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URBAN BLOCK OPTIMIZATION FOR ENERGY EFFICIENCY IN A DISTRICT LEVEL

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ABSTRACT

Urban building energy efficiency has been a focus on urban building layout design. To improve the urban energy saving, this study conducted a work by urban energy simulation through urban layout design. One campus-area building model and real energy datasets are applied to validate the different rule-based design strategies and their energy efficiencies. The results show that the design strategy with space coefficient of 0.8 and south low north high layout can save more energy of about 1.5% compared to original energy use.

Keywords: urban design, urban building energy simulation, district level, building spacing coefficient, urban layout

1. INTRODUCTION

With the continuous deepening of research on urban energy consumption, more and more urban planning and design studies begin to take energy conservation as an important consideration. The IPCC also lists urban planning as an important measure to mitigate global warming [1]. Urban energy is becoming the core of urban planning and design. Fonseca proposed an Energy Driven Urban Design concept based on Energy Performance, that is, focusing on the interaction mechanism between Energy and Urban environment to realize low-carbon and energy-saving Urban construction [2]. Energy performance under the guide of urban design aims to provide low energy demand of city layout, emphasis on coupling relationship between urban form and energy system, in order to obtain higher energy use efficiency, at the same time ensure that the user a high level of comfort [3], further defined the urban morphology of the coupling relationship between design and energy utility, and solved the energy infrastructure that decide a dot, size, and cost issues. A large number of studies show that reasonable urban form can effectively reduce building energy consumption. Nataniana took tel aviv as an example to study how to improve the density of different types of buildings in urban areas without increasing unit energy consumption by improving the photovoltaic potential [4]. Different researchers put forward two totally different views on whether urban density is conducive to alleviating urban heat island effect. One proposed that the high density would make it difficult for the heat generated by buildings to escape, and generate more heat in the city, leading to the output of cooling energy consumption. The other side believes that low-density urban blocks will lengthen the travel distance and present the phenomenon of urban sprawl, and the building energy consumption will increase accordingly. Salat et al. conducted a large-scale survey on the urban form of Paris and found that the lower the block density, the higher the heating energy demand [5]. Cheng et al. classified building layout forms and conducted energy consumption simulation one by one to study the correlation between layout forms and energy consumption [6]. Taking high-density residential buildings as the research object, Compagnon used simulation software to explore the building layout with the highest utilization of solar energy [7]. In addition, building orientation and street orientation affect the energy consumption of urban buildings. Littlefair found that when urban buildings are located in the northern hemisphere, higher solar energy utilization efficiency can be achieved by building orientation between 10° and 30° south [8]. Yekang found that when only one variable of street layout was changed, the cooling energy consumption of buildings in east-west street layout was lower than that of other orientations [9]. In addition, some scholars carry out research on building energy consumption by integrating multiple urban texture elements. However, taking the energy efficiency into the urban design as objective is not widely investigated currently.

Therefore, this study took the campus buildings of Southeast University as example to examine the impact of urban block design strategies on energy efficiency according to the rule-based design.

2. CASE STUDY

The Southeast University was selected as the case area, covering an area of 19.6 hectares. The total building area is 200,000 m2, the building density is 21%, and the plot ratio is about 1.0. There is a big difference in building volume, with the largest reaching 30,000 m2 and the smallest only 512 m2.The building was built in different ages, which can be roughly divided into four stages: 1915-1949, 1950-1966, 1976-1988 and 1988-present. The storey height of early buildings generally reached 5m, mainly 2~3 floors, mainly slope roof, relatively thick wall. The height of the building is mostly 4m, mainly 4~6 floors, flat roof, and thermal insulation performance is general, some of which are high-rise buildings, mainly flat roofs. As for building functions, the campus is mainly for postgraduate education (except for the school of architecture) and scientific and technological research base. Building functions can be divided into integrated services, administrative office, scientific research office, laboratory and classroom, etc. Different functional types of buildings have a large gap in service hours and energy intensity. As for the window-wall area ratio of various buildings, the values are distributed between 20% and 40%. Total 31 buildings are selected. Therefore, in order to simplify the calculation, take the average ratio of window wall area, that is, the south elevation is 35%, the north elevation is 30%, and the east and west elevation is 20%.

