Optimized Design of External Shading Device via Parametric Design Approach

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ABSTRACT
In this paper, parametric design approach is used to optimize the external shading device design, which take examples of horizontal shading devices and horizontal louver shading devices on south faced of buildings in Guangzhou, Shanghai and Beijing. The optimize goal of whole year shading effect is "Shading in summer and solar in winter, both as much as possible at the same time". In the first part of this paper, the external shading devices are optimized integrally and systematically. In the second part, the calculated data are analysed and organized, and some simple design rules for external shading devices have been summarized: tilt up 30° louver shading device is the best of four kinds devices involved in this paper, and a shading device can get better effect as latitude rise up.

KEYWORDS
External shading device, Optimize design, Grasshopper, Ecotect

INTRODUCTION

External shading device is one of the effective passive energy-saving measures, it is widely used in the excellent building examples during various periods (Huan Zhang et al 2005). The goal of the external shading design is "Shading in summer and solar in winter, both as much as possible at the same time", in which contains two points of one design process, and they are contradictory to a certain extent. What's more, the external shading contains a quantity of geometric parameters whose effects are different from each other. We can conclude that the optimize design of external shading device is a multidimensional complex issue which need time dimension and space dimension to be carried out systematically in an overall perspective throughout the whole year.

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The research on the external shading in the past tends to use simplified method which independently considers various parameters affecting the effects of external shading (Jianhai Zhang et al 2008). This method can evaluate the effects and proportion of various parameters when they contributed to the effects of external shading, while it is lack of overall and systematic consideration of the relevant parameters. What's more, traditional external shading design method is based on the formula of solar declination angle, elevation and azimuth angles (SCUT et al 2002). It results in the one-sidedness and irrationality for ignoring the effects of the shading in the whole year (Shen Hu et al 2010).

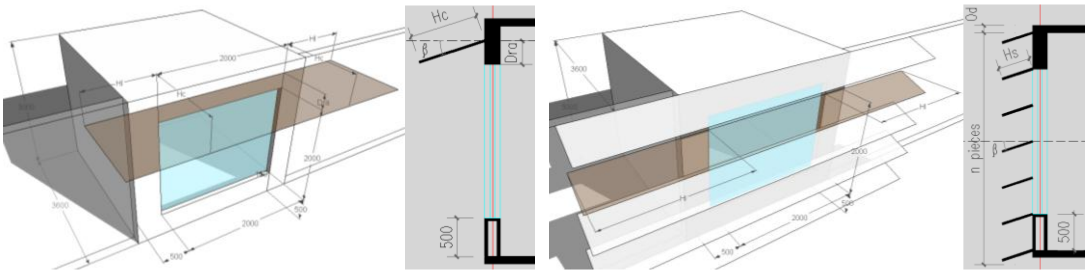
In this paper, Grasshopper (GH for short in below) was used to establish parametric model which take examples of horizontal shading devices and horizontal louver shading devices on south faced of buildings in Guangzhou, Shanghai and Beijing. The design of external shading devices were tried to be optimized, the calculation data was analysed and sorted out. On the basis, some simple and clear design rules for external shading devices have been summarized.

RESEARCH METHODS

The optimize design system in this paper of external shading devices is divided into three parts: generate of the parametric geometry for the external shading devices, evaluate the generated geometry and the formation of an automatic optimization process.

Parametric geometry model

The parametric models of external shading devices are divided into two parts: the shading devices with variable parameters, the room with fixed size of 3m×3.6m×3m. The size of the window is 2m×2m and the height of the windowsill is 0.5m (Figure 1 and Table 1).



a) Horizontal shading device *b) Horizontal louver shading device*

***Figure 1**. Parameters of Parametric geometry model (Unit: mm)*

***Table 1**. Parameters of Parametric geometry model*

Horizontal shading device			*Horizontal louver shading device*		
Variable	*Symbol*	*Unit*	*Variable*	*Symbol*	*Unit*
Length of the board	*Hc*	m	Depth of the board	*Hs*	m
Singled out length of both sides	*Hl*	m	Singled out length of both sides	*Hl*	m

Horizontal shading device			Horizontal louver shading device		
Tilt angle	α	°	Tilt angle	β	°
Distance between the root of the board and the adjacent side of the window	*Dra*	m	Louver number	*n*	piece
			Overall displacement	*Od*	m

The normal of the wall are selected to be the datum of the rotation angles (α and β). The angle is positive and called "tilt up" when the ends of the board is above the normal. It is negative and called "tilt down" when the situation is converse. When the board is parallel to the wall normal, the rotation angle changed to be 0 °.

