Education in the United Kingdom, etc. China has issued the national standard *Assessment Standard for Green Campus* (GB/T51356-2019) [5], that is to serve as the basis of evaluation to guide the construction of green campus. The third category includes research on multiple aspects of green campuses, such as green buildings, ecological landscape, green energy, green materials, green food, green education, healthy environment, green procurement, etc. In the book *The Nine Elements of a Sustainable Campus*, the author Mitchell Thomas identified, based on his own personal experience in unity College of Maine, nine elements for the agenda of sustainable development of campuses: energy, food, materials, management, investment, health, curriculum, interpretation and aesthetics, which has enriched the theory of sustainable development of the campus [6]. Since campuses encompass large numbers of buildings, achieving the goal of green building is a top priority for the development of green campuses.

The *Assessment Standard for Green Building* (GB/T 50378-2019), implemented in China in August 2019, first proposes the concept of green performance, which refers to the performance related to safety and durability, health and comfort, accessibility, resource efficiencies as well as surrounding environment [7]. A building performance study refers to the energy-saving design that takes into sufficient consideration on the external environment of buildings (climate, landform, and place), building factors (completion year, building function, building form, and building structure), and factors related to the energy-using system and equipment system, and it studies the impact on a building's green performance by the combined action of various factors.

A green building has high requirements for its full lifecycle, especially in the design phase. However, traditional architectural design lacks systematic design methods and tools, and the currently prevailing design mode of traditional design plus green building consultation has difficulty ensuring that the actual performance can be in accord with a green design [8]. Green BIM method provides a new idea for building green performance research and green campus construction.

The diversity of building types in Chinese universities determines the differences in their green performance. This study takes the university buildings in northern China as the research object, and selects the most representative types of classroom buildings, library and dormitory buildings, using the process given by the Green BIM decision cycle and taking the *Assessment Standard for Green Building* (GB/T 50378-2019) as the evaluation benchmark values and project objectives (as shown in Table 1), the study selects appropriate BIM software, establishes models in steps, and conducts targeted visual analysis in an attempt to determine problems in the green performance of different types of buildings. This study then determines the improvement objectives and finally creates an optimal scheme.

Methods

Green BIM and its research framework

In 2008, Eddy Krygiel and Bradley Nies introduced the concept of Green BIM, which they defined as "the process to generate and manage the full-lifecycle data information of building based on the building information model, improving the building performance and promoting and achieving the expected sustainable goal" (as shown in Fig. 1). Their work emphasizes the importance of BIM technology in the design and construction of green buildings [9], through its role in reforming design methods, and its influence on the different stakeholders

Table 1 Evaluation system and scores of the *assessment standard for green building* (GB/T 50378-2019)

Evaluation Item	Benchmark Value	Safety and Durability	Health and Comfort	Accessibility	Resource Efficiencies	Surrounding Environment	Improvement and Innovation
1	Benchmark values are necessary conditions for green building evaluation. When all the values are met, the green building level is the basic level	Safety	Indoor air quality	Trip and accessibility	Land saving and utilization	Site ecology and landscape	Including reducing the energy consumption of heating and air-conditioning systems in buildings, incorporating regional architectural culture, adopting the structural systems and building components in compliance with industrial construction requirements and applying BIM technology
2		Durability	Water quality	Service facilities	Energy saving and utilization	Outdoor physical environment	
3			Acoustic environment and light environment	Intelligent operation	Water saving and utilization		
4			Indoor thermal and humid environment	Property management	Material saving and green building materials		
Score	400	100	100	100	200	100	100

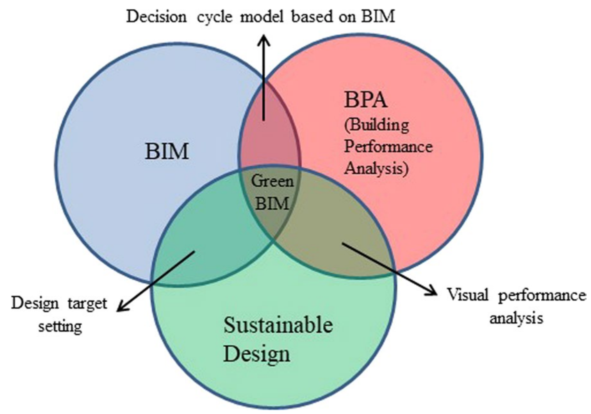


Fig. 1 Green BIM framework (Source: Institute of architecture, Ministry of the interior of Taiwan, Green Building Improvement Case Collection [R], p3)

in the building industry. In their opinion, Green BIM is characterized by: acknowledging the importance to the impact of climate and regional environment; linking benchmarking and target setting; using BIM architecture for building performance analysis; and realizing performance optimization through scheme comparison and modification.

The Green BIM decision process is designed to assess different design criteria and objectives. It requires the following steps first, to fully understand the local climate and environment of the construction site; second, to reduce energy demand and improve energy performance; third, to set evaluation benchmark values and project objectives; and finally, to select appropriate BIM software, establish a model in steps, and conduct targeted visual analysis [10]. A variety of BIM software programs provide a data exchange function, input the data in the model into relevant analysis software via exchange formats, such as IFC and gbXML, and present the results of the calculation and analysis within a short time, through such a decision cycle, the original scheme can be optimized and revised, thereby providing a guarantee for quick decision making on the green building design scheme [11] (as shown in Fig. 2).

Analysis of the green performance of different types of buildings in Chinese universities

The modelling software Autodesk Revit (version 2018) was used to create BIM models of three representative campus buildings: a classroom building, a library and a dormitory. These models were exported from their ".rvt" (Revit) format files as "0.3ds" (3-Dimension Studio), ".gbxML"(Green Building Extensible Mark-up Language) and ".dxf"(Drawing Exchange Format) files. The "0.3ds" format files were imported into Phoenics (Parabolic Hyperbolic or Elliptic Numerical Integration Code Series) to simulate and analyse wind environment. The ".gbxML" file was imported into Ecotect (Autodesk Ecotect Analysis) to simulate and analyse indoor environment, energy performance. The ".dxf" format files contain large amounts of high-precision information about the models, which is mainly used for overall analysis, such as daylighting intensity analysis, shadow shading and environmental impact analysis.

The BIM models all represent real buildings in Xi'an City, Shaanxi Province in China. This location, situated in a cold-climate region, was selected as the simulation site. The models were verified by comparing field test results

