Energy efficiency optimization for building envelopes on a green campus in Guangzhou

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Energy efficiency optimization for building envelopes on a green campus in Guangzhou

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Abstract Prediction and optimization of energy consumption is valuable to recognize the status and assist in green campus retrofitting and energy efficiency making. The study focused retrofit strategies in subtropical Guangzhou to achieve energy efficiency in a higher educational campus. According to the building's envelope features, optimization using a pseudo orthogonal test based on assumption of window design. In this paper, field investigation and numerical simulation were used to assess the thermal performance of this building. The prediction was primarily verified using a numerical simulation with 16 cases. It was concluded: (1) on basic cases, the results revealed the methods' reliability based on Energy-plus is adopted in the green campus; (2) the retrofit cases in thermal performance considering the building envelop, solar shading and windows' glazing; (3) the rooms of divergent orientation play varied significant role in energy consumption. The study provided the technic support for the energy optimization strategies of campus building in hot humid area.

KEYWORDS
Higher educational building, Prediction, Retrofit strategy, Energy efficiency, Energy-plus

1. Introduction

With the flourishment of Chinese higher education, many universities had built new campuses, the campus area and the number of students has increased rapidly. In 1997 to 2015, The total number of Chinese universities had increased from 1020 to 2848, about 2.8 multiples. Until May 2015, the construction area of higher education campus had reached 788, 000, 000 m^2, including 59,000,000 m^2 was under construction (Ministry of housing and urban-rural development. 2016). As public buildings, domestic higher education campus plays an important role in energy consuming, one that it is accounts for 8.4 percent of the total national energy consumption in China (Gao L. 2017).

Besides, the per capita energy of campus has pretty potential of energy efficiency, that was equivalent to 0.897t standard coal in energy consumption, which was 4 times than national average（Liu Q, Zhou R, et al. 2013）.Campus integrates the functions of education, livelihood and scientific research, its energy cost accounts for 10-15% in all funds. And the occupation density of classroom is 5-6 times than the office. Then, building energy consumption is more

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than 80% of the total energy consumption in campus (2018 Annual Report on China Building Energy Efficiency. 2018). Therefore, the energy conservation of campus focuses on building energy efficiency and retrofitting strategy. And the specific parameters are outdoor environment, architectural design performance, construction equipment performance, and construction operation and management in campus building.

This paper based on former studies, as the research building of Guangzhou University for instance, then the potential of energy efficiency and optimization has been analyzed in this building.

2. Envelope retrofit strategies

2.1 Solar shading

The solar shading plays a significant role in many energy efficiency strategies of building design. Several solar control and sun shading systems according to Whole Building Design Guide (WBDG, 2016). This book includes: vertical solar shading (fins); horizontal reflecting surfaces (daylight shelves); low-e solar shading glass (SC coefficient) (Liu. X.T, 2010); interior glare control devices, and landscape features.

The WBDG recommends placing a fixed horizontal cantilever on a glass facing south to control solar radiation from a direct beam of light. The optimal length of a cantilever depends on the number of window to wall ratio. And the length plays an important role in cooling loads to keep the balance between human comfort and energy consumption in the building. Optimizing the length of east glass and west glass are also suggested. Vertical shading do not largely lower cooling loads, but these components provide ventilate and glare control. As is known to us, the north face needs no shade.

Normally, solar shading strategies depends on latitude, daylight periods and building orientation. Another important factor is to consider both reducing the peak heat gain, heat release and cooling needs of the building, and improving the quality of natural lighting indoors. An extensive adjustment of solar shading products can be purchased commercially（El-Darwish I, Gomaa M. 2017）.

