Research on Energy-efficient Simulation Aided Optimization Design Method of Office Building Based on Parametric Target Control

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ABSTRACT

Referring to the building parametric design method, this paper introduces a simulation aided optimization design method with the objective of the lowest building energy consumption and the best building performance. In this paper, the reduction of indoor radiation heat gain and aiming a uniform radiation distribution on building surface are introduced as a target function by controlling building orientation, overhang length, glazing ratio and shading coefficient, and a good ventilation on each floor by designing openings of different sizes according to wind pressure distribution on building surface. Through several cases study, it is possible to apply the method to realize building energy efficient parametric simulation optimization and the building surface parametric optimization design.

INTRODUCTION

Building parametric design method is a design method affected by complex science, based on nonlinear theory and philosophy for ideological foundation and computers for aided design tools. The architecture form generated by the method always appears flowing, irregular, free and soft (Liu Chunyang 2010). The scheme is taken as a function of many design parameters, and the final design can be generated by controlling these parameters and the function relationship. With the rapid development of architectural theory and building technology, the novel design method is gradually applied into more and more projects by many architects in modern times.

Aiming at achieving an eye-catching architectural form, some architects always take complex science theories which have nothing to do with architecture as their design logic. As a result, the functional requirements are forced to fit in with the design logic.

And the core idea of parametric design method is deviated from.

As the first step of design, the scheme design phase concentrates the main points in the whole building design process. In this stage, the architectural form nearly takes shape, and most of the parameters which can affect the energy consumption are selected. Some related literatures show that, with the promotion of design, the energy-efficient space is smaller and smaller, and the cost of the same energy saving benefit is higher and higher (Yu Qiong 2011)

In conclusion, it is pointed out that the parametric design and energy-efficient design can be combined in the early stage. Three different aspects can be started from: building form, spatial arrangement, and envelope. The two aspects: building form and envelope, which are easier to realize are started from to seek for energy-efficient optimization design method in this paper.

SIMULATION ANALYSIS

Building air-conditioning and heating energy consumption can be expressed as:

$$E = \frac{Q_{sum}}{COP_s} + \frac{Q_{win}}{COP_w} \tag{1}$$

The radiation heat gain Q in summer occupies a large proportion of the air-conditioning cooling load Q_{sum}. So Q_{sum} can be reduced effectively by reducing Q. And what elements and affect Q?

Firstly, it is pointed out that the radiation distribution can be affected by the nonlinear characteristics of building envelope. For example, the self-occlusion, which results in a non-uniform radiation distribution on building surface, will be caused by the characteristic of the building forms (Figure 2 and Figure 3) compared with the conventional building form (Figure 1).
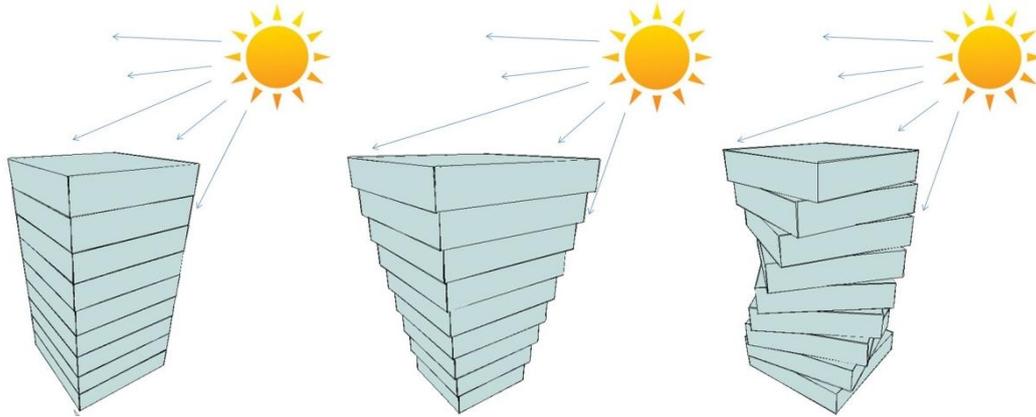
Figure 1. *Conventional form*   ***Figure 2.*** *Overhang*   ***Figure 3.*** *Angle rotation*

A steady-state load calculation formula (Zeng Jianlong 2006) of building envelope is introduced as the calculation model of indoor radiation heat gain. For glazing building envelope, the heat gain of unit area is:

$$q_{win} = K_{win} \cdot \Delta T + SC \cdot q_{solar} \qquad (2)$$

So the glazing ratio and the window shading coefficient have important influence on the indoor radiation heat gain.