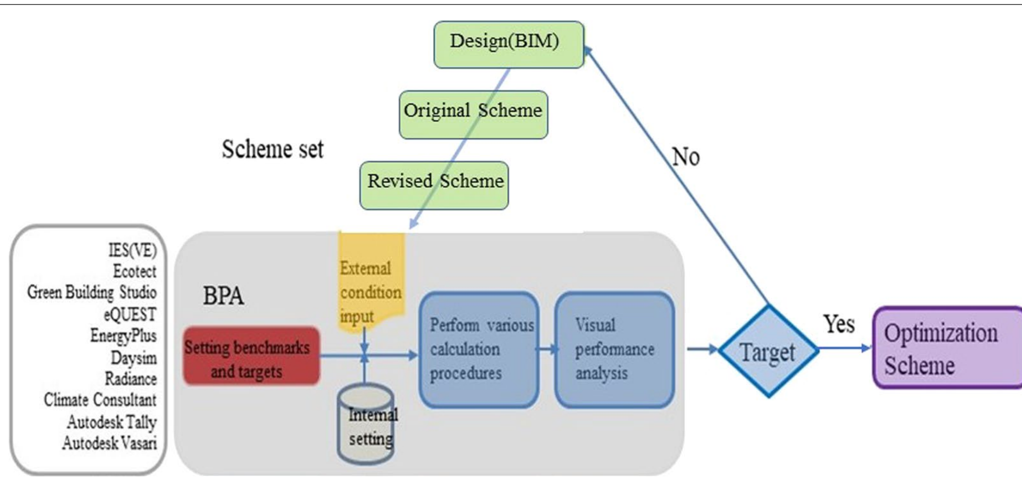


Fig. 2 Green BIM decision cycle model (Source: Institute of architecture, Ministry of the interior of Taiwan, Green Building Improvement Case Collection [R], p12)

with the simulation model. The detailed methods are as follows:

1. The wind environment of the classroom building was measured in the summer month of June in 2019, and the relevant parameters were measured for 48 h. Table 2 shows the climate features of Xi'an.
2. The thermal tests of the library and dormitory buildings were conducted in the typical summer month of July in 2018 and the typical winter month of January in 2019. Temperature, humidity, wind speed, CO_2 concentration and other relevant parameters of the building thermal comfort environment were measured for 48 h.
3. Each BIM model was fine-tuned according to the measured temperature and humidity parameters.
4. The research model was developed and prepared for the analysis. Table 2 shows the Revit 3D models of the three representative buildings.

Due to space constraints, the specific parameters of the classroom building, library and dormitory building are not specified here.

Ventilation design of classroom buildings for the objective of health and comfort

The health and comfort in the *Assessment Standard for Green Building* (GB/T 50378-2019) mainly covers indicators, such as indoor air quality, water quality, acoustic environment, light environment, and indoor thermal and humid environment. Most campus buildings in China use natural ventilation, which greatly affect the indoor environment. Therefore, the quality of natural ventilation is selected as the key green performance indicator for classroom buildings in this study.

(1) Typical forms and ventilation simulation of classroom buildings.

Classroom buildings in northern China are typically oriented in a north–south direction. Campus buildings that have an east–west orientation are commonly used as office buildings and laboratories [12]. The plan-view layout of teaching buildings was dominated by the form of an internal corridor in the early and middle terms in China (1960–1990), when such building types were commonly designed with only internal corridors. Newly built ones commonly have corridors as part of the façade (2000-present) [13]. The classroom buildings mostly had 3 to 4 floors in the early stage, whereas those in the middle stage and newly built buildings mainly have 4–6 floors, and 5-floor buildings are the most common (as shown in Fig. 3).

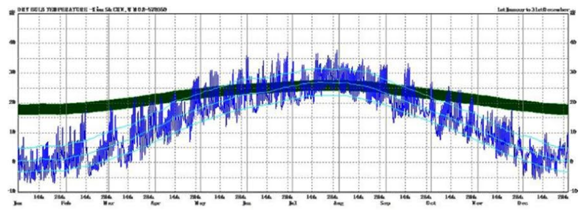
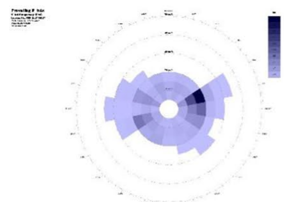
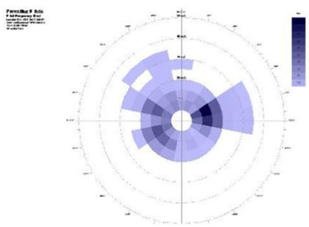
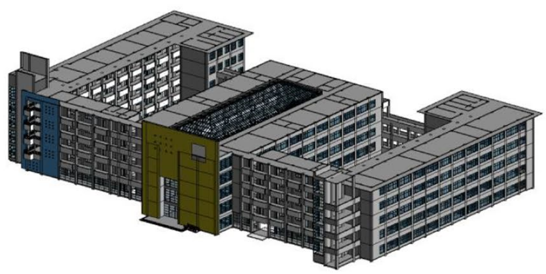
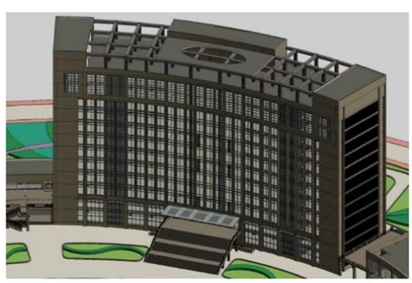
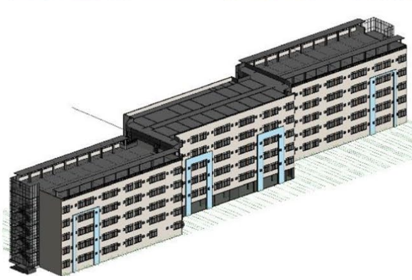
Based on the survey above, the study selects three types of internal corridor forms, namely, belt type, semi-enclosed type, and cluster type, to conduct the current ventilation test of specific buildings. On this basis, BIM technology is used for modelling, typical buildings are put into the specific wind field in northern areas (with northeast as the prevailing wind direction and southwest as the secondary wind direction), and the models are imported into the ventilation simulation software Phoenics to carry out the study.

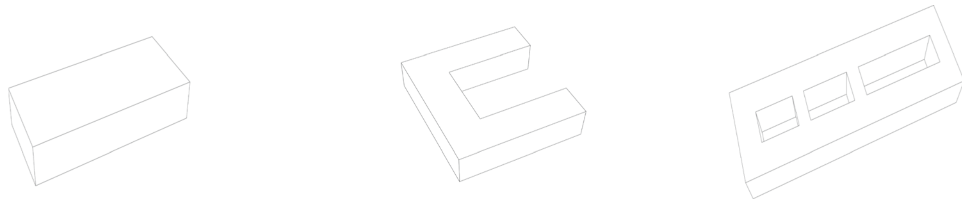
From the perspective of the plan-view layout of a single building, in the case of a 15° angle of a single belt-type building, the wind shadow is relatively small on the leeward side of the building, the area of flow around the building is not large but the wind speed is high, and the angle between the wind direction and the north and south facades is too small to be utilized for indoor ventilation. At an angle of 45°, the angle between the facades and the wind direction is large, which is conducive to indoor natural ventilation. In the case of a 30° angle, the surrounding wind environment is relatively uniform. Therefore, an angle of 30°–45° is the most appropriate orientation, among which 30° is better (as shown in Fig. 4).

When the courtyard opening of a single building of the semi-enclosed typefaces the north easterly wind at an angle of 15°, the vortex area of the wake flow is comparatively large. At an angle of 30°, the vortex area of the wake flow is smaller. At an angle of 45°, the vortex area of wake flow is the smallest. When the opening faces the south westerly wind, along with the increase in the angle, the vortex area on the windward side decreases gradually, and the vortex area in the leeward courtyard corner increases gradually. With two wind conditions taken into consideration, the appropriate orientation for this type of single building is 30°–45° (as shown in Fig. 5).

