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STUDY ON THE MICROENVIRONMENT EVALUATION OF THE ARCHITECTURAL LAYOUT BASED ON BUILDING INFORMATION MODELING: A CASE STUDY OF CHONGQING, CHINA

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ABSTRACT

With the development of urbanization, China's cities meet the restriction of resource and environment. UNEP releases the report 'Towards a green economy', which mentioned Green City is the direction in city's development. From the perspective of full development of the city, using Building Information Modeling for urban planning and urban management can make city ecological and humane, also breaking the situation that urban planning studies are uncorrelated with the ecological studies. Based on these theories, the paper takes the practice of urban renewal in Chongqing as an example. The two simulated models of different layouts are evaluated and analyzed, and then the comparison of evaluation results such as the index of sunshine, ventilation and energy consumption is obtained. The paper proposes some suggestions on the advancement of planning scheme and exerts practical significance on the relevant index quantification for urban planning and management, which is valuable and practical during the fast urbanization period of China.
Keywords: BIM model, Chongqing, ecological, urban planning.

1 INTRODUCTION

Joseph E. Stiglitz, the Nobel Economics Prize winner, had predicted the two things that had great impact on the world in the 21st century: the US high-tech industry and the China urbanization. In recent years, China is in the massive urbanization with large-scale demolition and reconstruction, which generates the huge amount of energy consumption and carbon emission. Nowadays, many cities have proposed the plans of developing Green City and many scholars have studied the know-how. Due to massive consumption and tremendous impact on environment, the construction industry should be taken seriously.

McHarg (1969) put forward in his book *Design With Nature* that human, architecture, nature and society should coordinately develop and proposed an effective way of ecological construction, which signified formal establishment of the theory of ecological architecture. In Hong Kong, urban renewal will be defined as the plan of environmental quality friendly redevelopment through the massive destruction and removal in the decay area. Cheung and Leung (2008) indicated that city's environment quality closely associated with urban renewal has significant impact on people's life. These researchers investigate seven renewal districts in Hong Kong, the results of the research show that after the renewal, the subjective expectation and psychological feeling of the residents on the environmental quality has had a positive impact on the quality of life. Yi Jiang and Borong Lin (2006) indicated that Human, Architecture and Nature coexist harmoniously, which is an important part of promoting strategy of sustainable development in 21st century [1]. Wen Hong (2000) reflected on the current massive and extensive construction of residential district and discussed several aspects from the renewal goals, renewal standard and environmental quality evaluation. Kun Wan (2004) proposed five planning concepts, including the concept of ecological priority, which emphasis the organic combination of ecological environment and natural landscape of planning area and the

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surrounding. Fuyu Lai (2008) pointed out that improving the living environment and realizing the intensive land use through urban renewal are important means to stimulate upgrading and vitality of city.

In recent years, aiming at achieving environmental-friendly and sustainable society, some scholars, experts, government officials and other international organizations have put forward a series of assessment tools in urban construction, such as the methods of environment impact assessment, strategic environmental assessment, life-cycle analysis, green bills and the tools of GIS (Geographical Information Systems)and BIM (Building Information Modeling). Joseph C. Lam and Danny H.W. Li (1998) proposed a simple quantitative method for estimating the likely energy savings in electric lighting due to day lighting and the possible cooling penalty [2]. S. Citherlet and J. Hand (2002) presented the developments, implementation of an extensive building representation that supports the holistic performance (energy consumption, lighting availability, occupant comfort, room acoustics and environmental impact) within a single application called ESP-r [3]. Zellner (2008) proposed the Urban Sustainability Assessment Framework of Energy (USAFE). Nyuk Hien Wong and Steve Kardinal Jusuf (2011) discussed the plan for advancement of urban design tool from the current situation to the future, in parallel with more mature design tools at the building level, such as the BIM. They proposed an integrated urban microclimate assessment method as the sustainable urban development and urban design tool [4]. Feng Yang and Stephen S.Y. Lau (2011) investigated the effect of urban design factors on summertime urban heat island (UHI) intensity and potential design strategies are proposed in an effort to mitigate UHI, including manipulating building layout and mass to improve shading during the day while facilitating site ventilation at night and increasing site vegetation cover through strategic tree planting [5]. Philipp Geyer and Martin Buchholz (2012) proposed a new approach of Parametric Systems Modeling (PSM) for building and city design that exploits the system engineering approach for architectural and urban planning, which overcome the limitations that CAD and some other tools fail to consider the overall system, including the physical and technological interdependencies among its components [6]. In the European commission sponsored research program SUCCESS, researches worked from the scale of the Chinese village to address the issues about sustainability, they used the software called sustainable Engine TM, which is seen as a powerful software system that integrates the capabilities of BIM, facility management and GIS software with a sort of system dynamics modeling software [7]. Philipp Geyer (2012) examined in his research the use of Systems Modeling Language (SysML) to model systems for sustainable building design and development method called PSM and addressed integrating systems modeling into the CAD/BIM-based design process to support a sustainable design [8].