In conclusion, Q can be expressed as an objective function:

$$Q = f(\theta, l, \eta, SC) \qquad (3)$$

The reduction of indoor radiation heat gain and an uniform radiation distribution can be achieved by controlling each floor's orientation θ, the roof overhang length l, the glazing ration η, the shading coefficient SC. And the energy-efficient optimization design objective can be achieved. Although there are many other parameters which can affect Q, only the four parameters above are promoted research on in this paper.

Similarly, if the objective is to strengthen the interior natural ventilation, the ventilation rate can be expressed as:

$$V = g(\Delta p, o, sa) \qquad (4)$$

Δp is the wind pressure difference between the windward side and the leeside, o represents the window's opening size, sa represents the interior spatial arrangement. So a good ventilation can be achieved by adjusting o and sa according to Δp.

The lighting energy consumption E_{light} can be expressed as follows if a minimum lighting energy consumption is the objective:

$$E_{light} = h(d, \delta, \theta, \eta) \tag{5}$$

d represents the room depth, δ represents the window's transmittance.

In conclusion, a research method is proposed in this paper: through controlling the parameters of building envelope, a simulation aided optimization design, aiming at achieving the building performance optimization objective is performed. Firstly, the sunshade is considered because the HVAC system energy consumption will be greatly influenced by the radiation heat gain in summer. Secondly, the reduction of the HVAC system energy consumption and an improvement of the indoor air quality will be achieved by strengthening the interior natural ventilation. Thirdly, the natural lighting should be considered to reduce lighting energy consumption.

In order to perform parametric energy-efficient design research on special office buildings, two cases are selected to be simulated and calculated the radiation and wind pressure distribution on building envelope, then some optimization measures are proposed accordingly.

Research on optimization method with the objective of reducing radiation heat gain

In this paper, the software Ecotect is used to perform simulation analysis to achieve a reduction the indoor radiation heat gain and an uniform radiation distribution on building surface through controlling θ, l, η, SC. Based on the simulation results, the objective function Q can be controlled by all the parameters above effectively to achieve the energy-efficient goal.

A solar radiation simulation of an office building in Shanghai is performed in this paper. Compared with the reference building, the radiation heat gain of the building is

lower than that of the reference building by 35.6% (Table 1) because each floor rotates a certain angle relatively. Results show that, too much radiation heat gain is caused by two reasons: η and the solar radiation energy density is too large.

Table 1. *Simulation results of daily average radiation heat gain of the south part of the building*

Orientation	South	East	North	West	Whole
Glazing ratio	0.44	0.25	0.45	0.32	-
Radiation heat gain of the office building（MWh）	29.4	5.2	23.1	6.7	64.4
Radiation heat gain of the reference building（MWh）	52.6	8.3	27.3	11.7	99.9
Difference of radiation heat gain（MWh）	23.1	3.1	4.2	5.0	35.5

According to the results, two optimization methods are carried out: 1.optimization of glazing ratio: an uniform radiation distribution is achieved by changing glazing ratio (Table 2); 2. optimization of external blinds: standard formula is used to calculate the shading coefficient and different external blinds are selected according to different orientations.

Table2. *Glazing ratio before and after the optimization of the south surface of the south part of the building*

Number of floor	1st	2nd	3rd	4th	5th	6th	7th
Before optimization	0.21	0.37	0.36	0.44	1.00	0.50	0.24
After optimization	0.28	0.21	0.32	0.33	0.27	0.26	0.20

According to the results, a reduction of radiation heat gain of 34414kWh can be achieved by optimizing the glazing ration. Energy-efficient benefit of 1.77kWh/m^2 can be achieved if the COP of the HVAC system in summer is 3.

A solar radiation simulation of an office building which has 4 pieces of cambered glass curtain wall outside the main body in Chengdu is performed in this paper. In order to achieve a uniform radiation distribution on the building envelope, a kind of glass with non-uniform texture on the surface is applied to control SC (Table 3).