Evaluating methods

The evaluation index include three values: the external shading coefficient of summer (*SDs*), the external shading coefficient of winter (*SDw*) and daylight factor (*C*). Based on the considerations of the whole year shade effects, *SDs* should be as small as possible and *SDw* should be as large as possible at a same time in a design process. According to the relevant standard (MDPRC 2001), and to facilitate the process of optimizing, the daylight factor *C* should be as large as possible when optimizing the external shading coefficient, as it share the same variation with external shading coefficient to some extent. The target value (*TV*) can be set to the following form when merging these three valves into a single Galapagos optimization target value (Formula 1).

$$TV=(1-SDs)+SDw+C \tag{1}$$

The external shading coefficient *SDs* and *SDw* can be obtained by the simplified calculation method in literature (Lihua zhao et al 2011). The daylight factor can be obtained by the software Ecotect. And the calculation parameters accord with the provision in the literature (Shen Hu et al 2010).

Automatic optimize design process

Using the Galapagos genetic algorithm module in GH software, an automatic calculation process was established (Figure 2). A whole optimization process will cost three to six hours.

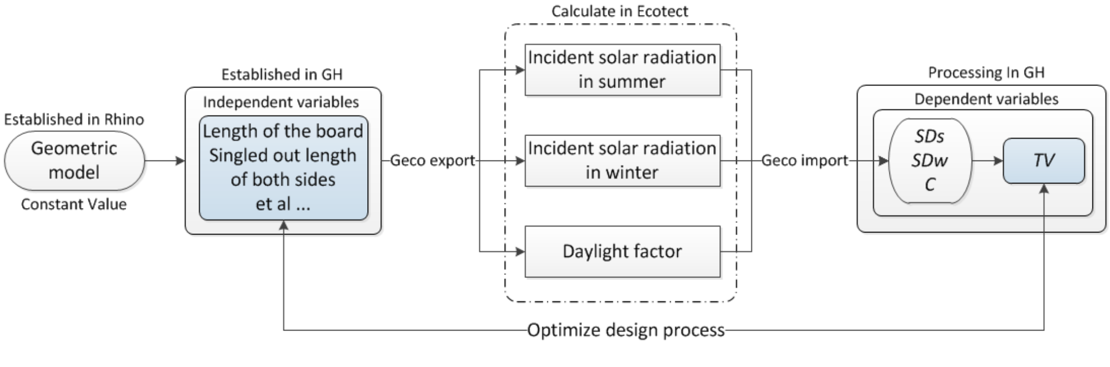


Figure 2. *Automatic calculation process*

RESULTS

Optimal design of horizontal shading devices

The results are shown in table 2 after perform several calculations of horizontal shading devices with variable tilt angle in Guangzhou, Shanghai and Beijing.

Table 2. *Optimal solutions of horizontal shading devices with variable tilt angle*

Parametric	*Guangzhou*	*Shanghai*	*Beijing*
TV	1.3998	1.6149	1.7145
SDs	0.4172	0.2489	0.1683
SDw	0.7763	0.8190	0.8454
SDw-SDs	0.3591	0.5701	0.6771
C	4.07%	4.48%	3.74%
Hc (m)	8.7	8.7	8.2
Hl (m)	10.1	10.3	10.2
α (°)	55	55	46
Dra (m）	0.26	0.26	0.11

Table 3. *Optimal solutions of horizontal shading devices with fixed tilt angle*

Parametric	*Guangzhou*	*Shanghai*	*Beijing*
TV	1.3756	1.5461	1.6262
SDs	0.5021	0.3072	0.1891
SDw	0.8324	0.8060	0.7789
SDw-SDs	0.3303	0.4988	0.5898
C	4.53%	4.73%	3.64%
Hc (m)	0.4	0.6	1.1
Hl (m)	16.9	3.3	11.7
Dra (m)	0.45	0.47	0.50

The optimal solution of the horizontal shading devices in that three cities share the same construction mode of tilting up. The geometric sizes and daylight factor *C* have no obvious variations with latitude. *SDw* are all greater than *SDs*, and this feature can illustrate that the optimize goal is achieved to some extent though the dimensions of the structure do not meet the actual demand.