But in many planning cases, these ecological plans and ideas are still on the surface, never are into practices. Urban planning is uncorrelated with the sustainable design [9], which brings some problems related to sunshine, ventilation and noise. Figure 1 shows that different stages in construction exert different influences on the architecture [10]. It can be seen that the early concept design cannot be ignored, because any slight errors at the early stage would be amplified in the after process and even influence the whole building function.

2 THE TARGET ORIENTATION AND EVALUATION METHOD OF THE LAYOUT DESIGN IN RESIDENTIAL AREAS

2.1 Target orientation

Green ecological building design and construction is one of the most important aspects in ecological city construction. Some Chinese scholars considered that the performance of green ecological

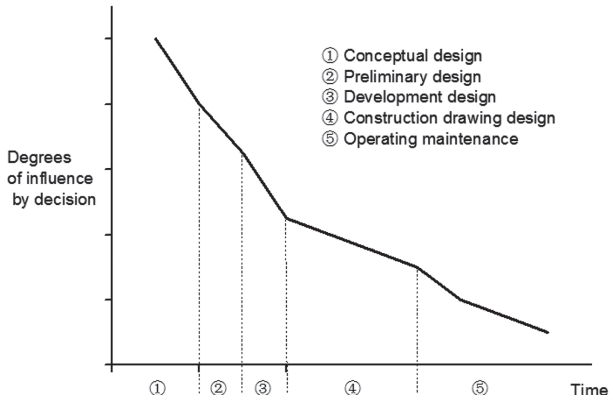


Figure 1: Degrees of influence at different construction stages.

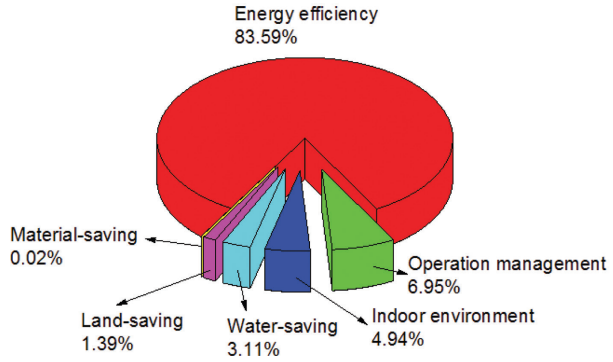


Figure 2: The statistics of incremental cost of green ecological building.

building should be reflected in the following six aspects: land-saving and outdoor environment, energy efficiency and energy utilization, water-saving and water resources utilization, material-saving and material resource utilization, indoor environment and operation management. Figure 2 shows the statistics of incremental cost of green ecological building. Among the six aspects above, energy efficiency has the fastest growth in incremental cost. In addition to the point minimization of the energy and resource consumption, construction pollution prevention is the core of the green ecological building [11], improving energy efficiency and indoor environment quality is the crucial target for sustainable design for ecological city construction.

On the basis of the nature geographical environmental conditions, the architectural design scheme is optimized and good natural ventilation and natural lighting can be obtained, which leads to the decrease of the architectural lighting and HVAC energy consumption. And natural ventilation and natural lighting are closely related with the envelope, density, spacing and layout of the buildings.

2.2 The influence mechanism of architectural layout on microenvironment in residential area

The architectural layout is the combination of a group of buildings in space, which comprises three types of spatial elements: a building entity itself, arrangement of the buildings and open space

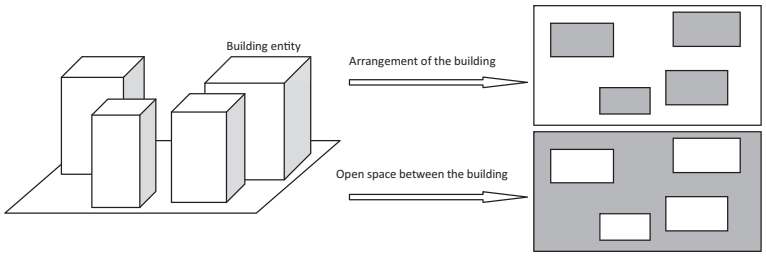


Figure 3: Three types of spatial elements.

between the buildings (Fig. 3) and is determined by considering the basic conditions, such as plan selection, orientation, spacing, green space ratio ,environment, different needs and other factors.

