Green BIM-based Study on the Green Performance of University Buildings in Northern China

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Green BIM-based Study on the Green Performance of University Buildings in Northern China

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Abstract

Background: Green BIM emphasizing the contribution of BIM technology to the design and construction of green buildings. It attaching importance to the impact of climate and regional environment, using benchmarking and target setting, using BIM architecture for building performance analysis and realizing performance optimization through scheme comparison and modification. A university campus is a community that has a certain geographical scope and spatial scale and involves a variety of functions, such as teaching, scientific research, and living space. Hence, a campus possesses urban characteristics and diverse building types, and the construction of green university campuses will play a leading role in green urban construction in China under the increasing ecological and energy pressure of cities.

Methods: Based on the Green BIM decision cycle model, the study employs BIM architecture to analyses building performance. By using the <Evaluation Standard for Green Building> as the evaluation benchmark values and project objectives and taking the most representative teaching buildings, libraries, and dormitory buildings in universities in northern China as examples, the study selects appropriate BIM software, establishes models in steps, and conducts targeted visual analysis. The purpose is to find out the commonness and difference through the analysis, and then realize that the diversity of building types in campus determines that the green performance research of different types of buildings should comprehensively consider various design factors.

Results and conclusions: Taking a university library in northern China as an example, the study optimized it from four aspects: base environment, function layout, envelope performance and system transformation, and management measures improvement. The results show that the total annual cumulative energy consumption load of the scheme is reduced obviously. The conclusions are that the improvement of university buildings' green performance must be comprehensively carried out from the aspects of planning, building design, system design, energy management, and energy conservation planning. In the future, we also need to carry out energy consumption data mining, continue the energy-saving transformation of existing buildings and energy consumption systems, achieve the goal of green and low-carbon campus.

Keywords: Green BIM, Northern China, University Building, Green Performance, Design Strategy

1. Introduction

A university campus is a community that has a certain geographical scope and spatial scale and involves a variety of functions, such as teaching, scientific research, and living space. Hence, a campus possesses urban characteristics and diverse building types, and the construction of green university campuses will play a leading role in green urban construction in China under the increasing ecological and energy pressure of cities [1]. Additionally, due to its talent cultivation effect via environmental education, students are influenced by the green and low carbon concepts that they constantly see and hear, resulting in a radiation effect of green campus concepts to the whole society when they enter society [2]. Finally, as a better component of the natural environment in cities, university campuses will effectively regulate the microclimate and ecological function of cities by maintaining natural ecology on a considerable scale [3].

By searching the general situation of research on green campuses in the English literature, discussion and research on green campuses emerged in succession in the mid-1990s, and the relevant research literature has been increasing year by year since 2000. For instance, in the EI database, retrievals with English terms "green campus", "ecological campus", and "sustainable campus" show that the earliest relevant literature appeared in the 1970s, and the number of studies was very limited during the period from 1970 to 1990; the number of relevant studies increased gradually from the mid-1990s, and there has been a surge in the number of relevant published studies since 2000. Especially in recent years, this has become a hot topic in academic research, and American scholars have in particular paid more attention to green campus topics in the past 20 years [4]. Based on the research focus, these studies can be divided into three aspects: first, discussion of the overall characteristics and contents of green campuses; second, research on green campus evaluation systems; and third, research on multiple aspects of green campuses, such as green buildings, the ecological landscape, green energy, green materials, green food, green education, healthy environment, green procurement, etc.

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 + green building consultation has difficulty ensuring that the actual effect can be in accord with a green design [5]. The design methods that are based on AutoCAD, SketchUp, etc. split the interactive relationship between plan-view function streamlining and spatial form design, and various disciplines are loosely connected and exhibit poor synergy. Two-dimensional drawings cannot fully display and convey information, and bottlenecks, such as poor communication, a good deal of repeated modelling, and low information integration, occur between all stages of the building's lifecycle, making it difficult to guarantee the green performance of the building.

The *Evaluation Standard for Green Building* (GB/T 50378-2019) implemented in August 2019 first proposes the concept of green performance, which refers to the performance related to building safety and durability, health and comfort, living convenience, resource conservation (energy savings, land savings, water savings, and material savings), and environmental liveability [6]. The concept of green performance is proposed to improve the original standard that regarded technology as the core and lacked humanity and perceptibility. The standard in Edition 2014 did not reflect high-quality buildings in the evaluation, and it was difficult for owners to feel the advantages of green buildings in terms of health, comfort, convenience, and liveability. A building performance study based on green performance analysis refers to the energy-saving design that takes into sufficient consideration 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 under the combined action of various factors.

2. Objectives of the Green BIM-based Green Performance Design of University Buildings

2.1 Green BIM and its research framework

In 2008, Eddy Krygiel and Bradley Nies formally put forward the concept of Green BIM (Building Information Modeling) for the first time, emphasizing the contribution of BIM technology to the design and construction of Green buildings and discussing the impact of BIM on the reform of design methods and the influence of BIM on all users and participants in the building industry to achieve the development goal of Green BIM through sustainable solutions [7]. In their opinion, Green BIM should have the following characteristics: attaching importance to the impact of climate and regional environment; using benchmarking and target setting; using BIM architecture for building performance analysis; and realizing performance optimization through scheme comparison and modification. According to existing studies, Green BIM can be 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).

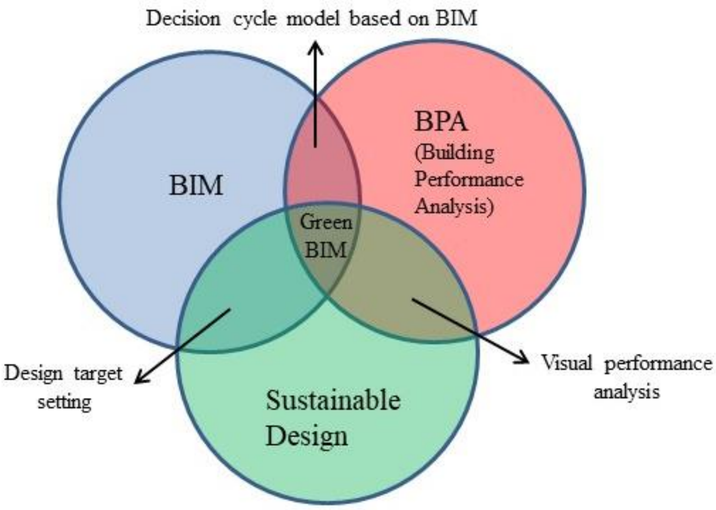


Fig. 1 Green BIM Architecture

(Source: Eddy Krygiel, Brad Nies, Green BIM: Successful Sustainable Design with Building Information Modelling)

The operation and process of the Green BIM decision cycle are designed to assess different design contents and objectives: first, to fully understand the local climate and base environment; second, to reduce demand and load and improve quality; 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 [8]. 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, thereby providing a guarantee for quick decision making on the Green building design scheme [9] (as shown in Fig. 2).

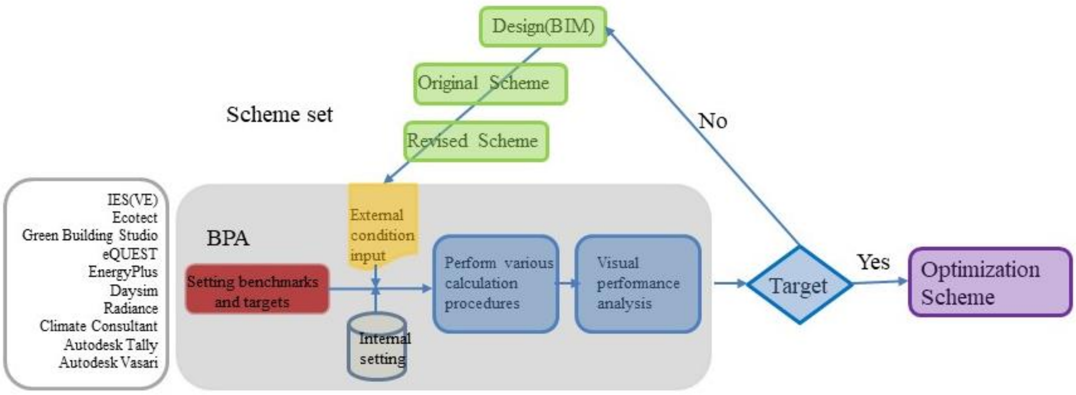


Fig. 2 Green BIM Decision Cycle Model

(Source: Institute of architecture, Ministry of the interior of Taiwan, Green Building Improvement Case Collection)

There are various types of buildings in Chinese colleges and universities. Diverse types of buildings, as well as different design standards and construction technologies, create large differences in the Green performance of different buildings. This study takes the most representative teaching buildings, libraries, and dormitory buildings in universities as the research object. The climate of the study area is that of northern China, where the overall layout of buildings is more compact and enclosed due to the influence of climate and the energy consumption of buildings needs to consider the comprehensive effect of thermal insulation in summer and winter. By using the process given by the Green BIM decision cycle and taking the *Evaluation Standard for Green Building* (GB/T 50378-2019) as the evaluation benchmark values and project objectives (as shown in Tab. 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.