Compared with other layout forms, the layout of the cluster type is more flexible, and the single buildings are more diverse. As revealed by CFD (Computational Fluid Dynamics) simulation analysis, the form of single buildings around the central space, the road and opening directions between single buildings, and the angle between the buildings and the prevailing wind direction all have an impact on the overall outdoor wind environment. Through the selection of the angle between single buildings and the prevailing wind direction, the interference of the wind shadow between the buildings can be reduced. Meanwhile, in the southeast direction where the wind frequency is very low in winter, the reasonable selection of openings can improve the wind environment during the transition season. However, a small opening in the combination will give rise to the Venturi effect and will accelerate the airflow, so narrow openings should be avoided as far as possible in the prevailing wind direction in winter (as shown in Fig. 6). Therefore, compared with

Table 2. Legend or example of simulation

Category	Type	Legend or example
Climatic characteristics of Xi'an	1. Annual dry bulb temperature distribution in Xi'an	
	2. Summer wind frequency map of Xi'an	
	3. Winter wind frequency map of Xi'an	
Building type	1. Classroom building	
	2. Library building	
	3. Dormitory building	

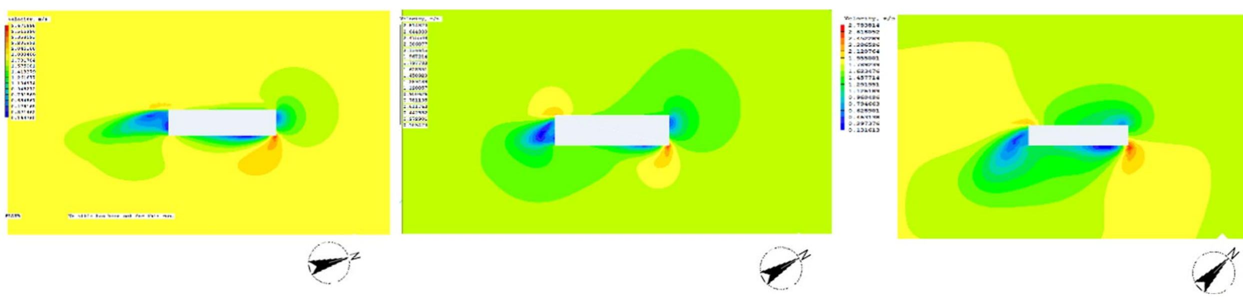


a. Internal corridor in the early and middle terms in China (1960-1990)

b. Internal corridor in the new term in China (2000-present)

c. external corridor encircling an internal courtyard (2000-present)

Fig. 3 Typical forms of teaching buildings in northern areas



(a) Northeast 15° (b) Northeast 30° (c) Northeast 45°

Fig. 4 Ventilation simulation analysis graphics of rectangular classroom buildings in different orientations

other types, the cluster type around the central space is more suitable for the university buildings in cold areas.

(2) Internal ventilation simulation of classroom buildings in northern China.

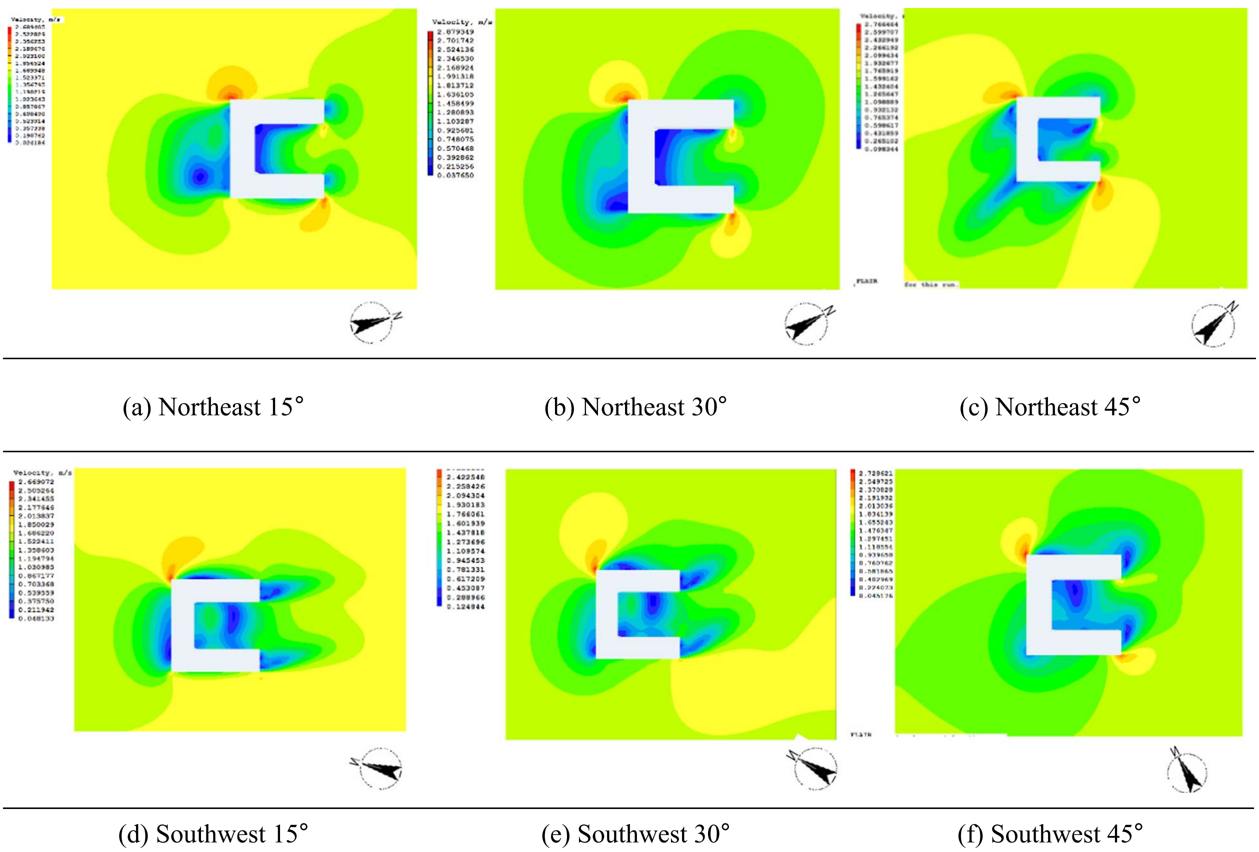
Classroom buildings in northern areas mostly adopt the plan-view layout of the internal corridor. The study sets the corridor width as 2.1 m, 2.4 m, 2.7 m, 3 m, 3.3 m, and 3.6 m for the CFD simulation experiment; the plan-view dimensions of classrooms on both sides of the corridor are 7800 mm × 14,500 mm. In addition, there are 8 evenly distributed 1400 mm × 700 mm ventilation openings at a height of 0.9 m above the ground in the exterior wall of each classroom and an 800 mm × 600 mm opening at a height of 2 m above the ground in the interior wall. Two 1400 mm × 1700 mm ventilation openings at a height of 0.9 m above the ground are centred in the exterior walls at both ends of the corridor, and the area of the two openings does not increase with the corridor width. These buildings are placed into the specific wind field in northern areas for simulation. The results are shown in Fig. 7.