For building entity, different forms, quality and volume of the building will have a different impact on the aperture area, external wall insulation and wind pressure. For example, the shape of the building directly influences the direct light and radiant heat of the building surface, also the indoor thermal environment and energy consumption. The shape of the building would affect the amount of direct sunlight to building envelope and inside room. Sunlight contains a large number of infrared and visible lights, if there are plenty of sunlight into the room in winter, it will produce much heat energy which can warm up the indoor and has good drying effect. While too much sunlight into room in summer would cause indoor overheat and deteriorate the thermal environment. The larger the length widths of the building size, the more the building gain the heat [12].

For the arrangement of the building, the influence of architectural arrangement forms on microenvironment is the embodiment of 'building shade block' [13]. The heat gains caused by solar radiation is the main part of the building air-conditioning load so that it is necessary for sun-shading board designs to reduce the thermal radiation into the interior and achieve energy saving.

For the open space between the buildings, it affects the flow field of residential area [14], namely wind environment [15]. For example, in residential areas of cold areas, there is better liquidity between the open spaces of the buildings when summer south wind flows, which is conducive to heat dissipation of the buildings. While there is increasing wind speed between the open space when winter north wind flows, it will cause the adverse effect on heating in winter and increase energy consumption and waste [16].

From the influence mechanism above, it can be seen that architectural layout in residential area due to the different entities and different combination patterns will naturally affect the microenvironment of the corresponding space.

2.3 The evaluation system of architectural layout based on BIM

The traditional evaluation methods of planning and design evaluation system are not comprehensive, the reasons are: (1) it is difficult to make quantitative analysis to the building at the conceptual design stage; (2) the statistics of building energy consumption needs lots of work and is complex in algorithm. Nowadays, the combination of qualitative analysis and quantitative analysis is the tendency of the urban scientific research. Using quantization in urban construction is good for better scientific decision. When bringing BIM into the three-dimensional platform of planning (Fig. 4) and using the meteorological data and external environment data, the author can simulate the built environment indexes (sunlight, ventilation, energy consumption, etc.) result from different spatial layouts. The design, management and decision-making can be assisted by evaluating these indexes.

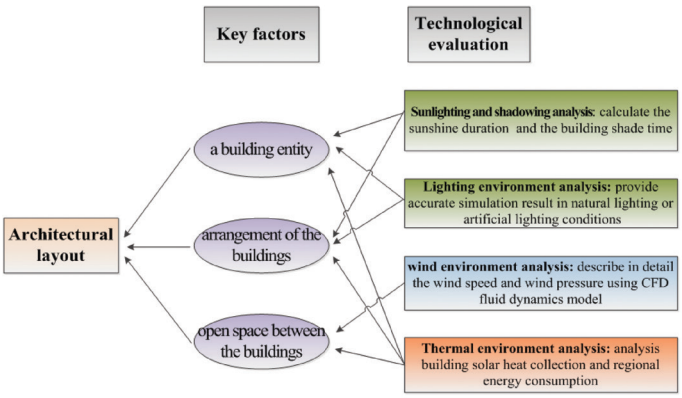


Figure 4: The evaluation system of architectural layout based on BIM.

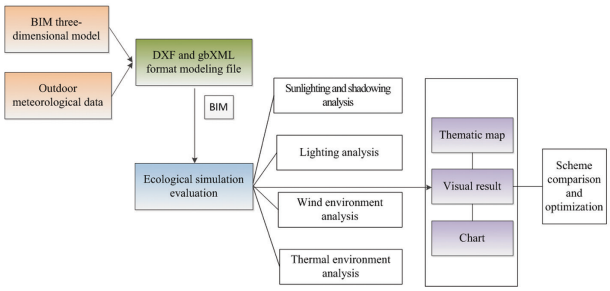


Figure 5: The flow chart of the architectural composition evaluation method based on BIM.