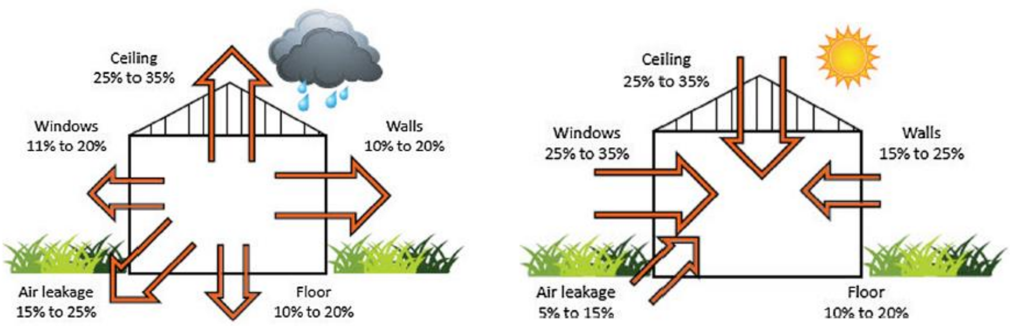


Fig. 1. *Air Flow through a House in Hot Humid Climate*

2.2 Window glazing

Window has many functions that distributing to buildings or rooms, it provides solar light, air-flow and security. By the way, orientation and glazing is a necessary process to achieve energy efficiency. The orientation of air-flow hinges on season changing, building function and operation. While the outdoor temperature is hot and the building is cooled inside, the window of classroom that it has high U-values should be more insulated to allow heat air-flow to be shed from the building.

Single-glazing windows has clear overview and badly insulation frames are almost applied over the world (OECD/IEA, 2013). These has highly U-values of approximately 4.5~6.2 W/m^2 K. Many countries have switched to low-e coated double-glazing, low-conductivity frames. And the use of inert gas is lower U-values in the residential area.

2.3 Insulation

Insulation is a process to construction that called Vacuum Insulation Panels (Alam M, Singh H, Suresh S, et al. 2017). VIPs have already been extensively applied in building envelopes, phase-changed material and insulating refrigerators (Liang Y, Wu H, Huang G, et al. 2017). Compared with other insulation materials, such as expanded polystyrene (EPS) (Dissanayake D M K W, Jayasinghe C, et al. 2017), polyurethane (PU) (Pisello A L, Fortunati E, Fabiani C, et al.) and glass wool, VIPs achieve thermal conductivity of 6~10 times lower (Bouquerel M, Duforestel T, Baillis D, et al.).

3. Methodology

3.1 Study area

Fig. 2. *Sites of survey*

The study area encompasses Guangzhou University at longitudes of 112.8° E and latitudes between 22.3° N and 24.10° N, belonging to the hot humid climate. The summer season almost for 6 months from May to October. The educational building built in 2004, is a 7-storey single plate building with brick-concrete structure and the area of 7980m^2. Occupants regulate the indoor thermal environment mainly through the distributed air conditioners in summer (Zhao L, Zhou X, et al. 2016). This investigation was carried out at Guangzhou University from July 2017 to June 2018.

Fig.2 shows the first building is 7 floors building of a footprint 3240m^2. The building is made up of 147 rooms, including 3 terrace classrooms, 17 conventional classrooms and 1 teachers' office on every floor.

Table. 1. *Description of 4 typical rooms in the building*

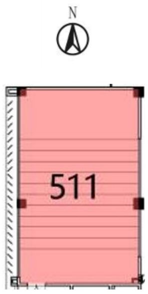
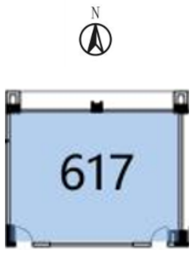
Room Description		622-terrace	511-terrace	617- convention	607- convention
Shape					
Orientation		East	West	North	South
Room Depth(m)		18.2	15.9	9.5	9.5
Room Width(m)		14.5	9.8	7.5	7.5
Room Height(m)		4.2~5.0	4.2~5.0	3.0	3.0
Material	Floor	Ceramic tiles			
	Wall	Plaster			
	Ceiling	Composite			
Frame		Aluminum Alloy			
Window		Single-glazing			
Window Height(m)		1.5	1.5	0.7	0.7
Graph					
Shading Devices		Vertical Louvers		Comprehensive sunshade	
Glazing ratio		0.36	0.24	0.48	0.48
HVAC		Cooling Only			
Lighting System		Fluorescent			
Seating Capacity		252	150	62	62