Tab. 1 Evaluation System and Scores of the <Evaluation Standard for Green Building (GB/T 50378-2019)>

Evaluation Item	Safety and Durability	Health and Comfort	Living Convenience	Resource Conservation	Environmental Liveability	Improvement and Innovation
1	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	100	100	100	200	100	100

2.2 Analysis of the Green performance of different types of buildings in Chinese colleges and universities

The modelling software used in this research is Autodesk Revit (version 2018), which is used to establish the BIM model of a teaching building, a library and a dormitory building. This program exports “.rvt” (Revit) format files as “.3ds” (3-Dimension Studio), “.gbxML” (Green Building Extensible Mark-up Language) and “.dxf” (Drawing Exchange Format) files. In the process of simulation analysis, a “.3ds” format file is imported into Phoenics (Parabolic Hyperbolic or Elliptic Numerical Integration Code Series) for wind environment simulation analysis. The “. gbxML” file is imported for Ecotect (Autodesk Ecotect Analysis) to perform local or indoor environment simulation analysis, such as thermal analysis, resource consumption analysis, daylighting and building shading analysis. The “.dxf” format file model has a high precision and contains a large amount of information, which is mainly used for global analysis, such as lighting intensity analysis, shadow shading and environmental impact analysis.

Xi'an City, Shaanxi Province, is selected as the simulation site and belongs to the cold area of the building climate division. The simulation models are in accordance with the actual construction conditions. The specific methods are as follows:

(1) The wind environment of the teaching building was tested in summer of June in 2019, and the relevant parameters were tested for 48 hours.

(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 related parameters of the building thermal comfort environment were tested for 48 hours.

(3) According to the construction method of the specific building, the model is adjusted through comparison with the measured temperature and humidity parameters to make it conform to the actual working conditions of the building.

(4) The research model was developed and prepared for the analysis.

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

2.2.1 Ventilation design of teaching buildings for the objective of health and comfort

The health and comfort in the *Evaluation 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. For teaching buildings, as the ones most frequently used by students in colleges and universities, natural ventilation will have an impact on the indoor air quality and thermal and humid environment, on the thermal comfort of students during use, and on the ultimate energy-saving goal. Hence, natural ventilation is selected herein to study the Green performance of teaching buildings.

(1) Typical forms and ventilation simulation of teaching buildings

Most of the teaching buildings in northern areas are arranged in a north-south orientation. Although some teaching buildings are arranged in an east-west orientation, their space for teaching is still in the north-south orientation, and the east-west-facing space is generally arranged as offices and laboratories [10]. The plan-view layout of teaching buildings was dominated by the form of an internal corridor in the early and middle stages, whereas that of newly built university teaching buildings is mainly in the form of an internal corridor and an external corridor encircling an internal courtyard [11]. The teaching buildings mostly had 3 to 4 floors in the early stage, whereas those in the middle stage and newly built buildings mainly have 4 to 6 floors, and 5-floor buildings are the most common (as shown in Fig. 3).

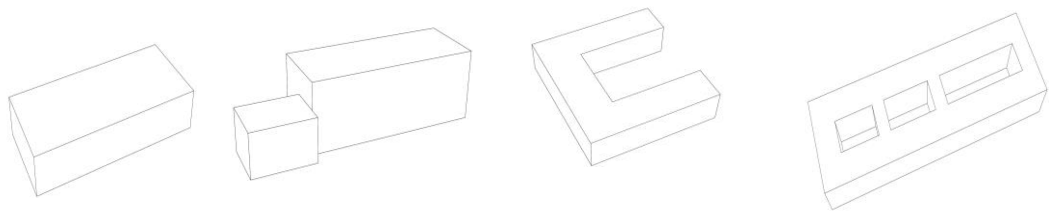
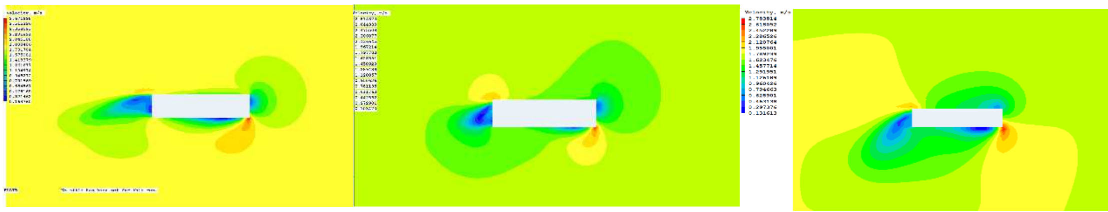


Fig. 3 Typical Forms of Teaching Buildings in Northern Areas (Source: Self-drawn)

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.

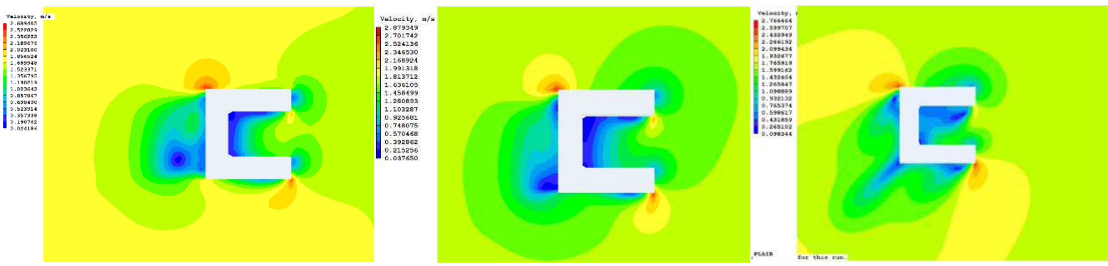
From the perspective of the plan-view layout of a single building, in the case of a 15° angle of a single belt-type building, the wind shadow is relatively small on the leeward side of the building, the area of flow around the building is not large but the wind speed is high, and the angle between the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



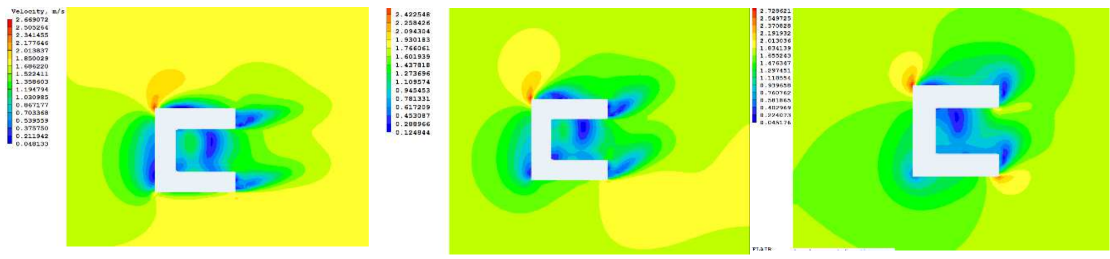
Northeast 15° Northeast 30° Northeast 45°

Fig. 4 Ventilation Simulation Analysis Graphics of Rectangular Teaching Buildings in Different Orientations (Source: Self-drawn)

When the courtyard opening of a single building of the semi-enclosed typefaces the north easterly wind at an angle of 15°, the wind speed is relatively high in most of the courtyard and lower at the corners, the vortex area is relatively small, and the vortex area of the wake flow is comparatively large. At an angle of 30°, the vortex area at the corners is larger than that at the angle of 15°, and the vortex area of the wake flow is smaller. At an angle of 45°, there is an increase in the wind speed at the corners inside the courtyard, but the total low-wind-speed area is the largest, and 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. The wind shadow of the wake flow of the building is the largest at 45°. With two wind conditions taken into consideration, the appropriate orientation for this type of single building is 30° -- 45° (as shown in Fig. 5).



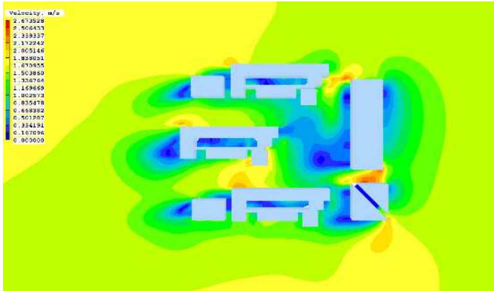
Northeast 15° Northeast 30° Northeast 45°



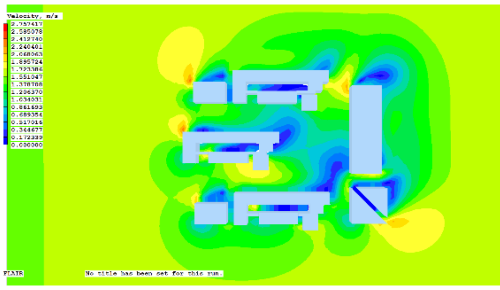
Southwest 15°	Southwest 30°	Southwest 45°

Fig. 5 Ventilation Simulation Analysis Graphics of Semi-enclosed Teaching Buildings in Different Orientations (Source: Self-drawn)

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 so that each single building can obtain relatively good outdoor wind. This type of layout can also keep out cold winds to a certain extent in winter. 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).