It makes up the one-sidedness of the traditional evaluation methods, takes overall consideration of dominant and potential influence and also makes it possible for planning decision makers to choose better scheme through simple and clear process by getting rid of the cockamamie computational formulas [17].

Combining the characteristics of the city, summarize the key factors influencing the architectural layout, and find these factors in architectural layout planning and design corresponding to the evaluation technologies of architectural layout design using BIM. It can be seen that the analysis can not only quantize the dominant influence result from the architectural layout but also the potential influence, such as the building energy consumption consumed in the operation stage in the thermal environment simulation.

On the basis of the above theory, the authors import external meteorological date to BIM, set-up different schemes of architectural layout, export the 3D model with the corresponding file format and then import these files to BIM for the analysis of thermal environment (energy consumption) and other simulation analysis [18]. Figure 5 shows the technical route of simulation analysis.

At the conceptual design stage, the designer can get timely feedback of the analysis and make appropriate decisions with effective efforts and correct direction, so as to avoid potential mistakes. The paper takes the practice of urban renewal in Chongqing as an example. The two simulated models of different layouts are evaluated and analyzed, which provide a reference for regional ecological planning and a selection of architecture layout in the design phase.

3 CASE STUDY

3.1 The overview of the study object

Qixinggang used to be one of the most densely populated areas in Yuzhong District in Chongqing. Recently, this district is underdeveloped because it cannot accommodate large commercial mass. The local government plans to make this area to be the CBD service area in Jiefangbei, with new high plot ratio service international apartments. This type of products is the best commercial/residential property for executive mobile office of the World's top Five Hundred Enterprises. This kind of building style attracts not only the native managers, but also the foreigners from Japan, Korean and the Westerners. Those people require higher qualities of both indoor and outdoor environmental amenity. High-class building environment requires not only deluxe hardware equipment, but also the environment-friendly and highly comfortable commercial and residential space.

The total building area is about 13,000 m^2. The planned plot ratio is 5.2. The total building areas of the two schemes are almost the same. The modes of business operation of these two are: business hotels, rental offices, comprehensive offices and leisure area.

Plan 1, the plan layout is distributed as the circumference fit (Fig. 6, left). The 1# building is at the northeast corner. The over ground part includes the double-deck podium building (9.0 m), and the 29-layer tower (90.0 m); the 2# building is at the west wing of the buildings. The over ground part includes the double-deck podium building (9.0 m), with the 17-layer tower (54.0 m) both built in the southwest and northwest directions; 3# building is at the south corner.

Plan 2, the plan layout is distributed as matrix (Fig. 6, right). The 1# building is at the northeast corner. The over ground part includes the 4-layer podium building (19.5 m); the 2# building is at the north corner, the over ground part includes the 5-layer podium building (24.0 m) and the 15-layer tower (54.0 m); the 3# building is at the west corner, the over ground part includes the 5-layer podium building (24.0 m) and the 25-layer tower (84.0 m); the 4# building is at the south corner, the over ground part include the 5-layer podium building (24.0 m) and the 15-layer tower (54.0 m); the 5# building is at the east corner, the over ground part includes the 5-layer podium building (24.0 m) and the 15-layer tower (54.0 m).

3.2 The study index

People spend 80% of their time working and living indoors nowadays. Unlike building without comfort improbable indoor environment can lead to distracting, worry and diseases, building with

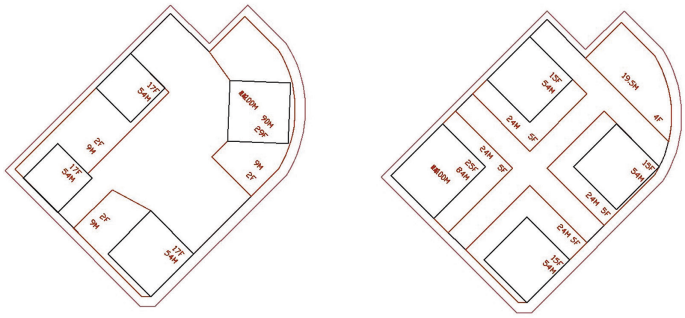


Figure 6: The architectural layout plan (left: circumference fit distribution, right: matrix distribution).

suitable indoor environment have benefits on their occupants, these benefits include increased productivity, improved physical and psychological conditions. Thus, the indoor environment could satisfy the occupants with effective environment evaluation system, architectural layout evaluation optimization, expansion of the current design ideas, expanding the current design ideas, technology roadmaps and management mechanism in the design progresses. The modern main current indoor environment indicators that are based on ecological evaluations include: sunlight, ventilation, thermo technical, energy consumption, noise and landscape visibility [19].