Table. 2. *Typical campus building models - Building construction information*

Envelopes	Exterior Walls	Ceiling	Floor	Single-glazing	Double-glazing	Internal separation
Thermal Conductivity [W/(m^2 • K)]	U=1.47	U=0.77	U=0.54	U=5.5	U=2.5	U=1.24

The functions of the rooms are almost science and education. After investigation and measurement, classrooms are distributed into 4 types according to the orientation. The information of this building is shown in Table. 1.& Table. 2.

3.2 Numerical simulation

Simulation of energy consumption is carried out by using the Design Builder. And it combined with the Energy-Plus computing engine. Design Builder is chosen because it provides flexible geometric input and a wide range of material libraries and load configuration files. In addition, it has control procedures to ensure the accuracy of the results with an independent energy engine.

Table. 3. *Typical campus building model - Interior design parameters*

	Indoor temperature (℃)	Indoor fresh air volume (m^3)	Occupation Density (P/m^2)	Lighting power (W/m^2)	Equipment power (W/m^2)
Classroom	26℃	/	0.90	12	13
Office	26℃	/	0.35	11	15

Table. 4. *Energy breakdown (W • h/m2) in difference strategies*

Orientation	No.	Strategy	Glass curtain wall	Glazing ratio	Solar shading
622-East	1	Base 1	Single-glazing	0.36	0.60
	2	Retrofit 1-A	Double-glazing	0.36	0.60
	3	Retrofit 1-B	Double-glazing	0.48	0.60
	4	Retrofit 1-C	Double-glazing	0.48	0.45
511-West	5	Base 2	Single-glazing	0.24	0.60
	6	Retrofit 2-A	Double-glazing	0.24	0.60
	7	Retrofit 2-B	Double-glazing	0.36	0.60
	8	Retrofit 2-C	Double-glazing	0.36	0.45
617-North	9	Base 3	Single-glazing	0.48	0.90
	10	Retrofit 3-A	Double-glazing	0.48	0.90
	11	Retrofit 3-B	Double-glazing	0.48	0.55
	12	Retrofit 3-C	Double-glazing	0.48	0.45
607-South	13	Base 4	Single-glazing	0.48	0.90
	14	Retrofit 4-A	Double-glazing	0.48	0.90
	15	Retrofit 4-B	Double-glazing	0.48	0.55
	16	Retrofit 4-C	Double-glazing	0.48	0.45

Based on the current construction information, detailed information, materials and system of the case area, the basic simulation model is established. The purpose of creating 4 basic models is to estimate the annual cooling loads of conventional building practices in the unmodified case study of energy efficient retrofit. In this way, it can compare the effect and sensitivity of each component and system in total energy consumption after modification. The information is shown in Table. 3.& Table. 4