Wind Speed Nephogram of Teaching Buildings of the Cluster Type (North easterly Wind)

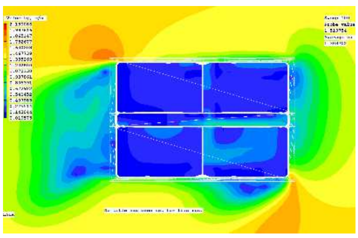


Wind Speed Nephogram of Teaching Buildings of the Cluster Type (South westerly Wind)

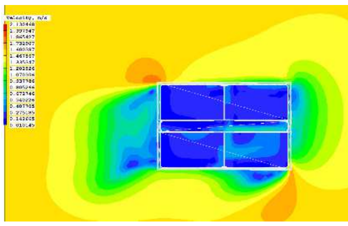
Fig. 6 Ventilation Simulation Analysis Graphics of Teaching Buildings of the Cluster Type (Source: Self-drawn)

(2) Internal ventilation simulation of teaching buildings in northern areas

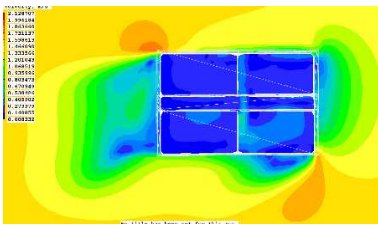
Teaching buildings in northern areas mostly adopt the plan-view layout of the internal corridor. With respect to such teaching buildings, the study sets the corridor width as 2.1 m, 2.4 m, 2.7 m, 3 m, 3.3 m, and 3.6 m for the CFD simulation experiment; the plan-view dimensions of classrooms on both sides of the corridor are 7,800 mm × 14,500 mm. Additionally, there are 8 evenly distributed 1,400 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 1,400 mm × 1,700 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.



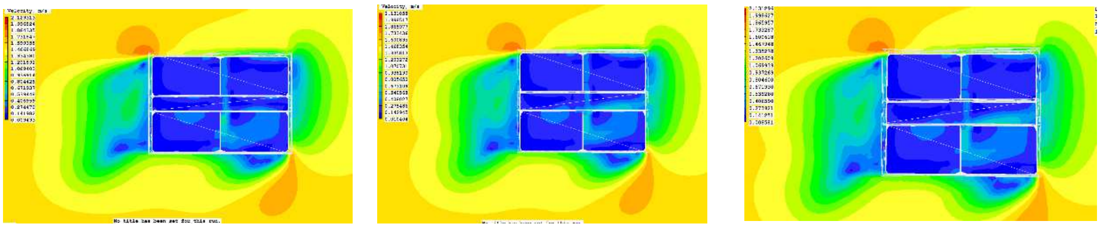
Corridor Width 2.1 m



Corridor Width 2.4 m



Corridor Width 2.7 m



Corridor Width 3 m	Corridor Width 3.3 m	Corridor Width 3.6 m

Fig. 7 Ventilation Simulation Analysis Graphics of Teaching Buildings with Different Internal Corridor Widths (Source: Self-drawn)

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. Along with the increase in corridor width, the function of the corridor as a horizontal wind corridor is weakened, and the cross ventilation effect inside the building is enhanced. Since a corridor wider than 3 m will increase the overall depth of the building, the economic benefits of the building will be reduced to obtain a better cross ventilation effect; therefore, it is advisable to choose a smaller corridor width in the layout with a relatively long corridor and use a horizontal wind corridor to control indoor natural ventilation.

2.2.2 Energy-saving design of library buildings for the objective of resource conservation

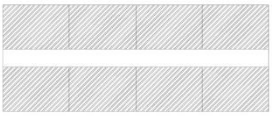
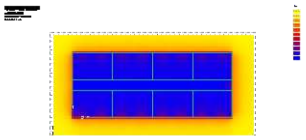
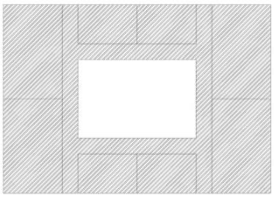
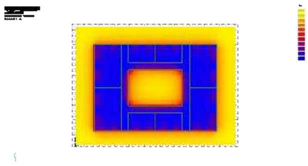
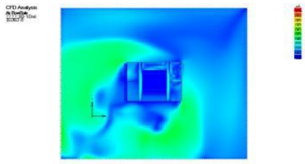
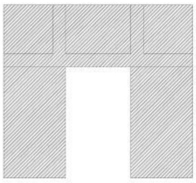
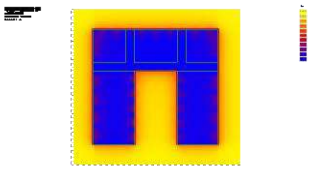
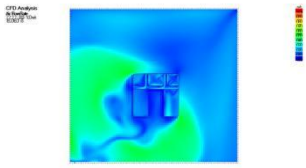
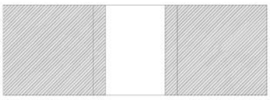
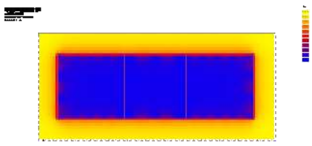
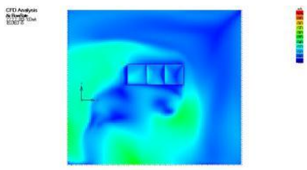
The resource conservation in the *Evaluation Standard for Green Building* (GB/T 50378-2019) covers four indicators, i.e., land saving and utilization, energy saving and utilization, water saving and utilization, and material saving and Green building materials. The libraries of colleges and universities generally have a large volume and many energy use points, 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

The major functions of university library buildings are book collection, borrowing, self-study, and auxiliary offices. In terms of their functional nature, modern university library buildings mainly feature functional layouts integrating collection, borrowing, 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 [12]. The daylighting and ventilation simulations of these basic layout forms are analysed and compared with Ecotect, and the results are shown in Tab. 2.

Tab. 2 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**)**

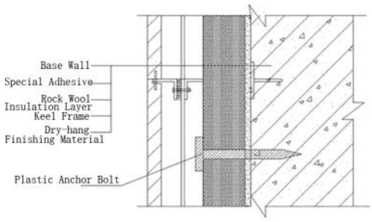
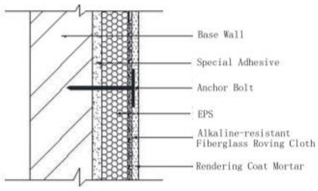
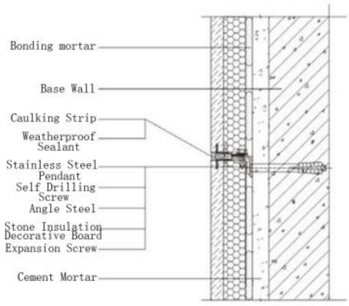
Layout Form	Diagram	Daylighting Analysis	Wind Field Analysis
Symmetrical distribution			
Hollow square-shaped single corridor			
U-shaped distribution			
Belt-shaped distribution			

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 form utilization rate is high, and the indoor and outdoor wind pressure ventilation effect is good, but the volume coefficient of the building 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 [13].

(2) Outer-building 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 [14]. The service time of university library buildings is usually from 09:00 a.m. to 22:00 p.m. In the design of the outer envelope wall of library building, the better the thermal insulation performance of the exterior wall is, the less heat transmitted indoors and outdoors through the envelope will be, and the less the operating load of the indoor full air-conditioning mechanical equipment will be. 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 [15]. The internal thermal insulation technology of the exterior wall has a lower insulation efficiency than the external thermal insulation, and 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 [16]. 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 [17]. According to the actual requirements of public construction projects, the selection of external insulation materials and the construction practices of exterior walls can be adjusted in line with the exterior wall's system type, construction technology level, climatic environment, and fireproof performance requirements, as shown in Tab. 3.