The results show that a corridor width of 2.1 m or 2.4 m will achieve the highest wind speed, while a corridor width of 2.7 m or 3 m will lead to the lowest; when the width is 3.3 m or 3.6 m, the wind speed is lower than that when the width is 2.1 m or 2.4 m, but the wind speed above 0.7 m/s is more evenly distributed, and the area of wind speed above 0.4 m/s in the classroom increases. Via the increase in corridor width, the function of the corridor as a horizontal ventilation corridor is weakened, and the cross-ventilation effect inside the building is enhanced.

Energy-saving design of library buildings for the objective of resource efficiencies

The resource conservation in the *Assessment Standard for Green Building* (GB/T 50378-2019) covers four indicators, i.e., land saving and utilization, energy saving and utilization, water saving and utilization, and material saving and green building materials. The libraries of universities generally have a large volume and more energy consumption, and the energy use is complex, so the factors related to energy conservation are selected here to carry out a green performance study on library buildings.

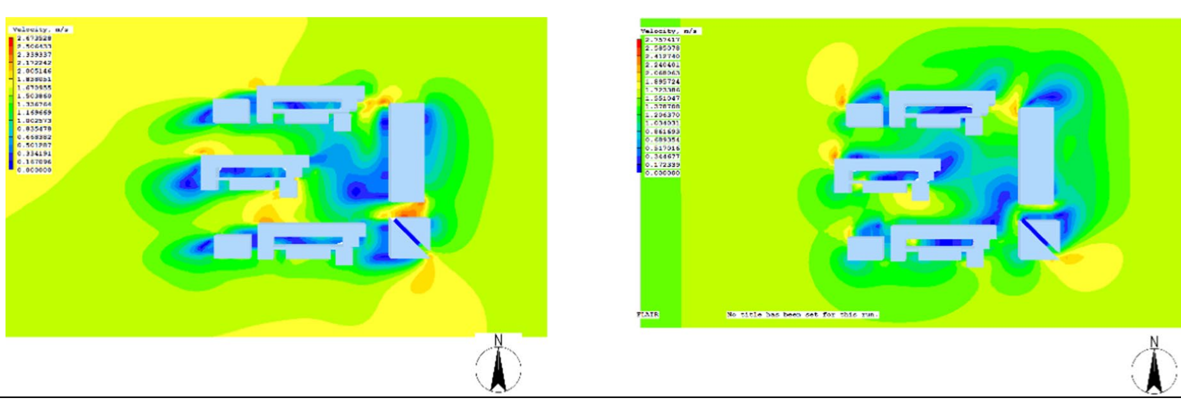
(1) Building form design



(a) Northeast 15° (b) Northeast 30° (c) Northeast 45°

(d) Southwest 15° (e) Southwest 30° (f) Southwest 45°

Fig. 5 Ventilation simulation analysis graphics of semi-enclosed classroom buildings in different orientations



(a) Wind Speed Nephogram of Classroom buildings of the Cluster Type (North easterly Wind)

(b) Wind Speed Nephogram of Classroom buildings of the Cluster Type (South westerly Wind)

Fig. 6 Ventilation simulation analysis graphics of teaching buildings of the cluster type

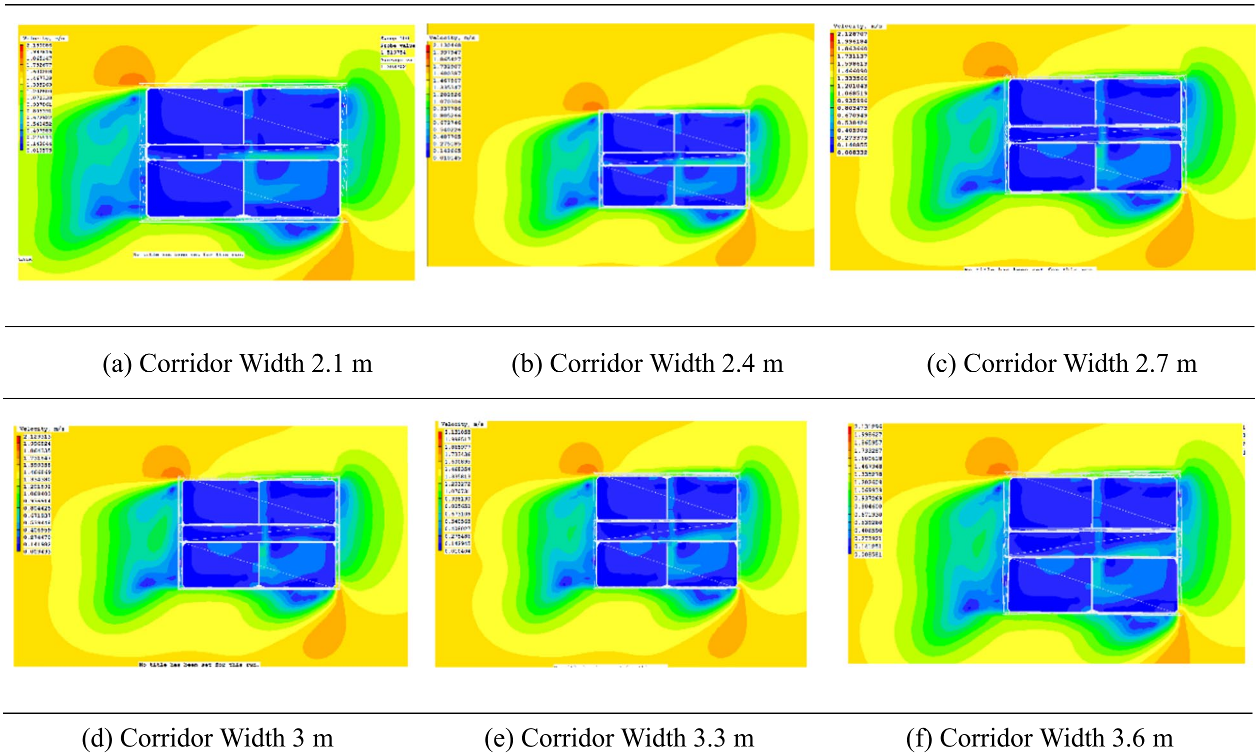


Fig. 7 Ventilation simulation analysis graphics of classroom buildings with different internal corridor widths

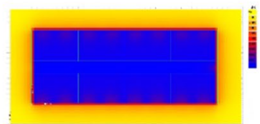
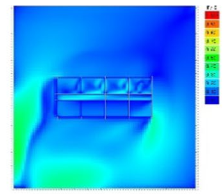
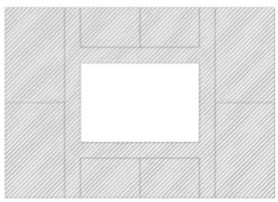
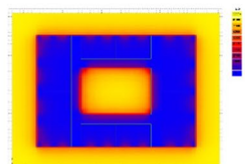
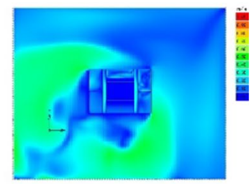
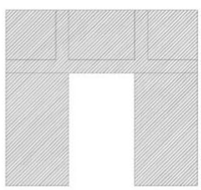
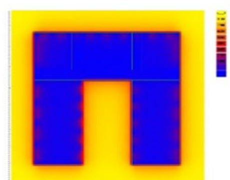
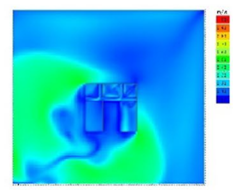
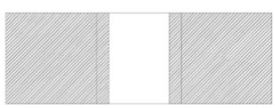
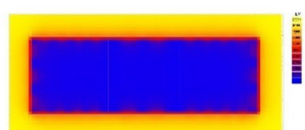
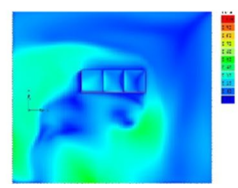
The major functions of university library buildings are book collection, borrowing service, self-study, and auxiliary offices. In terms of their functional nature, modern university library buildings mainly feature functional layouts integrating collection, borrowing service, and reading, and the functional plan-view layouts are primarily divided into the following forms: symmetrical distribution, hollow square-shaped single corridor, U-shaped distribution, and belt-shaped distribution [14]. The daylighting and ventilation simulations of these basic layout forms are analysed and compared with Ecotect, and the results are shown in Table 3.