4. Results and analysis

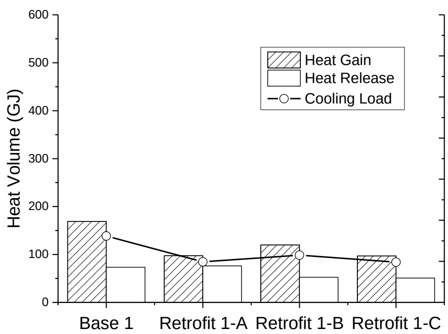
4.1 Results

Table. 5. *Cooling loads breakdown(kW/m²) in difference strategies*

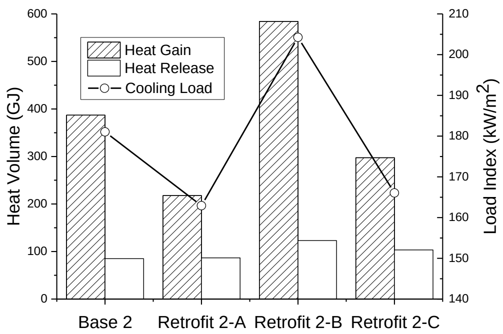
Load breakdown(kW/m²)	Retrofit Strategy			
Orientation	Base case	Double-glazing	Air tightness	Solar shading
622-East	156.17	149.87	151.50	149.80
511-West	181.05	162.94	204.24	166.06
617-North	165.56	154.64	153.80	152.74
607-South	167.22	156.01	154.51	154.11

According to Table. 5, cooling loads reduced from 156.17 kW/m² to 149.80 kW/m² in the east room of this building by retrofit measure, such as double-glazing and solar shading. Cooling loads were less from 181.05 kW/m² to 162.94 kW/m² in the west room after application. It also reduced from 165.56 kW/m² to 152.74 kW/m² after the modification of the retrofit strategies.

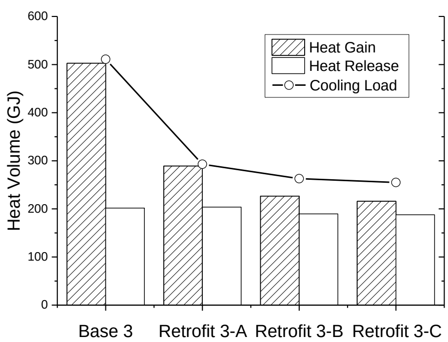
4.2 Analysis



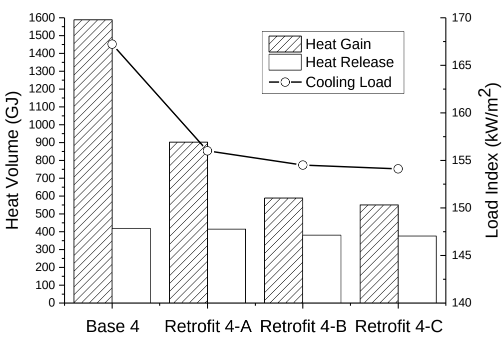
(a) 622-East



(b) 511-West



(c) 617-North



(d) 607-South

Fig.3. *Architectural heat volume and annual design hourly load*

Table. 6. The Reduction of energy consumption with four samples

Energy Reduction (%)	Retrofit Strategy			
Orientation	Base case	Double-glazing	Air tightness	Solar shading
622-East	-	4.0%	3.0%	4.1%
511-West	-	10.0%	-12.8%	8.3%
617-North	-	6.6%	7.1%	7.7%
607-South	-	6.7%	7.6%	7.8%

It is depicted in Table 6, the energy consumption in dealing with 3 strategies(kW/m^2) reduces in different orientation and occupation density. The retrofit strategy sample in the 4 classroom samples, the strategy of double-glazing reduced the amount of 10.0% in energy consumption.

Followed, was the concrete louvers with 10 mm retrofit strategy reduced 8.3% of energy consumption in a typical westward room. The sun-shading is a great measurement of energy efficiency potential. The study building of Guangzhou University has adopted a series of solar shading techniques such as vertical shading, horizontal shading and comprehensive shading. On the base, solar shading still has a good potential to energy-saving.

The least effective strategy was the window to wall ratio that increased 12.8% in energy consumption. The charts showing the tendency of energy in the above, that can be seen Fig.3.

5. Conclusions

In conclusion, the strategy of sun shading reduced energy consumption by 7.32%, then double-glazing reduced energy consumption in numerical simulation by 6.6%. The window to wall ratio could not exceed 0.48 in campus building. The bigger ratio can elevate the annual energy demand in westward classroom. Finally, the heat volume of southward classroom is almost 3 times higher than other orientations in heat gain that retrofit applications can focus on the directions with double-glazing, solar shading and insulation.

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