3.3 Study results and analysis

3.3.1 Sunlight and shadowing analysis

The premise of the using sunlight is to make sure that there is enough sunlight indoors. In the high-density area, it is necessary to study the building density and height to make sure every building has certain time receiving the sunlight.

Figures 7 and 8 show the sunlight duration analysis on severe cold day. The colder the color, the less sunlight duration time will be; and the warmer the color, the more sunlight duration time will be. The plotting scale on the top right corner of the figures is the sunlight duration time (unit: hour). It is concluded from Figures 7 and 8 that the sunlight duration time of the circumference fit distribution varies from 0 to 10 h, and the sunlight duration time of the matrix distribution varies from 0.8 to 5.8 h. The circumference fit distribution has more sunlight duration time than that of the matrix distribution, and the sunlight is more homogeneous, which indicates that the circumference fit distribution has advantages on getting more sunlight duration time and saving land.

Figures 9 and 10 show the sunlight duration analysis of the south of a building on the severe cold day. The sunlight duration time reduces while the plotting scale color changes from yellow to blue. It is concluded from the figures above that the south building of the circumference fit distribution has more homogeneous sunlight. On the basis of abundant sunlight, the south of building in the circumference fit distribution has more flexible windowing choices.

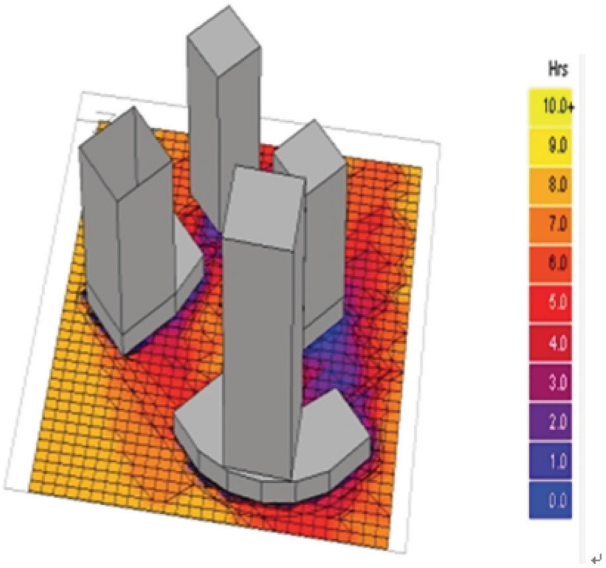


Figure 7: The severe cold day sunlight duration analysis of the circumference fit distribution.

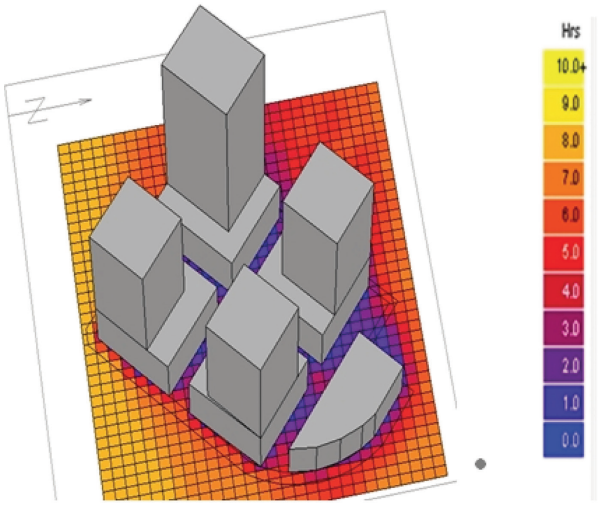


Figure 8: The severe cold day sunlight duration analysis of the matrix distribution.