Through analysis of the daylighting and wind field conditions of buildings, it can be found that the four layout forms have their own advantages and disadvantages. In the symmetrical distribution form, the indoor daylighting is comparatively uniform, but the long and narrow plan-view layout is relatively simple, and it easy to subject the building to a large wind load. In the hollow square-shaped single corridor form, the indoor daylighting is sufficient, the space utilization rate is high, and the indoor and outdoor wind pressure ventilation effect is good, but the building shape coefficient itself is large, and the problems of solar radiation heat and heat loss are prominent. The building in the form of U-shaped distribution has a high daylighting rate and good indoor ventilation. The building in the form of belt-shaped distribution has many windows that open to the outside, but it is hard to produce wind pressure ventilation because of the open space of a single building, and the natural daylighting in the middle rooms is poor [15].

(2) Envelope energy saving design and material selection.

Northern China has distinct conditions in summer and winter. It is cold in winter, so a high requirement is imposed for the thermal insulation of buildings to maintain the indoor temperature balance; the high-temperature weather in summer also has a high requirement for the thermal insulation performance of the building envelope to reduce the impact of outdoor high temperatures on indoor environment comfort [16]. The thermal insulation technologies of exterior walls are mainly classified into three types: external thermal insulation of exterior walls, internal thermal insulation of exterior walls, and self-thermal insulation of exterior walls (it refers to the use of envelope material itself has a certain thermal insulation performance, can meet the requirements of 50% or 65% energy saving) [17]. The internal thermal insulation technology of the exterior wall brings a lower insulation efficiency than the external thermal insulation, and

Table 3 Analysis of the daylighting and wind field conditions in the basic plan-view layouts. Source: Qibo Liu, Juan Ren. Research on the Building Energy Efficiency Design Strategy of Chinese Universities Based on Green Performance Analysis

Layout Form	Diagram	Daylighting Analysis	Wind Field Analysis
Symmetrical distribution			
Hollow square-shaped single corridor			
U-shaped distribution			
Belt-shaped distribution			

there are problems in heat bridge treatment. This design is widely used in renovation projects in hot-summer/cold-winter and hot-summer/warm-winter regions [18]. Due to its strong climate adaptability, the practice of the external thermal insulation of exterior walls is widely used in newly built buildings. Based on the different climatic characteristics of different regions, the selection of insulation materials and the practice of constructional thermal control are also different [19].

A glass curtain wall is a common facade form and window opening form of modern public buildings and is usually used as the envelope and decorative structure of a single facade or multi-oriented facade. The window–wall ratio can be as high as 0.8–0.9, so the requirement for its thermal performance is higher than that for other window types, and the designs of wind pressure resistance, watertightness, airtightness, Plane deformation performance, and thermal insulation are all extremely important. Regarding the selection of wall glass, the study mainly summarizes the types and application scopes of building energy-saving glass materials whose heat transfer coefficient is below 3.0 in the thermal indicators of glasses as specified in the *Design Standard for Energy Efficiency of Public Buildings* (GB 50189-2015) [20], as shown in Table 4.

(3) System design

In Chinese universities, the library is one of the few buildings that use AC for heating/cooling with additional mechanical ventilation. A major problem is that existing central air conditioning and ventilation system, have low energy efficiency and are becoming obsolete; The design commonly doesn't consider the occupancy schedules, which are highly regulated, and cannot be dynamically adjusted according to the meteorological conditions. Therefore, it is challenging to quantify the energy performance and identifying the system components with the

Table 4 Energy-saving designs, characteristics, and application scopes of wall glass types

Type	Practice	Characteristics	Application scope
Low-E glass	Solar-radiant Low-E film-coated glass	Realizing the selective shielding of solar radiation energy, preventing glare from entering the room	It is used at high northern latitudes
Hollow glass	Vacuum thermal-insulating glass Light-transmitting Low-E + air + transparent glass Light-transmitting Low-E + argon + transparent glass	Reduce the heat transfer coefficient of glass. Guarantee the indoor constant temperature and humidity performance	Hollow glass is mainly used in buildings that need heating, air conditioning, noise or condensation prevention, and no direct sunlight and special light
Ultra-white solar glass	Applying a coating that can absorb solar energy to ordinary glass	It can achieve the absorption of solar energy, and being used for constructing solar eco-building and making solar radiator	Northern areas with strong solar radiation
Double-layer respirable curtain wall glass	Double-structure glass curtain wall of external circulation type Double-structure glass curtain wall of internal circulation type	It is composed of inner and outer curtain walls to realize the effect of thermal insulation and energy conservation	Buildings taking curtain wall as the outer-building envelope for main facade in most regions

worst energy performance. Future energy-saving designs of library buildings will require HVAC systems with complicated functionality, for example, to reduce the load of HVAC system and the surrounding environment.

Planning and layout of dormitory buildings for the objective of surrounding environment

The surrounding environment in the *Assessment Standard for Green Building* (GB/T 50378-2019) mainly includes two indicators, namely, the site ecology and landscape and the outdoor physical environment. Dormitory buildings in Chinese universities generally designed as residential building clusters [21]. For buildings in northern areas, good sunlight conditions both indoors and outdoors will influence the indoor heat gain of the building on the one hand and the outdoor walking and activity comfort of students on the other hand. As a result, the green performance study is carried out here based on the overall layout forms of dormitory buildings. The layout designs show in Table 5 coincides with one of a paper published by the author [15], but with the addition of diagonal layout and optimized integrated layout of long and short staggered, the overall layout types are more diverse, can fully explain which layout form is more suitable for the objective of environmental liveability.

In Table 5, the typical layout of dormitory buildings is simulated and analysed using the solar radiation analysis sunshine analysis simulation software of Ecotect software. Through the analysis of the sun shading between buildings, the advantages and disadvantages of different layout methods are evaluated. It can be seen from Table 5 that:

1. Dormitory buildings should be arranged at a reasonable sunlight spacing between buildings. As an extensively used form in northern areas, row layouts have better sunlight conditions than courtyard layouts.
2. To satisfy the basic sunlight requirement, the staggered layout is less blocked than the row layout at a reasonable sunlight spacing between buildings.
3. From the perspective of a single building form, a long-corridor layout is more reasonable than a short-corridor layout in terms of land use, whereas a short corridor is better than a long corridor in terms of sunlight conditions; therefore, the two should be combined and to arrange long-corridor dormitory buildings on the northern side and short-corridor buildings on the southern side to reduce blocking.