Tab. 3 Characteristics of Exterior Wall's System Types and Selection of Thermal Insulation Materials (Source: Self-drawn by the Author)

System Type of Exterior Wall		Characteristics	Material Selection
Curtain wall dry-hanging system		There are many embedded components, so materials with high strength and high ductile deformation should be selected; A ventilation layer can be set to take away the heat in air layer by air flow and reduce the impact of solar radiation; The fireproof performance is somewhat poor.	Rock wool, mineral wool, ceramic insulating plate, foamed concrete slab
Thin-plaster finish system		Has good waterproof performance and wind pressure-resistant performance and solves the problems of wall cracking and seepage; Meets the requirements of energy-saving design standard in cold and severe cold regions.	Polystyrene foam plastic board, inorganic light-aggregate insulating mortar
Insulation-decoration integrated board system		The insulating and decorative system is extended to the wall surface and has an outstanding thermal insulation effect and little heat bridge effect; Prevents deformation resulting from the negative pressure generated by the exchange between high and low temperature of internal accumulated water; The board has a light weight, high strength, and relatively long service life.	Fluorocarbon metallic paint finish, PU metallic paint finish, faux stone or faux granite finish

A glass curtain wall is a common facade form and window opening form of modern public buildings and is usually used as the outer-building 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, plan-view deformation, 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) [18], as shown in Tab. 4.

Tab. 4 Energy-saving Designs, Characteristics, and Application Scopes of Wall Glass Types (Source: Self-drawn by the Author)

Type	Practice	Characteristics	Application Scope
Low-E glass	Solar-radiant Low-E film-coated glass	It changes the thermal emissivity of glass by changing the physical and optical properties of building glass, thereby realizing the selective shielding of solar radiation energy, preventing glare from entering the room, and meeting the demand for energy conservation and consumption reduction.	It is used at high northern latitudes for glare control and thermal insulation and heating by exploiting solar radiation.
Hollow glass	Vacuum thermal-insulating glass Light-transmitting Low-E + air + transparent glass Light-transmitting Low-E + argon + transparent glass	Two (or three) sheets of glass are bound with a kind of composite binder having high strength and airtightness to reduce the heat transfer coefficient of glass and lighten the mechanical load of indoor air conditioning. High-performance hollow glass can 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	Solar glass has a high requirement for production technology; it can achieve the absorption of solar energy, thereby improving the effect of energy conservation and environmental protection 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; an air layer is added between the curtain walls, where the air is always in a flowing state 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.

(3) System design

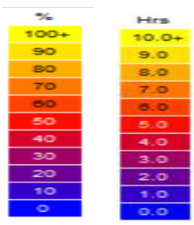
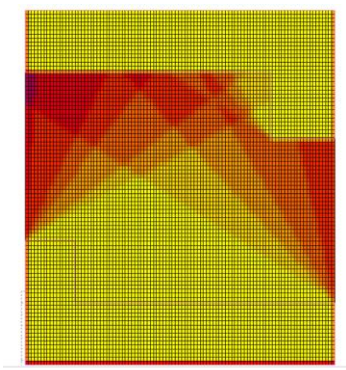
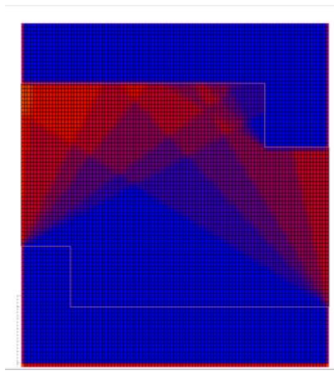
The air-conditioning and ventilation system of university library buildings generally has the problems of poor design effect, old unit, and low energy efficiency; the major problem of heating system is the unsound regulation mechanism, which is unable to regulate the system dynamically according to meteorological conditions and energy use rules, thus causing excess heat supply in some periods of time and wasting energy. In regard to metering, zone metering is commonly not available, so it is impossible to compare and analyse various energy use areas of buildings and difficult to identify the weak points of energy use.

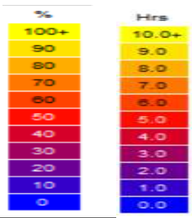
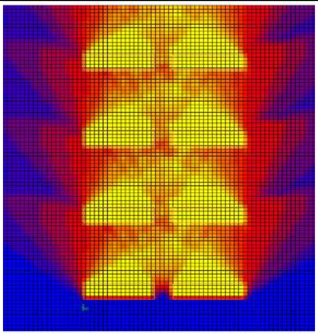
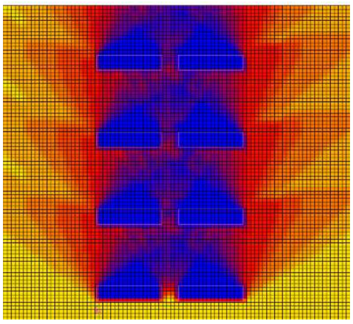
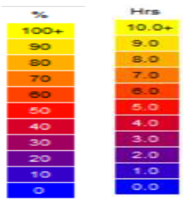
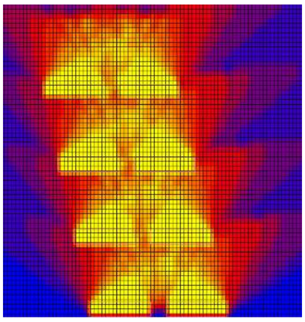
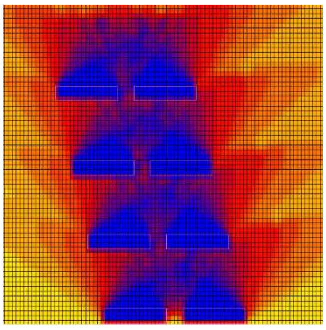
For the energy-saving design of library buildings with complex volumes and functions, it is difficult to achieve the main purpose of controlling building energy consumption and improving indoor space comfort by relying only upon passive energy-saving technologies, and the energy-saving control engineering of building equipment is also an important link in the energy-saving design.

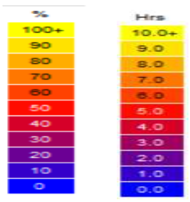
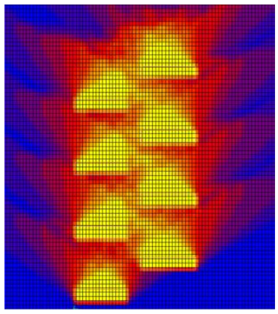
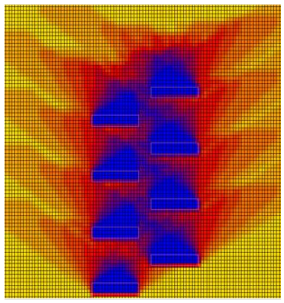
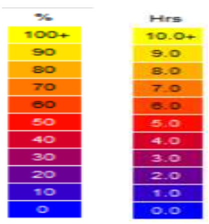
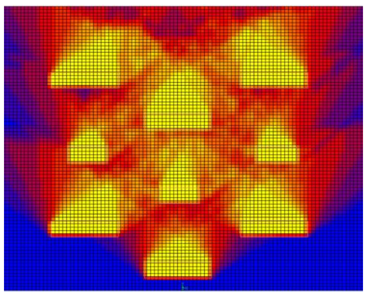
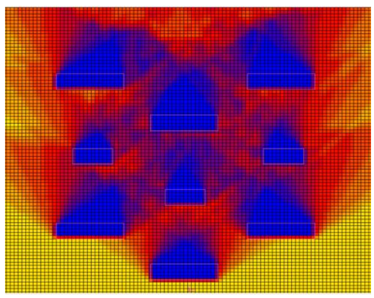
2.2.3 Planning and layout of dormitory buildings for the objective of environmental liveability

The environmental liveability in the *Evaluation Standard for Green Building* (GB/T 50378-2019) mainly includes two indicators, namely, the ecology and landscape and the outdoor physical environment. Dormitory buildings in Chinese colleges and universities generally form an architectural complex [19]. For buildings in northern areas, good sunshine 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 of table 5 coincides with one of a paper published by the author [13], but with the addition of diagonal layout and optimized integrated layout of long and short staged, the overall layout types are more diverse, which can fully explain which layout form is more suitable for the objective of environmental liveability.

Tab. 5 Ecotect Simulation Analysis of Typical Layout Designs of Dormitory Buildings (Source: Self-drawn by the Author)

Layout Form	**Courtyard layout**	
Blocking Percentage 		

Analysis	In the enclosed layout, the impact of building blocking is great, and the sunshine condition is also the worst of all; the sunshine 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**
Blocking 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 sunshine duration of 4 -- 3 hours on the lower floors, and 10% of them have a sunshine duration of 1 -- 2 hours, which does not meet the sunshine requirement.
Evaluation	Moderate
Layout Form	Diagonal layout
Blocking Percentage 	 
Analysis	The N-S blocking of buildings is 40% -- 50%, and the E-W blocking is 90% -- 70%. The sunshine condition is moderate, and the diagonal layout does not solve the effect of E-W blocking.
Evaluation	Moderate
Layout Form	Staggered layout

Blocking 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 sunshine duration of 4 -- 5 hours on the lower floors. Most buildings have a sunshine duration of 5 -- 7 hours. Different from the sunshine condition of row layout, there are few 1--2 hour sunshine 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
Blocking Percentage 	 
Evaluation	Good

It can be seen from Tab. 5 that:

(1) Dormitory buildings should be arranged at a reasonable sunshine spacing between buildings. As an extensively used form in northern areas, row layouts have better sunshine conditions than courtyard layouts.