Table 3. *The daily average radiation heat gain and SC of the south-west surface*

Number of floor	The radiation energy density	The radiation energy density	SC1	SC1 ×SC2 （SC2=0.8）	SC3

	(no curtain wall) (kWh/m²)	(curtain wall) (kWh/m²)			
3-5	1.02	0.58	0.57	0.45	0.88
6-10	1.09	0.67	0.61	0.49	0.81
11-15	0.87	0.80	0.92	0.74	0.54

According to the results, the cambered glass curtain wall's shading coefficient (SC1), which is affected by the material's transmittance and the self-occlusion caused by the cambered shape, gradually increases with the number of floor rising. The inner curtain wall is made up of double glazing whose shading coefficient（SC2）is 0.8. In the criterion, shading coefficient of building envelope shouldn't be higher than 0.4 when the glazing ratio is between 0.5 and 0.7 in area where summer is hot and winter is cold. For the surface whose shading coefficient (SC1×SC2) is higher than 0.4, the shading coefficient (SC3) caused by the non-uniform texture of the glass curtain wall is calculated as a supplement for the SC, to achieve an uniform radiation distribution on the building envelope finally.

Research on optimization method with the objective of strengthening interior natural ventilation
In the horizontal direction, the wind pressure difference of the windward side and leeside of the office building is high in the center and low on both sides; in the vertical direction, the wind pressure difference first increases, then decreases with the number of floor rising. In this paper, a good ventilation in different floors is achieved by designing openings of different sizes according to the wind pressure results (Table 4).

Table 4. Wind pressure difference and opening sizes of different floors from west to east

Number of floor	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Δp (from west to east)(Pa)	3.48	3.22	3.53	3.53	3.63	3.46	3.48	3.48	3.49	3.64	3.57	3.47	2.78
	3.72	3.71	3.81	3.86	3.91	3.93	3.94	3.93	3.95	4.02	4.02	3.87	2.92
	3.74	3.79	3.88	3.94	4.01	4.03	4.03	4.04	4.04	4.09	4.10	3.92	2.62
	3.67	3.77	3.85	3.94	4.02	4.07	4.06	4.05	4.05	4.08	4.10	3.90	2.54
	3.51	3.65	3.74	3.85	3.93	4.00	4.01	3.99	4.00	4.02	4.03	3.89	2.93
	3.29	3.42	3.54	3.66	3.74	3.80	3.86	3.85	3.88	3.89	3.95	3.88	3.04
	2.90	3.07	3.16	3.29	3.46	3.51	3.54	3.61	3.68	3.72	3.87	3.88	2.84
	2.29	2.48	2.25	2.48	3.09	3.13	3.09	3.22	3.30	3.40	3.71	3.80	3.16
	0.69	0.83	1.13	0.98	2.20	2.42	2.02	2.60	2.91	2.78	3.51	3.29	2.72
The average	3.03	3.11	3.21	3.28	3.55	3.59	3.56	3.64	3.70	3.74	3.87	3.77	2.84

Δp (Pa)	
Opening proportion	75% 73% 71% 69% 64% 63% 64% 62% 61% 61% 59% 60% 80%

DISCUSSION

Research on building parametric energy-efficient design is a new try with the development of green building. It is possible to achieve a unification of aesthetics and technology under the rational logic if more energy-efficient ideas can be introduced in the architectural scheme design phase, and the energy requirement or the HVAC system load can be taken as an objective function of the building envelope design. So it is necessary to discuss the influence on the solar radiation heat gain, wind pressure distribution caused by the nonlinear characteristics of building envelope, then propose energy-efficient optimization measures accordingly.

In this paper, with the objective of a reduction of the radiation heat gain and a good interior natural ventilation, two office building cases whose building envelope have nonlinear characteristics are selected, and software Ecotect and Phoenics are applied to perform simulation analysis and quantitative optimization according to the simulation results and optimization logic, finally a rational building envelope is generated.

In this paper, only two objectives are promoted research on: reducing the radiation heat gain and strengthening the interior natural ventilation. It should be pointed out that: (1) Only a few controllable parameters are proposed in this paper. More related parameters which can affect the energy consumption and building surface should be proposed to increase the optimization design diversity in the next step; (2) How to weigh the importance of objectives from the overall angle, and seek for ways to deal with the contradictions between different optimization measures, are problems needed to be solved in the future, because there are interactions among several optimization objectives and measures in practice.

CONCLUSION

Although research in this paper is based on a large number of simulation analysis, it should be pointed out that, simulation is not to replace design, but a good aided optimization design tool. With the appearance of more requirements of architectural aesthetics and energy-efficient performance, simulation technology, rational applications of which can provide guidance for design, also needs to be improved to face new challenges in the future.

ACKNOWLEDGEMENTS

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