Results—Green BIM-based optimized design of green performance of a university library in northern China

In this study, the university library is selected as a case building to carry out a comprehensive green performance improvement and retrofit research. The case building is located in Xi'an, Shaanxi, China, and was completed in 2006. The building area is 31,000 m^2, the building height is 51.5 m, a total of 13 floors. The main structure of the building is reinforced concrete frame structure. The envelope is a non-load bearing clay hollow brick wall with a thickness of 240 mm. The facing is mainly dry hanging granite and spraying stone-like paint. The inner side of the external wall is coated with 20 thick rare earth composite wall insulation material. This study uses BIM software to establish the basic model, and following the operation and process of Green BIM decision cycle, carries out the optimization design and simulation of the retrofit scheme from the perspective of green performances, which is described as follows:

(1) Optimization of the site environment based on environmental liveability: in combination with the regional prevailing wind direction, wind environment simulation software is used to analyse the wind environment of the site selected for the building under the influence of other buildings. The natural ventilation demand of the lower floor south-facing rooms of the building affected by the trees is improved by tree transplantation (as shown in Fig. 8).

(2) Optimization of the functional layout based on health and comfort: the problem of insufficient daylighting in the reading area is improved through the change in furniture arrangement. A light-pipe lighting system is added, reduce the power consumption by indoor artificial lighting. High windows are added in the partition walls on both sides of corridor to meet the requirement for natural ventilation inside and outside the building. The daylighting roof of the atrium is transformed into an accordion structure, an electric sun-shading curtain is installed indoors to timely block the sunlight from the west, ensure comfort in the atrium space (as shown in Figs. 9, 10, 11).

(3) Building envelope performance transformation based on resource conservation: the building was completed only approximately 17 years ago. To transform the external thermal insulation of the exterior wall, it is necessary to transform the exterior facade (which is uneconomical and unfeasible), in a way that the transformation of the internal thermal insulation of the exterior wall is adopted. In this project, 50 cm-thick PU hard foamed plastic is used as the insulating material to replace the 20 cm-thick rare-earth thermal insulation materials for the composite wall, and the average heat transfer

Table 5 Ecotect simulation analysis of typical layout designs of dormitory buildings

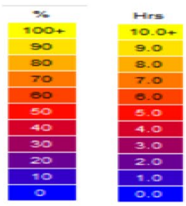
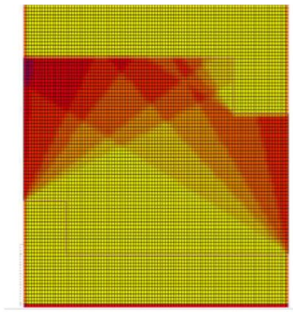
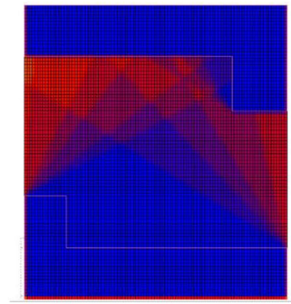
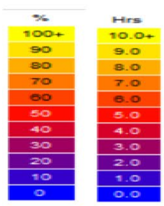
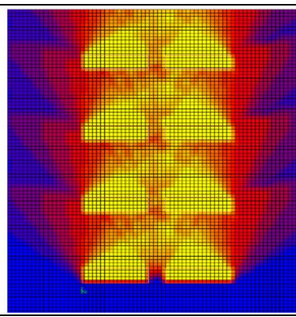
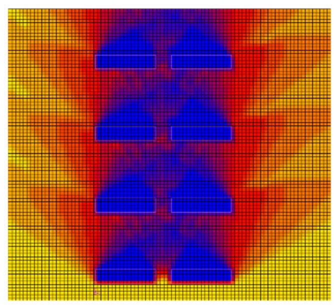
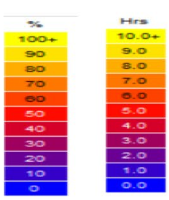
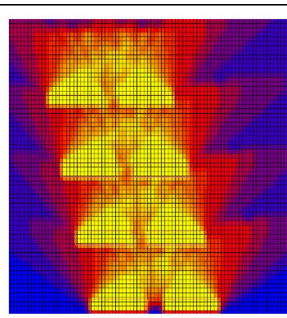
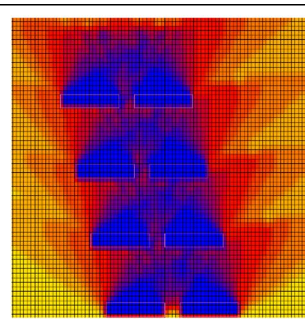
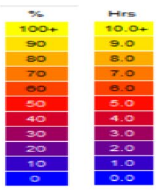
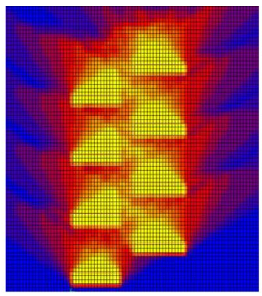
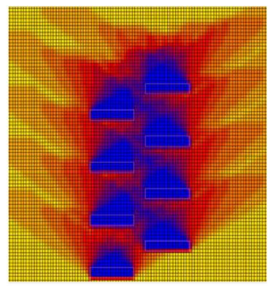
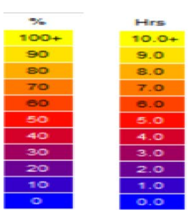
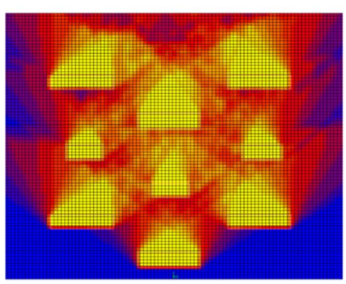
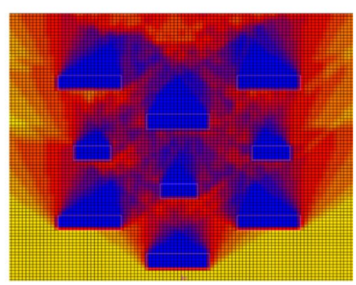
Layout Form	**Courtyard layout**
Sun Shading Percentage 	 
Analysis	In the enclosed layout, the impact of building blocking is great, and the sunlight condition is also the worst of all; the sunlight duration is 4 hours at the maximum and even less than 1 hour in some parts on the first floor of south-facing building.
Evaluation	Poor
Layout Form	**Row layout**
Sun Shading Percentage 	 
Analysis	The N-S blocking of buildings ranges between 50% and 60%, and the E-W blocking of middle dormitory buildings almost reaches 90% -- 100%. Approximately 90% of dormitory buildings have a sunlight duration of 4 -- 3 hours on the lower floors, and 10% of them have a sunlight duration of 1 -- 2 hours, which does not meet the sunlight requirement.
Evaluation	Moderate
Layout Form	Diagonal layout
Sun Shading Percentage 	 

Table 5 (continued)

Analysis	The N-S blocking of buildings is 40% -- 50%, and the E-W blocking is 90% -- 70%. The sunlight condition is moderate, and the diagonal layout does not solve the effect of E-W blocking.
Evaluation	Moderate
Layout Form	Staggered layout
Sun Shading Percentage 	 
Analysis	The N-S blocking of buildings is 40% -- 50%, and the E-W blocking is 90% -- 70%. Approximately 90% of dormitory buildings have a sunlight duration of 4 -- 5 hours on the lower floors. Most buildings have a sunlight duration of 5 -- 7 hours. Different from the sunlight condition of row layout, there are few 1-2 hours sunlight areas in the staggered layout and little impact of building blocking on east and west sides.
Evaluation	Fairly good
Layout Form	Optimized integrated layout of long and short staggered
Sun Shading Percentage 	 
Evaluation	Good

coefficient of the wall is 0.50 W/(m^2·k). For the glass curtain wall, a double-layer respirable glass curtain wall system of external circulation type is selected, and integrated sun-shading measures for the glass curtain wall are employed to prevent indoor overheating.