(2) To satisfy the basic sunshine requirement, the staggered layout is less blocked than the row layout at a reasonable sunshine 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 sunshine conditions; therefore, the two should be combined to arrange long-corridor dormitory buildings on the northern side and short-corridor buildings on the southern side to reduce

blocking.

3. Results --Green BIM-based Optimized Design of Green performance of a University Library in Northern China

Taking a university library in North China as an example, this study uses BIM software to establish the basic model, according to 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 performance, which is described as follows:

(1) Optimization of the base 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 year-round natural daylighting demand of the lower-floor south-facing rooms of the building affected by the shade of trees is improved by tree transplantation. The inadequate sun-shading condition in summer is improved by the planting of deciduous trees more than 20 m away from the building on the southern side (as shown in Fig. 8).

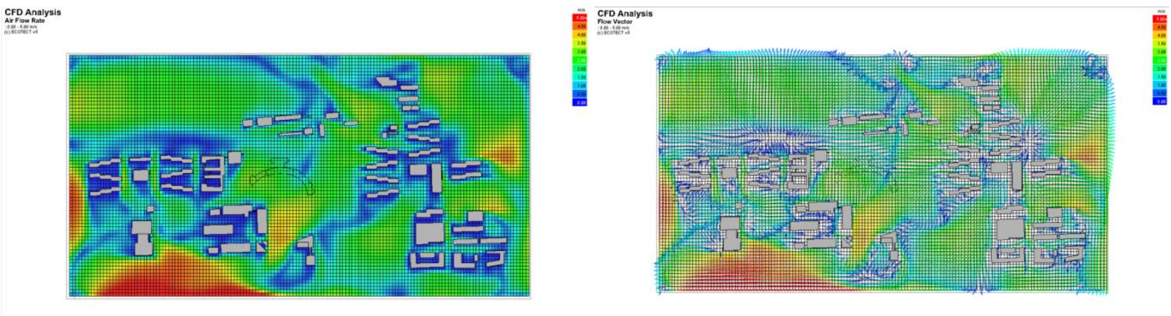


Fig. 8 Schematic Diagram of the Wind Environment and Flow Field of the Architectural Complex at the Base of a Library (Source: Self-drawn)

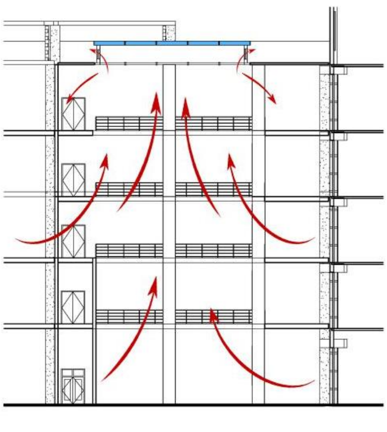


Fig. 9 Schematic Diagram of Thermal Pressure Ventilation in the Atrium (Source: Self-drawn)

Fig. 10 Accordion Lighting Roof of the Atrium (Source: Self-drawn)

(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, and pipes are set outdoors to collect natural light so that sunlight can be scattered by the light guide plate to supplement indoor natural lighting and reduce the power consumption by indoor artificial lighting. High windows are added in the partition walls on both sides of corridor, and the high windows and the window sashes in the exterior facade are opened at specific time to meet the requirement for normal natural ventilation inside and outside the building. The lighting roof of the atrium is transformed into an accordion structure, with raised inclined planes facing the east and the west for lighting to fully absorb incident light from different directions. An electric sun-shading curtain is installed indoors to timely block the sunlight from the west, obtain relatively soft diffused light, and ensure comfort in the atrium space (as shown in Fig 9, Fig 10).

(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, so the transformation of the internal thermal insulation of the exterior wall is adopted. In this project, in consideration of the economic efficiency, aesthetics, and feasibility of energy-saving design, 50-thick PU hard foamed plastic is used as the insulating material to replace the 20-thick rare-earth thermal insulation material for the composite wall, and the average heat transfer 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 the heat generated by solar radiation can be discharged to the outside by means of natural ventilation instead of mechanical equipment, thus reducing the energy consumption of mechanical equipment inside the building. 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 updated and adjusted according to the modified content, and the energy consumption simulation analysis of Ecotect air conditioning, heating and ventilation energy consumption is carried out again after the transformation design. The total annual cumulative energy consumption load of the scheme after transformation has decreased, the annual heat load has decreased by 59.1%, and the total annual cooling load has decreased by

21.5%. After calculation, the total annual accumulated load decreased by approximately 47.4% after the transformation. The results are shown in Figure 11.

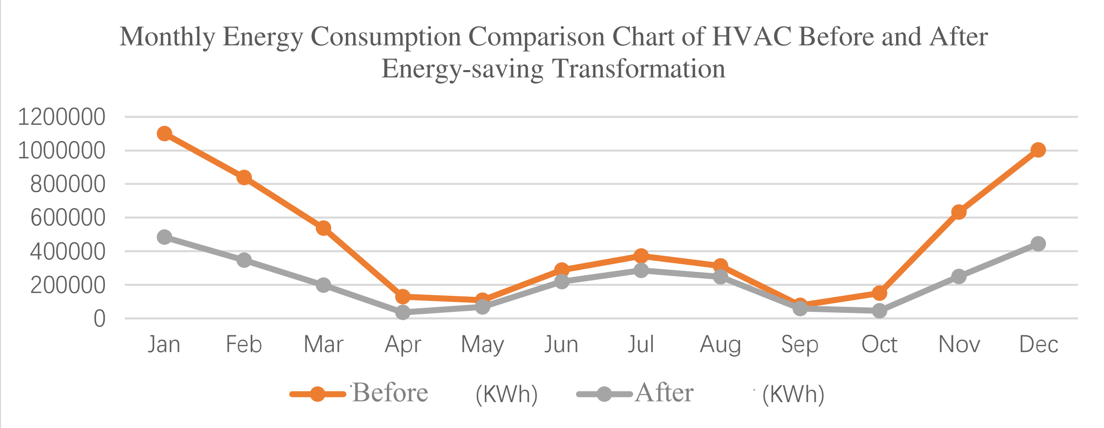


Fig. 11 Monthly Energy Consumption Comparison Chart of HVAC Before and After Energy-saving Transformation (Source: Self-drawn)

(4) Management measures based on improvement and innovation: An automatic control device is added indoors to realize the automatic control of room temperature at different personnel densities and to avoid overcooling indoors; meanwhile, the air-conditioning system is timely replaced and cleaned to improve energy use. A university-level energy management platform and single-building metering devices are added to boost energy conservation at management and awareness levels.

4. Conclusion and Discussion

China started the work of improving energy conservation and the formulation of relevant standards and regulations in the 1980s. It has been more than 40 years since then, but it is still commonly considered that energy-saving buildings do not save energy [20]. With the gradual advancement of design ideas, methods, and technologies of Green buildings, Green performance has been put on the agenda. The energy-saving design based on the Green performance of buildings places stress on the safety and durability, health and comfort, living convenience, resource conservation, and environmental liveability of buildings, which complies with the people-oriented ecological and Green development philosophy.

(1) There are diverse types of university buildings whose planning and layout are subject to the overall planning of campus, and the light, wind, temperature, and humidity of the built environment will all have an impact on individual buildings. The reasonable layout of various types of university buildings on campuses can reduce traffic energy consumption and raise the energy use efficiency of various functional facilities. The selection of building orientation is an important link in passive

energy-saving design. The best orientation can be selected through simulation analysis of solar radiation, the trajectory of the sun, current daylighting illumination, and the wind environment of the base.

(2) 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 greatest extent and reduce energy consumption. China's Green buildings with conservation at the core especially emphasize the importance of natural ventilation and lighting for energy conservation [21], and the spatial layout design of buildings will influence natural ventilation and lighting, which is one of the key issues of energy conservation.

(3) The design of thermal insulation and heat storage performance of the outer-building envelope is an important link in the passive energy-saving design of architectural details, so reasonable improvement of the thermal performance of the outer-building envelope can decrease the energy consumption of cooling in summer and heating in winter, avoid the heat bridge effect, reduce the impact of the outdoor climate on the inner environment of the building during the service time, and achieve the goal of an energy-saving building design.