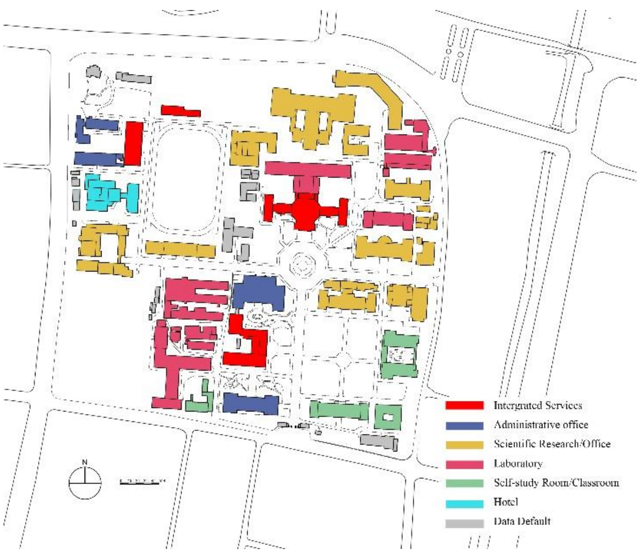

Fig. 1 The case buildings' area in this study.

3. METHODOLOGY

The method and process of energy-driven urban form optimization design can be divided into four stages: data collection and analysis, energy consumption model construction and verification, form optimization and scheme comparison. Environmental data is the primary data in simulation condition setting, which can be divided into meteorological data and peripheral environment data. Meteorological data is the boundary condition form EWPmap website,http://www.ladybug.tools/epwmap/. Urban morphology data is the key data of this paper, including density, building spacing, building orientation, overall planning and layout and other indicators. The basic data of urban morphology are mainly obtained through regional cad files and satellite maps. For the analysis of urban morphology data, the above data are calculated based on the plane profile in regional cad files, and the architectural plane layout and vertical layout are described and quantified. Secondly, the geometric block model was built on Rhino platform and the surrounding environment was analyzed. In Grasshopper, all kinds of data collected and sorted were successively input by using the basic parameter framework of Ladybug and Honeybee architectures to complete the construction of energy consumption model. Energy consumption model was started, data were transferred into EnergyPlus and Radiance for calculation, and the obtained calculation results were transferred back to Grasshopper. After simple processing, Excel sheets could be generated and data visualization could be realized. In addition, the results of microclimate simulation can be obtained. By checking the measured energy consumption data, a more accurate energy consumption model can be obtained. Thirdly, based on the energy-driven urban form optimization strategy, the driving factor of urban form is taken as an independent variable, and combined with the actual situation of the campus, the overall number of buildings and the form and function of individual buildings are set as the major premise in this study, so the total density of the area does not change before and after the optimization. In this study, building spacing coefficient was selected as the driving factor of energy consumption for urban density, and the coefficient (X=L/H) was set as 0.8 and 1.1. If the building spacing coefficient is smaller, the building layout is more compact and the concentration square proportion is larger. If the building spacing coefficient is larger, the building layout is looser and the concentration square proportion is smaller. In this study, vertical layout was selected as the

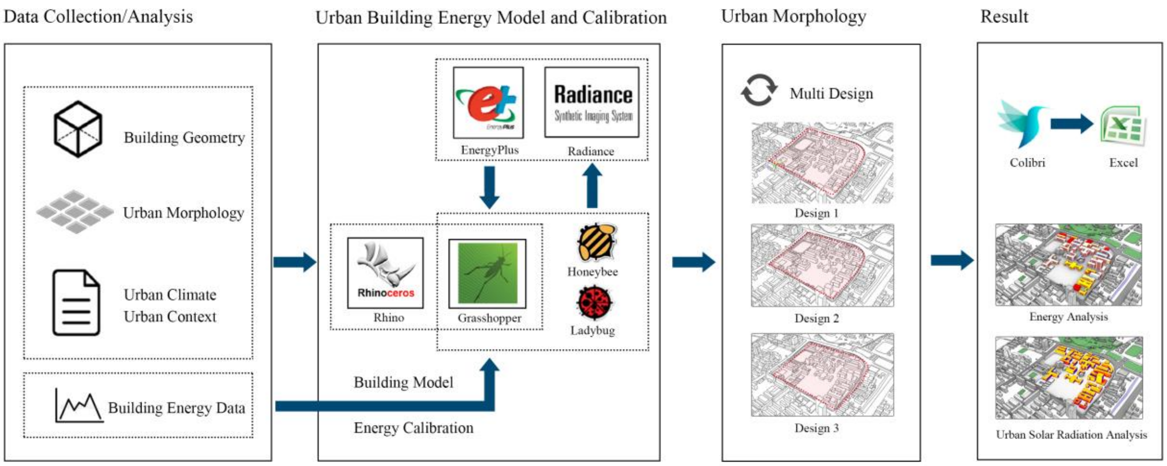

Fig. 2. The overview of methodology in this study.

driving factor of energy consumption of urban fabric. The vertical layout is set up in three steps. The site is divided into three parcels: the north, the central and the south, and ensure that the area of each block is similar and there is enough space to arrange different spacing schemes. In order to ensure the similar function of open space, the playground is uniformly arranged in the west of the area and the basic etiquette square is arranged in the south entrance (see figure). Then, the buildings are arranged according to the height in the three plots, which can be divided into three vertical layout modes: south high north low, south low north high, south/north low and middle high. Due to the small number of high-rise buildings, the north-south high, middle low mode is not set.