After the optimization and improvement of the passive energy-saving design of the university library in North China, the data of the BIM analysis model are revised and adjusted according to the modified content, and the energy consumption simulation analysis of air conditioning, heating and ventilation energy consumption is carried out again after the retrofit design. The total annual cumulative energy consumption load of the scheme after retrofit has decreased, due to the heating in winter in northern China, the energy consumption reduction effect from November to next March is obvious, and there is a

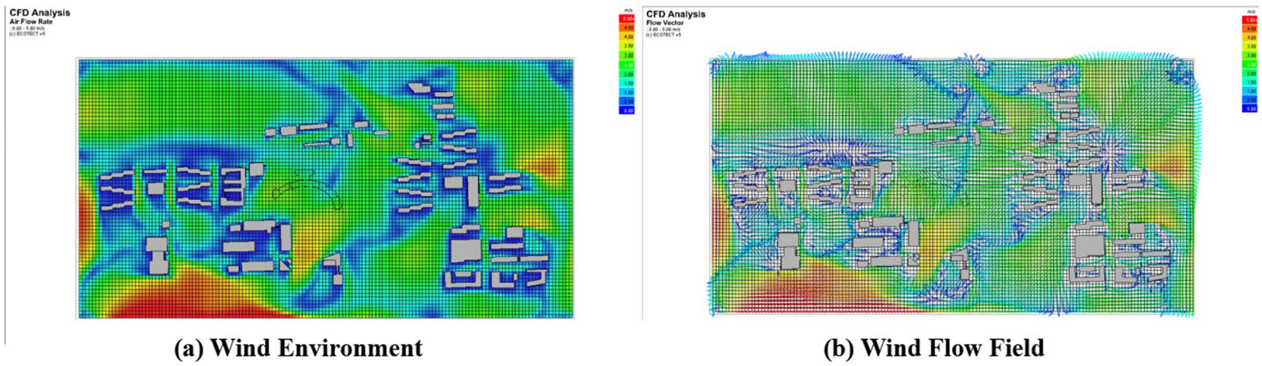


Fig. 8 Schematic diagram of the wind environment and flow field of the architectural complex at the base of a library

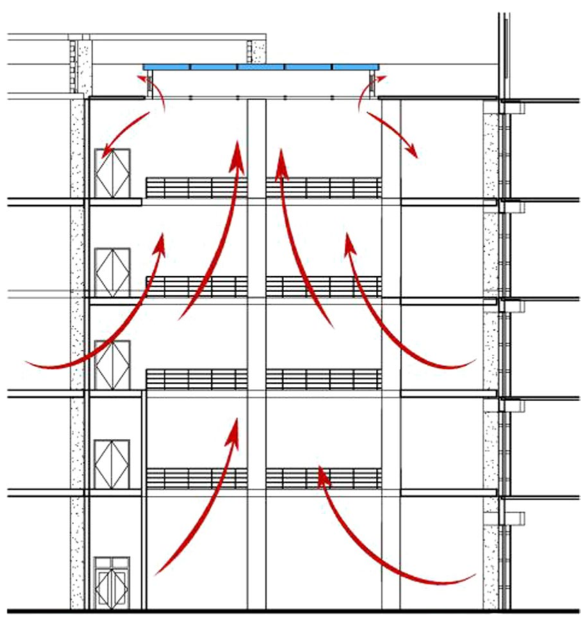


Fig. 9 Schematic diagram of thermal pressure ventilation in the atrium

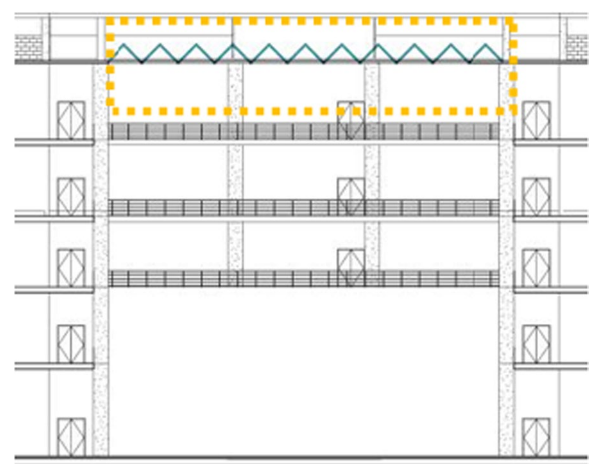


Fig. 10 Accordion lighting roof of the atrium

great difference before and after the transformation, the annual heat load has decreased by 59.1%; and the total annual cooling load also has decreased by 21.5% (The cooling time is from June to August). After calculation, the total annual accumulated load decreased by approximately 47.4% after the retrofit. The results are shown in Fig. 12.

(4) Management measures based on improvement and innovation: an automatic control device should add indoors to realize the automatic control of room temperature at different personnel densities and to avoid overcooling; meanwhile, in the air-conditioning system should timely replaced and cleaned to improve energy use. In addition, installing monitoring facilities and understand the holistic energy performance of the whole campus will boost energy conservation at management and awareness levels.

Discussion

The concept of green performance and the application of Green BIM decision cycle model can really promote the concept, method and technology of green building design. Then change the phenomenon of "energy-saving buildings do not save energy" [22]. From this paper, we can see that:

in China, university buildings are divided into 7 categories and 13 types, so it is difficult to include all the contents in one paper. At the same time, the problems faced by various types of buildings are not the same. The purpose of this study is to propose a research and analysis method for reference, and to provide ideas for the