(4) For large buildings in colleges and universities, such as libraries and sports/event venues, it is difficult to achieve the goal of controlling building energy consumption and improving indoor space comfort by relying only upon passive energy-saving technologies. For this reason, the energy conservation of the water supply and drainage system and HVAC system is particularly important. To date, the energy management platforms of more than 40 colleges and universities in China have passed the review of the Ministry of Housing and Urban-rural Development [22]. Such platforms are helpful for discovering weak links in energy use, effectively preventing unreasonable utilization of energy, and enhancing the energy-saving awareness of personnel to some extent.

Abbreviation

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
Fig. Figure
Tab. Table

Ethics approval and consent to participate

Not applicable

Consent for publication

All the authors agree to publish the article.

Availability of data and materials

All data and materials can be obtained free from the author, and the authenticity of the data is guaranteed.

Competing interests

The authors declare that they have no competing interests.

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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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Figures

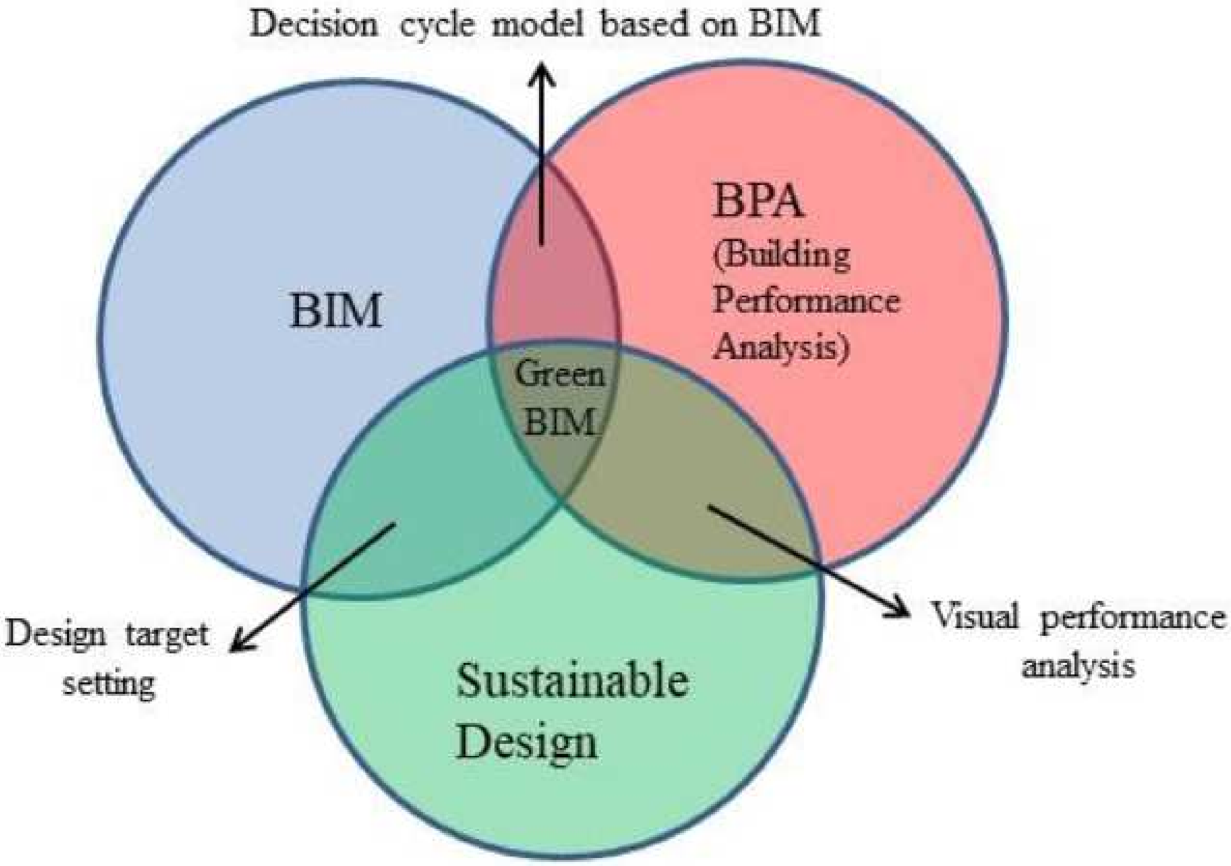


Figure 1

Green BIM Architecture (Source: Eddy Krygiel, Brad Nies, Green BIM: Successful Sustainable Design with Building Information Modelling)

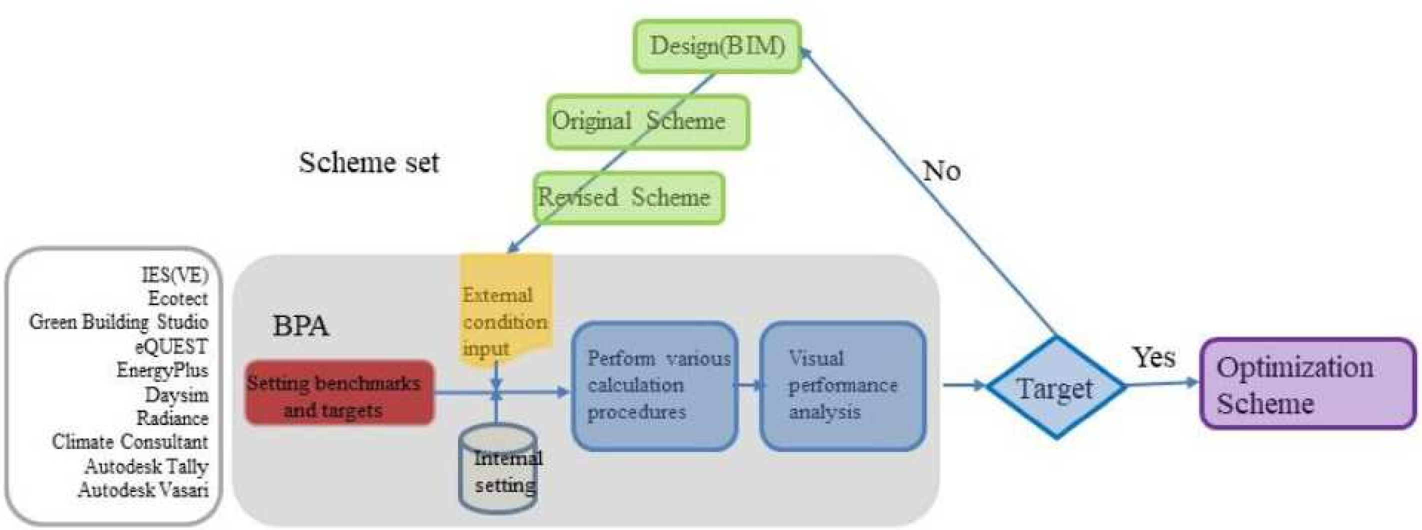


Figure 2

Green BIM Decision Cycle Model (Source: Institute of architecture, Ministry of the interior of Taiwan, Green Building Improvement Case Collection)

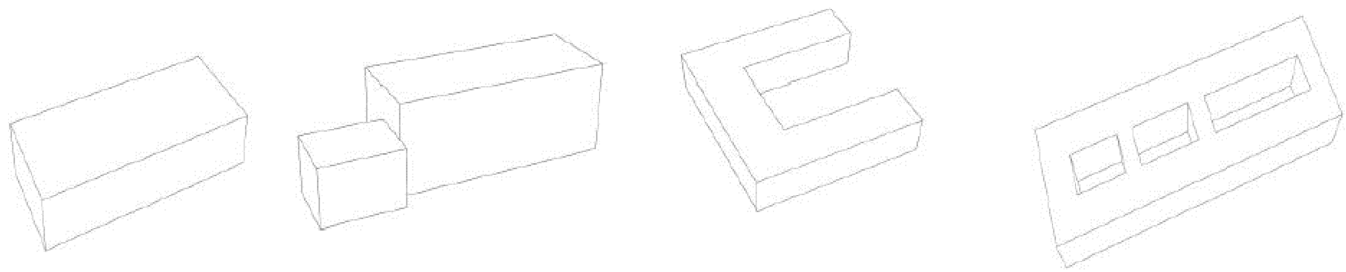


Figure 3

Typical Forms of Teaching Buildings in Northern Areas (Source: Self-drawn)