The results are shown in table 3 after perform several calculations of horizontal shading devices with fixed tilt angle (perpendicular to the wall) in Guangzhou, Shanghai and Beijing.

According to the optimal solutions of three cities, the length of the shading board *Hc* become lager when latitude increase and *SDw* are all greater than *SDs*, this feature can illustrate that the optimization design goal is achieved to some extent.

Optimal design of horizontal louver shading devices

After calculate several times of the horizontal louver shading device in Guangzhou, the tilt angle β =30°and the number of the shading board *n*=8 are relatively stable in several optimal solutions of the five independent variables. What's more, the number of independent variables will be simplified in this paper to meet the actual demand better. The number of shading board is fixed at 8 and the tilt angle is fixed at 30°tilt up and 30°tilt down.
The results are shown in table 4 after perform several calculations of horizontal louver shading devices which tilt up to 30°in Guangzhou, Shanghai and Beijing.
According to the optimal solutions of three cities, the geometric size and daylight factor *C* have no obvious relevant trend with latitude and *SDw* are all greater than *SDs*, this feature can illustrate that the optimization design goal is achieved to some extent.
The results are shown in table 5 after perform several calculations of horizontal louver shading devices which tilt down to 30°in Guangzhou, Shanghai and Beijing.

***Table 4**. Optimal solutions of horizontal louver shading devices which tilt up to 30°*

Parametric	*Guangzhou*	*Shanghai*	*Beijing*
TV	1.3906	1.5902	1.6955
SDs	0.4278	0.2794	0.1945
SDw	0.7778	0.8262	0.8533
SDw-SDs	0.3500	0.5468	0.6588
C	4.07%	4.35%	3.67%
Hs (m)	0.20	0.19	0.27
Hl (m)	8.9	2.0	11.8
Od (m)	0.13	0.34	0.28

***Table 5**. Optimal solutions of horizontal louver shading devices which tilt down to 30°*

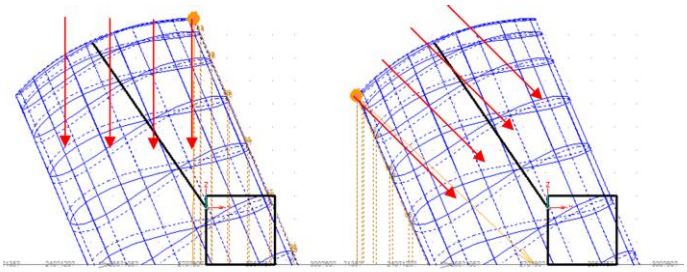
Parametric	*Guangzhou*	*Shanghai*	*Beijing*
TV	1.3806	1.5567	1.6066
SDs	0.4954	0.2811	0.2407
SDw	0.8362	0.7999	0.8149
SDw-SDs	0.3408	0.5188	0.5742
C	3.99%	3.78%	3.24%
Hs (m)	0.08	0.11	0.14
HL (m)	2.8	17.0	12.9
Od (m)	0.14	0.36	0.36

According to the optimal solutions of three cities, the depths of the board *Hs* become lager by 0.03m regularly as latitude increase. *SDw* are all greater than *SDs*, this feature can illustrate that the optimization design goal is achieved to some extent.

DISCUSSION

When the tilt angle of the horizontal shading device is variable, parameter values of the optimal solution are exaggerated for the actual project: the length of the board *Hc* are very large, and they are all the tilt up forms (the angle is positive) which are uncommon in usual. But in terms of the variable regular pattern of the solar elevation angle in summer and winter (Figure 3), the calculated results are reasonable, in other words, such form can meet the sun incident in the occasion of the lower solar elevation angle in winter, and the horizontal component which singled out from the shading boards also can obscure the solar in summer with the higher sun elevation angle. The horizontal louver shading devices which tilt up have a similar shading mechanism.