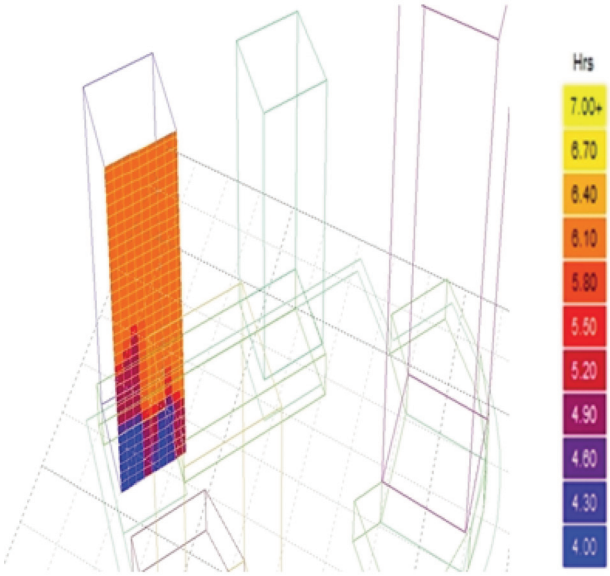


Figure 9: The severe cold day sunlight duration analysis of the south elevation in the circumference fit distribution.

Figures 11 and 12 show the (12:15 a.m.) architecture-shadow analysis of the two planning schemes on the severe cold day. The circular arc represents the track of the sun and the yellow point represents the sun. It can be seen from the model that, for the circumference fit distribution, the shadow of the western super high-rise building has little overlap with the other high-rise buildings around, and the overlap duration time is just 3 h, which means there is little over among the architectural complex. And for the matrix distribution, the shadow of the north-eastern building has obvious over-

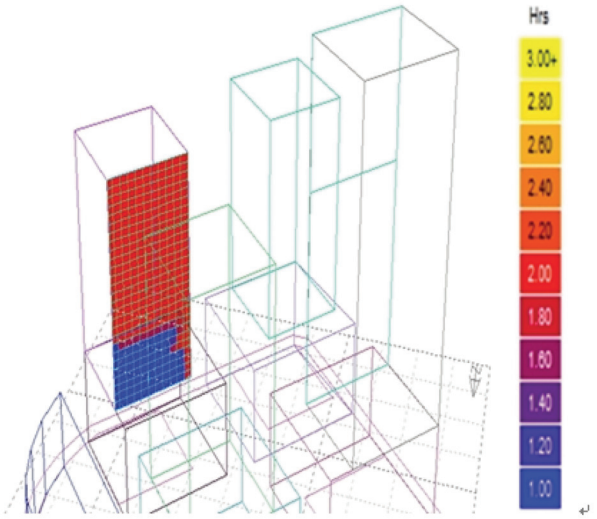


Figure 10: The severe cold day sunlight duration analysis of the south elevation in the matrix distribution.

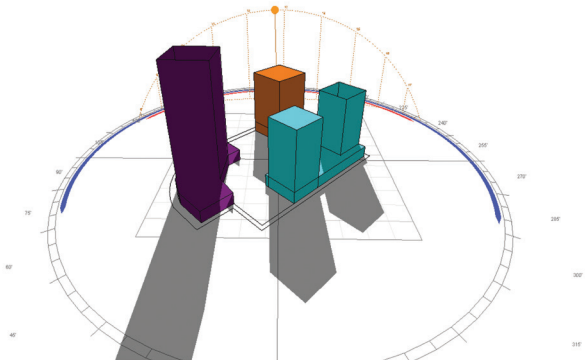


Figure 11: The architecture-shadow analysis of the circumference fit distribution on the severe cold day.

lap with the other buildings around, and the overlap duration time is over 10 h, which means there is obvious over among the north-eastern building and the other buildings around. Both the planning schemes meet the sunshine spacing requirements, and the circumference fit distribution has more sunlight on the ground floor than that of the matrix distribution.

3.3.2 Indoor lighting analysis

Good lighting designs help reduce the lighting energy consumption. As a total of 75% of indoor day lighting coefficients of the office and hotel buildings should meet the requirements of the current national standard <Architectural Lighting Design Standard> (GB/T50033). One of the typical rooms of the two planning schemes is selected for tests, using Ecotect and Radiance to simulate the indoor

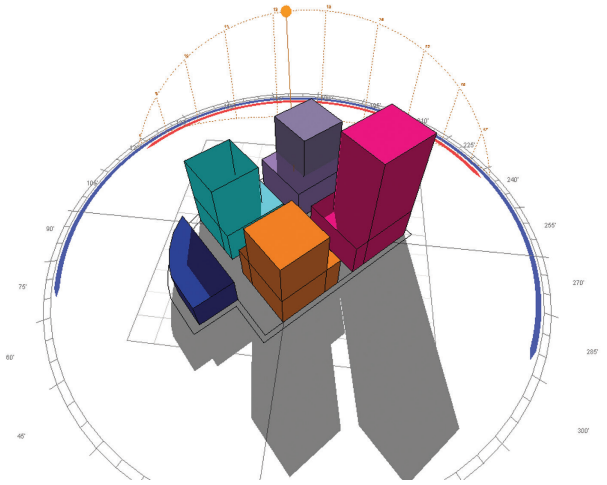


Figure 12: The architecture-shadow analysis of the matrix distribution the severe cold day.