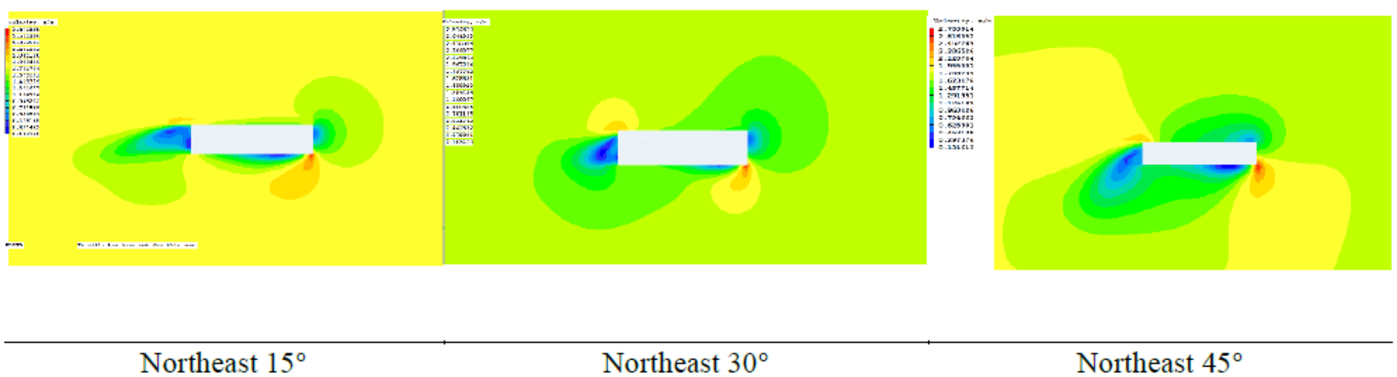
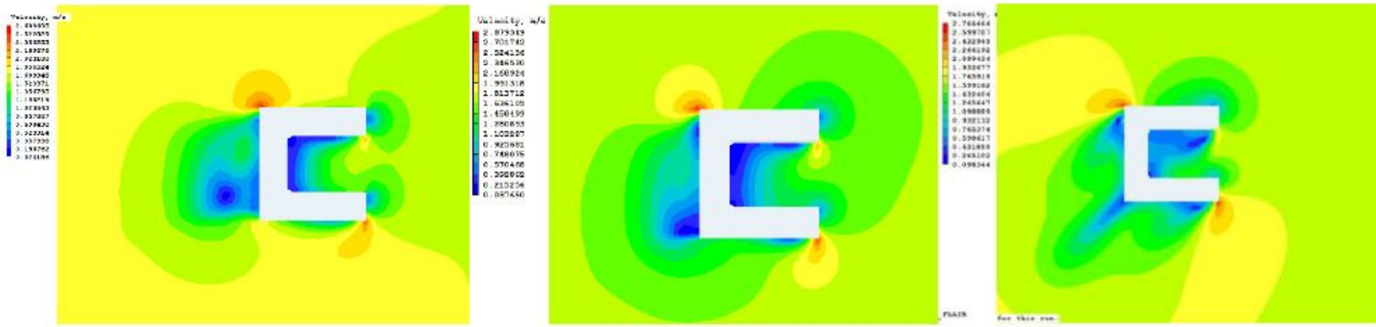
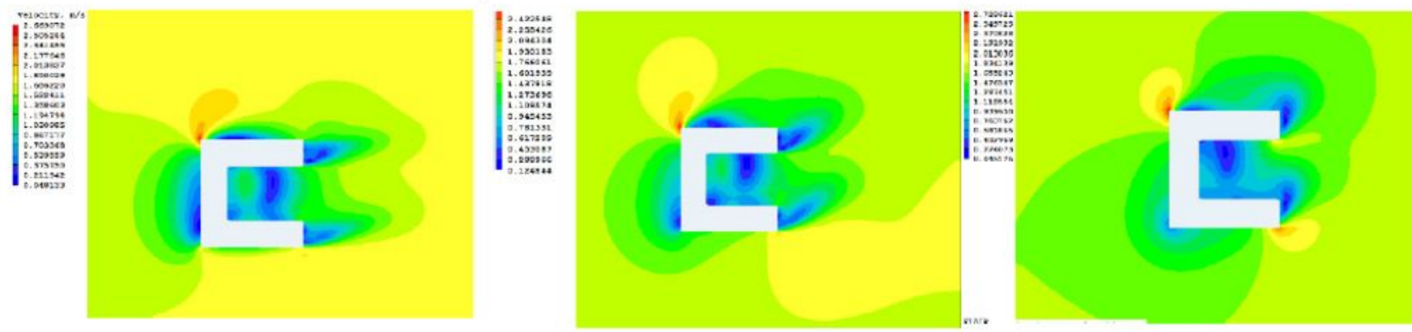


Figure 4

Ventilation Simulation Analysis Graphics of Rectangular Teaching Buildings in Different Orientations (Source: Self-drawn)



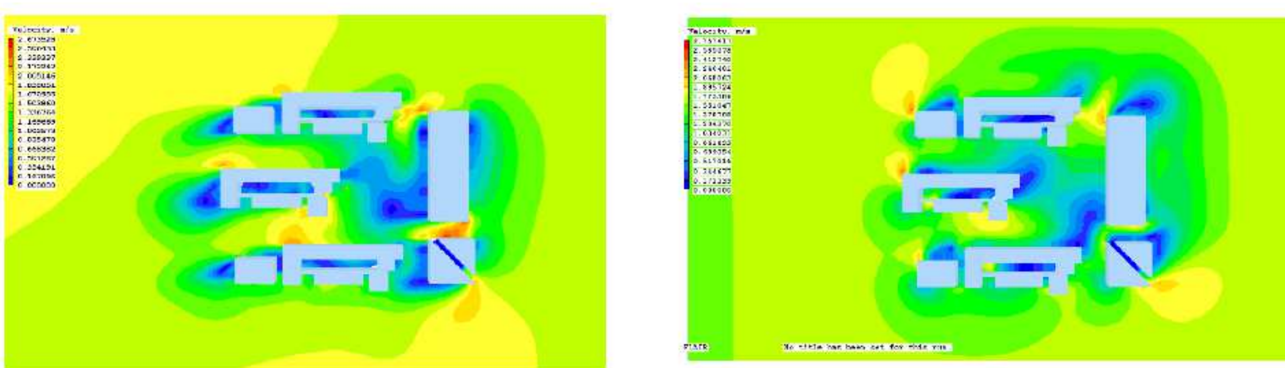
Northeast 15°	Northeast 30°	Northeast 45°



Southwest 15°	Southwest 30°	Southwest 45°

Figure 5

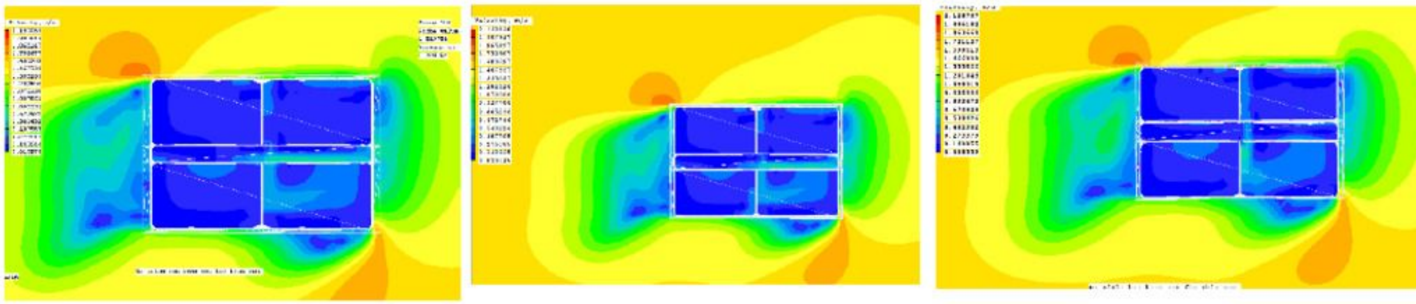
Ventilation Simulation Analysis Graphics of Semi-enclosed Teaching Buildings in Different Orientations (Source: Self-drawn)



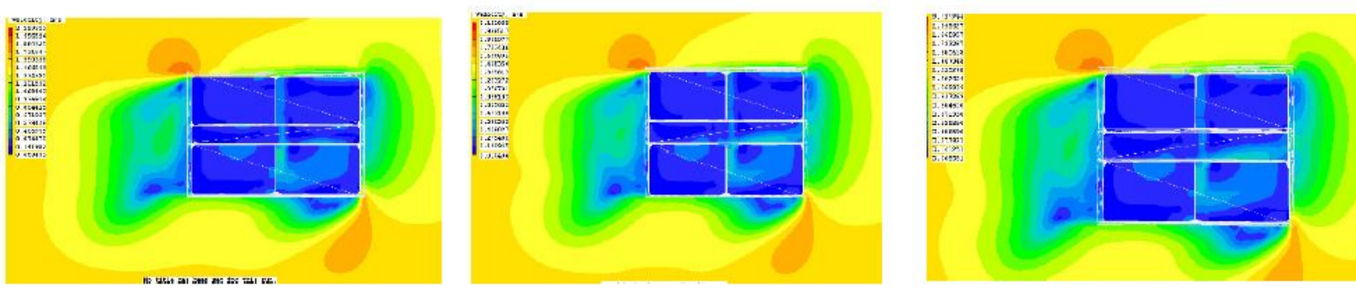
Wind Speed Nephogram of Teaching Buildings of the Cluster Type (North easterly Wind)	Wind Speed Nephogram of Teaching Buildings of the Cluster Type (South westerly Wind)