When the board of horizontal shading device is perpendicular to the wall, the length of the board *Hc* and the distance between the root of the board and the adjacent side of the window *Dra* are all within the common ranges, and this can be accepted by the actual project; the length singled out on both sides *Hl* are about 17m, and this explains its influence on the effect of external shading can’t be ignored, and it suit the flat connectivity design on the south facade of the building.



a) Summer solstice noon   b) Winter Solstice noon

***Figure 3**. Solar incidence angle in Guangzhou (optimal solution model of horizontal shading device with variable tilt angle)*

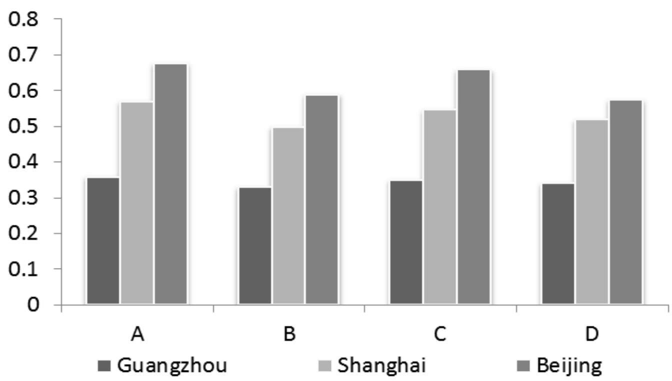


***Figure 4** “SDw-SDs” in optimal solutions of three cities*

In figure 4:

A: Horizontal shading device with variable tilt angle

B: Horizontal shading device with fixed tilt angle (perpendicular to the wall)

C: Horizontal louver shading device which tilt up to 30 °

D: Horizontal louver shading device which tilt down to 30 °

The results of several rounds of calculation illustrate the value of the external shading coefficient is more stable: the changes of the outside shading coefficient in each computation is about three decimal places, and this is much smaller than the changes in the geometrical dimensions; therefore, the external shading coefficient can better reflects the regular pattern of the changes of the external shading facilities caused by the changes in latitudes between three cities (Figure 4).

As shown in Figure 4, for the four kind of shading devices involved in this paper, "*SDw-SDs"* in optimal solutions for each kind are all increase as latitude increase, and this explains that in the condition with the optimization goal of "biggest difference between *SDw* and *SDs*", the same kind of external shading component can obtain a better shading effect throughout the whole year along with the increasing latitude; in addition, it can be the same sequence according to the "*SDw-SDs*" from max to min in three cities: horizontal shading device with variable tilt angle (tilt up) → horizontal louver shading device which tilt up to 30° → horizontal louver shading device which tilt down to 30° → horizontal shading device with fixed tilt angle (perpendicular to the wall), and this explains in the condition with the default optimization goal, the external shading devices obtain such sequence under the shading effect throughout the whole year, but take the actual needs into account additionally, horizontal louver shading device which tilt up to 30° will be the best of the four kind devices which involved in this paper.

CONCLUSION AND IMPLICATIONS

This paper aims four common shading devices which consist of horizontal shading devices (variable tilt angle and perpendicular to the wall), horizontal louver shading devices (tilt up and down to 30°), along with the optimize design goal of "shading in summer and solar in winter, both as much as possible at the same time", and take examples of Guangzhou, Shanghai and Beijing, using GH and Ecotect to establish generation system based on the parameter optimize design, calculating nearly one hundred times, and do a lot of data analysis, the more important in the main conclusions of the work contains: (1) considering the full year effect of external shading and actual demand, the best one of the four kind external shading devices which involved in this paper is horizontal louver shading device which tilt up to 30°; (2) the same kind of external shading component can obtain a better shading effect throughout the whole year along with the increasing latitude.

The generation system based on the parameter optimize design in this paper could adjust the parameters (independent variables and constants) of the parametric model for different specific design requirements (for example, singled out length of both side can be fixed, or the shading device can be changed to be synthesized shading device or other kind, and facade can be changed, et al), to more in line with the needs of actual design; and these adjustments are relatively easy to be achieved. Due to the limitation of length, this paper dose not investigate more about the optimal design of external shading, but the method which described in this paper could be a problem-solving mode to assist the theoretical studies and program design better.

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