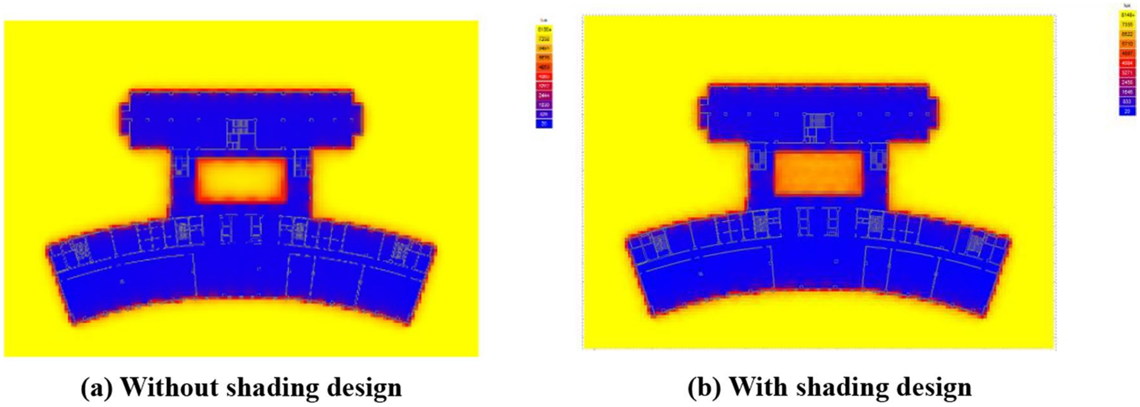


Fig. 11 Simulation of sunshade design for atrium daylighting roof

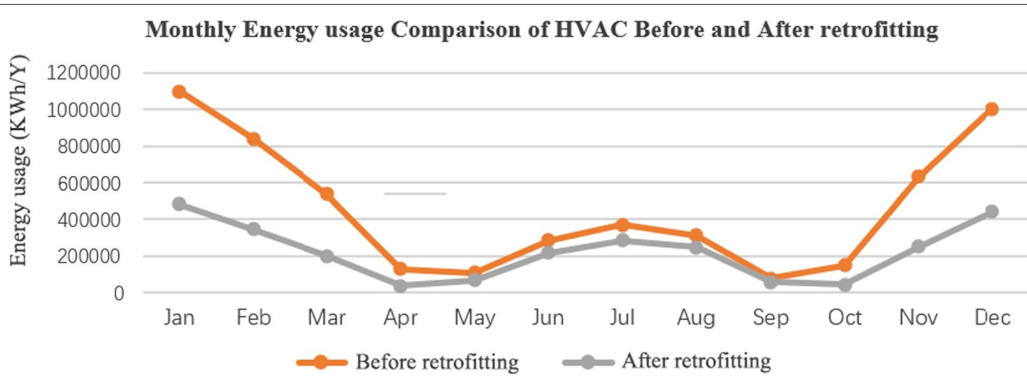


Fig. 12 Monthly energy consumption comparison chart of HVAC before and after energy-saving transformation

development of green buildings and green campus construction in universities.

Conclusion

1. The characteristics of built environment in different regions and the planning of campus will have an impact on building green performance. Reasonable layout of different types of buildings can reduce traffic energy consumption and enhance the use efficiency of various facilities; good orientation is conducive to passive energy-saving design.
2. The optimization of spatial layout is conducive to the improvement of building green performance. University buildings have complex functions, so green building design and energy-saving transformation should be carried out according to the characteristics of different types of buildings. An efficient plan-view layout adapted to functions can not only improve the energy use efficiency of buildings but also meet the requirements of buildings for sound, light, and heat to the maximum extent and reduce energy consumption.
3. For most university buildings without central air conditioning system, the design of thermal insulation and heat storage performance of the envelope is very important. By improving the thermal performance of the envelope, the impact of outdoor climate on the internal environment during the service time can be effectively reduced, and achieve the goal of an energy-saving building design.
4. For large-scale buildings in universities, such as libraries, sports and sports/event venues, the energy conservation of water supply and drainage system and HVAC system can work together with passive energy-saving technology, to control building energy consumption and improve indoor comfort.

Abbreviations
BIM: Building Information Modeling; rvt: Revit; 3ds: 3-Dimension Studio; gbxML: Green Building Extensible Mark-up Language; dxf: Drawing Exchange Format; Phoenics: Parabolic Hyperbolic or Elliptic Numerical Integration Code Series; Ecotect: Autodesk Ecotect Analysis; CFD: Computational Fluid Dynamics.

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Authors' contributions
All authors made the same contributions to the article. Both authors read and approved the final manuscript.

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Declarations

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Not applicable.

Consent for publication
All the authors agree to publish the article.

Competing interests
The authors declare that they have no competing interests.

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References
1. G Wei-hong L Xiao 2016 Planning design strategy and practice research on green university campus J BEE 44 70 80
2. H Tan S Chen Q Shi L Wang 2014 Development of Green Campus in China J Clean Prod 64 646 653 https://doi.org/10.1016/j.jclepro.2013.10.019
3. Liu X (2017) Study on the Holistic Design Strategy of Green University Campus in Hot and Humid Areas. South China University of Technology, https://www.cnki.net/doctoraldissertation. Accessed 12 Apr 2017
4. Simpson W (2008) The Green Campus: Meeting the Challenge of Environmental Sustainability. Appa Assn of Higher Education, Alexandria.
5. Ministry of Housing and Urban rural Development (2019) Assessment Standard for Green Campus (GB/T51356–2019).
6. M Thomashow A Cortese 2014 The Nine Elements of a Sustainable Campus MIT Press Cambridge
7. Ministry of Housing and Urban rural Development (2019) Assessment Standard for Green Building (GB/T 50378–2019).
8. J Basbagill F Flager M Lepech M Fischer 2013 Application of life-cycle assessment to early-stage building design for reduced embodied environmental impacts Build Environ 60 81 92 https://doi.org/10.1016/j.buildenv.2012.11.009
9. Krygiel E, Nies B (2008) Green BIM: Successful Sustainable Design with Building Information Modelling. Sybex, Indianapolis
10. Institute of architecture, Ministry of the interior of Taiwan (2015) Green Building Improvement Case Collection. http://www.cie.org.tw/research/data. Accessed 25 Dec 2015
11. J Kwok Wai Wong J Zhou 2015 Enhancing environmental sustainability over building life cycles through Green BIM: a review Automat Constr 57 156 165 https://doi.org/10.1016/j.autcon.2015.06.003
12. Q Liu R Zhou 2013 Research of energy efficiency technology system of university existing building in cold climate zone Industr Constr 43 49 53
13. J He 2009 Theory and Design Practice of Contemporary University Campus Planning 1 China Architecture Publishing & Media Co., Ltd. Beijing
14. J Bao R Gong 2010 Seeking for Library Architecture Design– Towards Open Library Architecture 1 China Architecture Publishing & Media Co., Ltd. Beijing
15. Q Liu J Ren 2020 Research on the building energy efficiency design strategy of chinese universities based on green performance analysis Energy Buildings https://doi.org/10.1016/j.enbuild.2020.110242
16. Q Liu W Feng 2015 Research on the efficiency and economic impact of energy-saving transformation of residential buildings in different climatic regions of China Adv Mater Sci Eng https://doi.org/10.1155/2015/634904
17. H Huo J Shao H Huo 2017 Contributions of energy-saving technologies to building energy saving in different climatic regions of China Appl Therm Eng 124 1159 1168 https://doi.org/10.1016/j.applthermaleng.2017.06.065
18. J Yang Y Zhang L Wang 2017 Research on the current situation and countermeasures of internal insulation technology in hot summer and cold winter area Constr Wall Innova Build Energy Saving 10 52 55
19. J Yuan C Farnham K Emura 2017 Optimum Insulation Thickness for Building Exterior Walls in 32 Regions of China to Save Energy and Reduce CO2 Emissions Sustain Basel https://doi.org/10.3390/su9101711
20. Ministry of Housing and Urban rural Development (2015) Design Standard for Energy Efficiency on Public Buildings (GB 50189–2015)
21. C Wang 2007 Ecological student apartment 1 China Architecture Publishing & Media Co., Ltd. Beijing
22. N Zhou N Khanna W Feng J Ke MD Levine 2018 Scenarios of energy efficiency and CO2 emissions reduction potential in the buildings sector in China to year 2050 Nat Energy 3 978 984 https://doi.org/10.1038/s41560-018-0253-6

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