Figure 6

Ventilation Simulation Analysis Graphics of Teaching Buildings of the Cluster Type (Source: Self-drawn)



Corridor Width 2.1 m	Corridor Width 2.4 m	Corridor Width 2.7 m



Corridor Width 3 m	Corridor Width 3.3 m	Corridor Width 3.6 m

Figure 7

Ventilation Simulation Analysis Graphics of Teaching Buildings with Different Internal Corridor Widths (Source: Self-drawn)

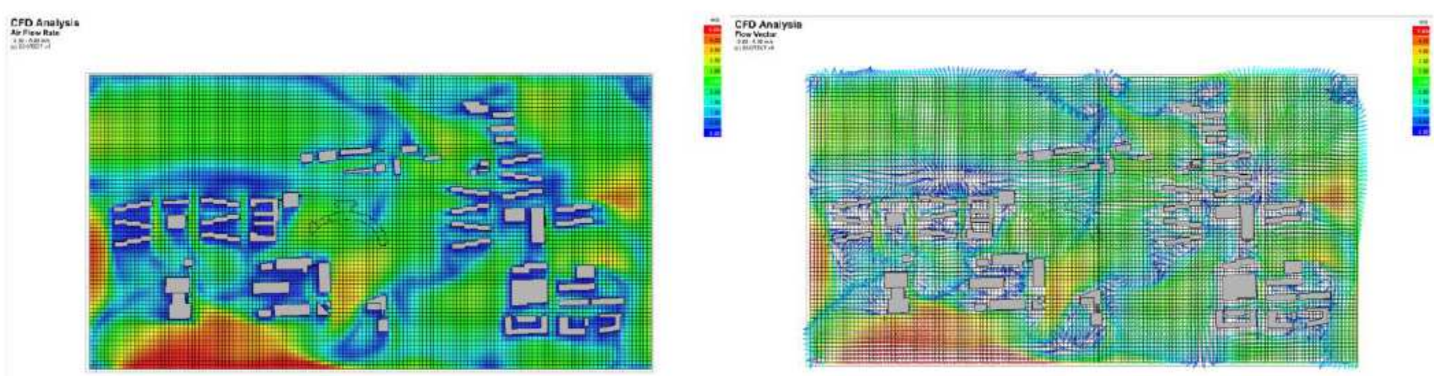


Figure 8

Schematic Diagram of the Wind Environment and Flow Field of the Architectural Complex at the Base of a Library (Source: Self-drawn)

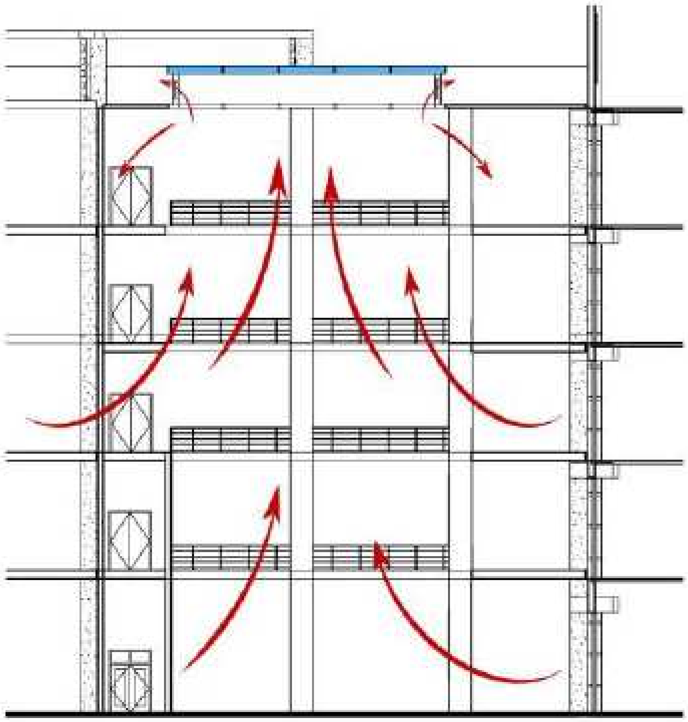


Figure 9

Schematic Diagram of Thermal Pressure Ventilation in the Atrium (Source: Self-drawn)

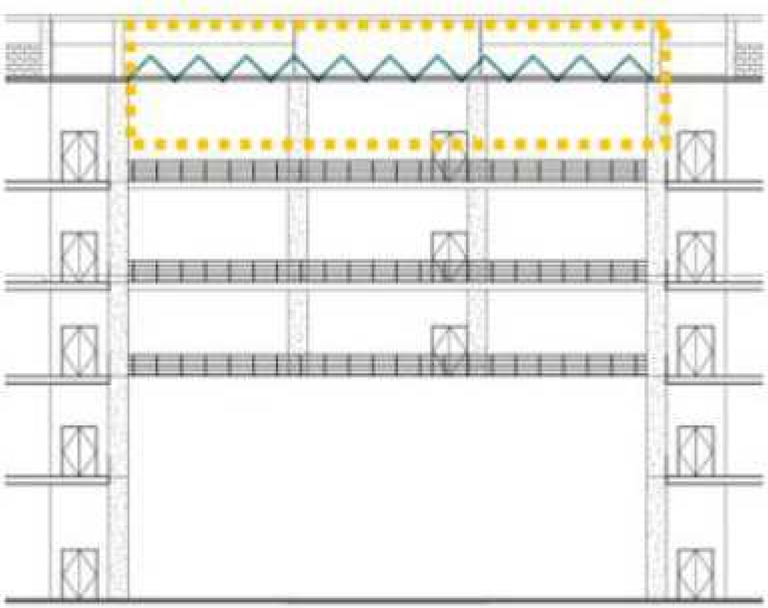


Figure 10

Accordion Lighting Roof of the Atrium (Source: Self-drawn)

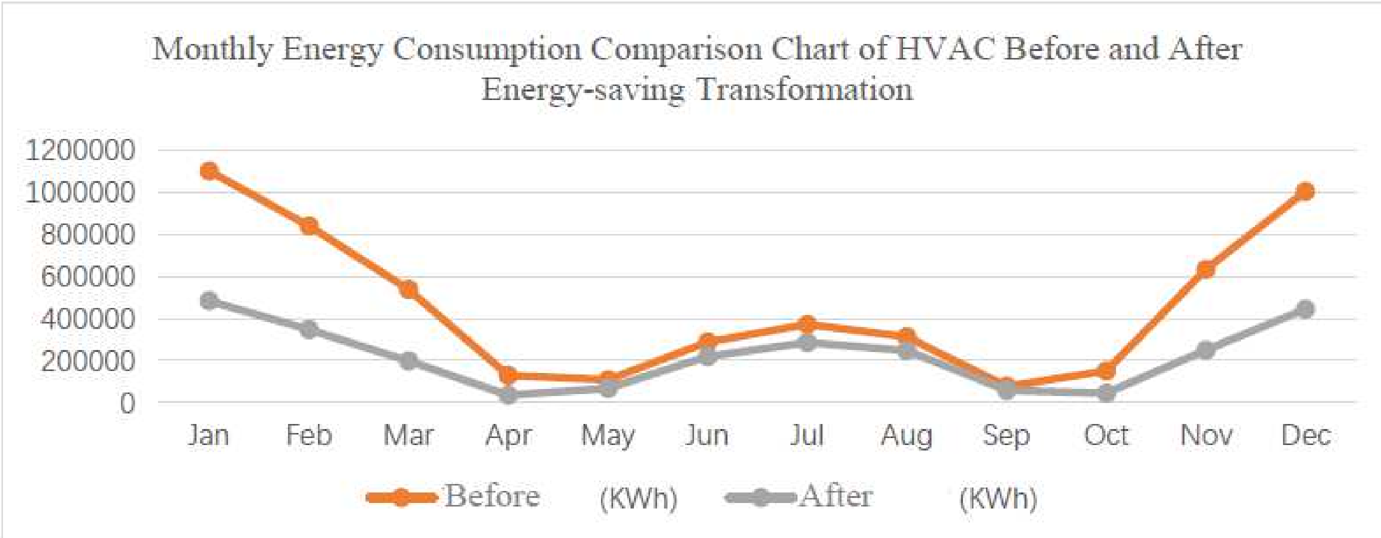


Figure 11

Monthly Energy Consumption Comparison Chart of HVAC Before and After Energy-saving Transformation (Source: Self-drawn)