natural lighting illumination at 9:00 on September 21st (weather: sunny). The result shows that 75% area of the room can obtain the illumination between 270 lux and 5400 lux.

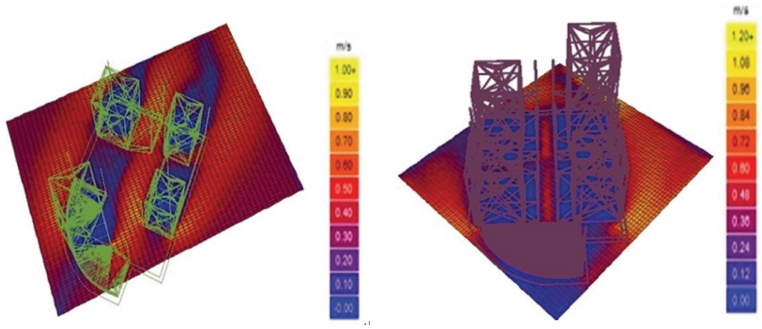
3.3.3 Wind environment analysis

The condition of the wind environment around building complex has direct influence on the occupants' life. Wind environment is not only related to the climate but also to the layout and orientations of buildings. Chongqing is in East Asian Monsoon area. Along with the influence of the northeast to southwest parallel hill valley topography, there is north wind in winter and south wind in summer. Each year, the wind speed in winter is the lowest (0.97 m/s) and highest in spring (1.3 m/s) and summer (1.2 m/s). The annual cumulative average wind speed is 1.12 m/s, which is one of the lowest wind speeds in China.

Figures 13 and 14 show the wind speed comparison between the two planning schemes at different heights in certain wind conditions. The wind speed varies from 0 to 1.2 m/s as the colour of the plotting scale changes from blue to yellow. According to the comparison, it is concluded that both of the two planning schemes have varying degrees of influence on the surrounding wind environment on the ground floor and varying degrees of ventilation problems. Especially for the matrix distribution, the natural air cannot flow smoothly due to the ventilation problems. Because of unreasonable architectural layout, heat island appears in the whole area. At the height of 20.0 m, the circumference fit distribution has good nature ventilation, while the matrix distribution has ventilation problems among most of the buildings, which will lead to the increase of energy consumption and worse built environment since poor ventilation prone to form the heat island area.

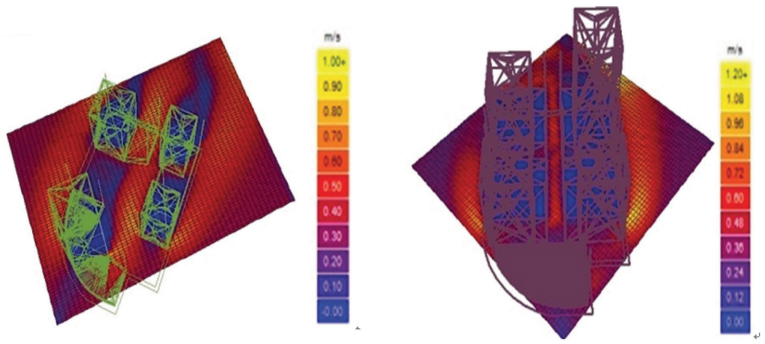
3.3.4 Energy consumption analysis

Energy consumption analysis is very important in the thermal environment analysis. Building energy consumption means the energy consumption for building function and operation. The most of the public building energy consumption is for building heating and air-conditioning. Thus, the index of building heating and air-conditioning energy consumption can evaluate the building energy efficiency quality. Assuming that both of the two planning schemes have the same indoor comfort level,



(a) (b)

Figure 13: The wind speed comparison between the two planning schemes at the height of 0.4 m.



(a) (b)

Figure 14: The wind speed comparison between the two planning schemes at the height of 20.0 m.

which means that the indoor comfort physical parameters (indoor average temperature, dress quantity, relative humidity, wind velocity and daylight levels), the heating/cooling load and the building envelope conditions are the same. The simulation result is shown below.