4. RESULTS

The total actual annual energy consumption in the campus of southeast university is 13.865 million kWh, and the average energy intensity per unit area of the building is 72.26kWh/ (m2·a). Through the energy consumption simulation of the original campus form, the total energy intensity was 69.54kwh /(m2·a), the total energy intensity of refrigeration was 26.33kwh /(m2·a), the energy intensity of refrigeration was 21.47kwh /(m2·a), and the energy intensity of heating was 4.85kwh /(m2·a).

In the urban form optimization plan, excluding the entrance square and the playground, there is a certain area of concentrated open space on the north side of the complex, while the outdoor space between buildings is relatively small, and the height of buildings gradually increases from south to north.

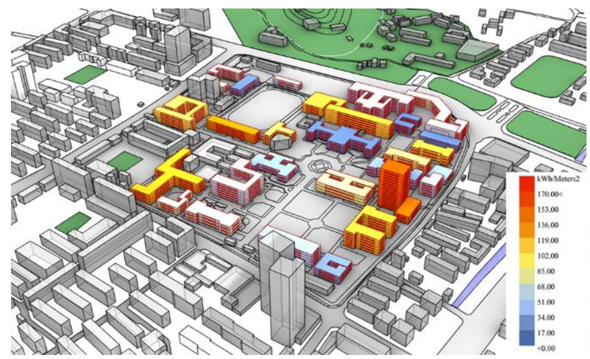

Fig.3. The energy simulation results for original layout.

When the density is 0.8, the following data are obtained through energy consumption simulation of the form: the total energy intensity of refrigeration and heating is 25.93kwh /(m2·a), the energy intensity of refrigeration is 21.13kwh /(m2·a), and the energy intensity of heating is 4.80kwh /(m2·a).When the spacing coefficient is 1.1, the following data are obtained through energy consumption simulation of the form: the total energy intensity of refrigeration and heating is 25.95kwh /(m2·a), the energy intensity of refrigeration is 21.21kwh/(m2·a), and the energy intensity of heating is 4.74kwh /(m2·a).

Table.1. Results for urban layout with south low north high.

		Total	Cooling	Heating
0.8	Results	25.93	21.13	4.80
	Δ	-0.39	-0.34	-0.05
1.1	Results	25.95	21.21	4.74
	Δ	-0.37	-0.26	-0.11

The buildings are arranged in a decreasing height from the center to the north and south. Through the energy consumption simulation of this form, the following data are obtained: the total energy intensity of heating and cooling is 26.05kWh/(m2·a), the energy intensity of cooling is 21.16kWh/(m2·a), and the energy intensity of heating is 4.89kWh/(m2·a).The amount of solar radiation is larger than the former, and the average radiation temperature of the site does not change much. When the spacing coefficient is 1.1, the following data are obtained through energy consumption simulation of the form: the total energy intensity of refrigeration and heating is 26.02kwh /(m2·a), the energy intensity of refrigeration is 21.23kwh /(m2·a), and the energy intensity of heating is 4.79kwh /(m2·a).

Table.2. Results for urban layout with south/north low and middle high.

		Total	Cooling	Heating
0.8	Results	26.05	21.16	4.89
	Δ	-0.27	-0.31	0.04
1.1	Results	26.02	21.23	4.79
	Δ	-0.30	-0.24	-0.06

On the north side of the complex, there is a certain area of concentrated open space, while the outdoor space between buildings is relatively small, and the height of buildings gradually decreases from south to north. The following data are obtained by simulating the energy consumption of this form: the total energy intensity of refrigeration and heating is 26.18kwh /(m2·a), the energy intensity of refrigeration is 21.36kwh /(m2·a), and the energy intensity of heating is 4.82kwh /(m2·a).When the spacing coefficient is 1.1, the following data are obtained through energy consumption simulation of the form: the total energy intensity of refrigeration and heating is 26.16kwh /(m2·a), the energy intensity of refrigeration is 21.39kwh /(m2·a), and the energy intensity of heating is 4.76kwh /(m2·a).

Table.2. Results for urban layout with south high north low.

		Total	Cooling	Heating
0.8	Results	26.18	21.36	4.82
	Δ	-0.15	-0.12	-0.03
1.1	Results	26.16	21.39	4.76
	Δ	-0.17	-0.08	-0.09

5. CONCLUSION

Through the urban energy simulation and urban layout design with campus-area building models and real energy datasets, this study validated the different rule-based design strategies and their energy efficiencies. The results show that the design strategy with space coefficient of 0.8 and south low north high layout can save more energy. The total building energy can be reduced by 0.39kWh/(m2·a), about 1.5% of original energy use.

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