Figures 15 and 16 show the annual and monthly energy consumption comparisons between the two planning schemes. It is showed that the circumference fit distribution has lower building energy consumption than that of the matrix distribution.

Visibility analyses through BIM technology can provide guidelines for the design of ecological layout at the beginning of the construction project. The better architectural layout is more advantageous to obtain sunlight. It is suitable to arrange the buildings at the southern side of the tall building, as well as to reduce the indoor solar radiation at day time, which leads to lower air-conditioning energy consumption. On the condition of nature ventilation or air-conditioning in summer, the architectural layout should take advantage of the outdoor wind, as to strengthen the nature ventilation effect. Different architectural layouts result in different wind speeds and wind pressures; reasonable architectural layout is suggested to reduce wind pressure and energy consumption.

In the case studied above, the circumference fit distribution, which is reasonable in over-all layout, along with the better open position and building direction, is the better scheme.

Plan 1 MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 1606258 W at 06:00 on 23rd January
Max Cooling: 1907079 W at 15:00 on 6th August

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	675091904	0	675091904
Feb	515371904	0	515371904
Mar	263675120	10655418	274330528
Apr	48116412	9728536	57844948
May	0	53584980	53584980
Jun	0	198499024	198499024
Jul	0	358283584	358283584
Aug	0	397272928	397272928
Sep	1312308	129055544	130367848
Oct	44497068	7907062	52404128
Nov	256963824	0	256963824
Dec	518304320	0	518304320
TOTAL	2323332608	1164987076	3488319684

(a)

Plan 2 MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 2487103 W at 06:00 on 23rd January
Max Cooling: 5290158 W at 13:00 on 6th July

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	1065436480	0	1065436480
Feb	820512128	0	820512128
Mar	429202528	9613573	438816096
Apr	90110056	7403014	97513072
May	0	81288080	81288080
Jun	0	364042272	364042272
Jul	0	678990912	678990912
Aug	0	790195584	790195584
Sep	4132440	282158016	286290464
Oct	79665616	4337496	84003112
Nov	419350112	0	419350112
Dec	825369856	0	825369856
TOTAL	3733778944	2218028800	5951807488

(b)

Figure 15: The annual energy consumption comparison.

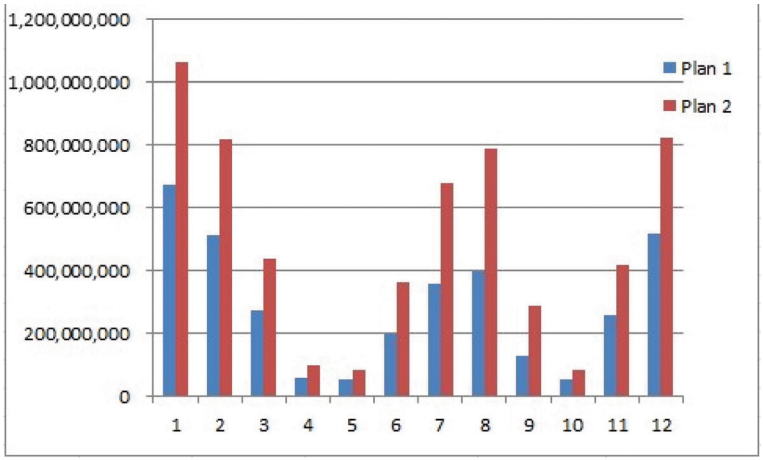


Figure 16: The monthly energy consumption comparison.

4 CONCLUSION AND DISCUSSION

It is better to provide comprehensive and accurate coordination platform for the terminal decision making of architectural layout by using BIM technology to analyze the related indexes and quantitative evaluation results. Auxiliary planning and design by using BIM technology is the tip of the iceberg when talking about the application of BIM technology. It is convenient to use the existing information directly and there is no need to set up the model repeated, which avoids the drain of information by complex procedures in transfer process.

Apparently, simulation cannot replace design but could help as a useful optimization design tool. When bringing three-dimensional simulation into planning, quantitative data combined with visual three-dimensional model are the development tendency of planning management platform. The built environment simulation analysis in urban planning based on BIM technology makes it possible to quantify the ecological index, which has vital significance to the research on livability and sustainability of high-density urban space.

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