Research on Energy-saving Shape Design of High School Library Building in Cold Region

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Abstract. Considering climatic characteristics in cold region, existing high school libraries in Changchun are researched according to investigation of real conditions of these library buildings. Mathematical analysis and CAD methods are used to summarize the relation between building shape and building energy saving of high school library. Strategies are put forward for sustainable development of high school library building in cold region, providing reliable design basis for construction of high school libraries in Changchun.

1. Introduction

For the university libraries in the severe cold area are affected by the regional climate characteristics and their use purposes, the high energy consumption of buildings has always been a chronic problem that constrains the sustainable development of university construction. Based on this problem, this paper takes the university libraries in Changchun as the research object, and combines the data of the real investigation in the method of mathematical analysis and computer aided design, sums up the energy consumption features of the university library buildings, and puts forward a sustainable development strategy for the university library Building, thus provides a reliable design basis for the construction of university libraries in the region.

2. Analysis of Energy Consumption Features of University Libraries

In the campus planning, the construction of libraries has always been the key point of campus planning for they carry two major functions: teaching and research, and integrate academic and service in one, thus they, usually as the landmark of the university campuses, play a vital role in the sustainable development [1]. Their service targets are mainly students and research workers, and their use time is rather concentrated, which is mainly between 9:00 to 17:00 from Monday to Friday.

2.1 Analysis of Energy Consumption of University Libraries

The shape change of buildings will directly affect the amounts of energy consumption of buildings. The "Standards of Energy Conservation of Public Building" (GB50189-2015) clearly stipulates that the shape coefficient of buildings in the cold area should not be more than 0.40 to facilitate the design of low-energy consumption buildings [2].

The transfer ways of heat and moisture through the building envelope structure can be divided into radiation, convective heat transfer and thermal conductivity. Under the effects of integrated heat transference, the amount of heat transferred through the envelope structure of unit building area is [3]:

$$q_{HT} = (t_i - t_e)\left(\sum_{i=1}^{m} \varepsilon_i K_i F_i\right) / A_0$$

q_{HT} - the transference amount of heat and moisture of unit building area through envelope structure （W/m^2）;

K_i -the thermal conductivity of envelope structure [W/（m^2·K）];

$t_i - t_e$ -the difference between indoor and outdoor temperatures（℃）;

F_i -the area of envelope structure（m^2）;

ε_i -the correction coefficient of thermal conductivity of envelope structure;

A_0 -the building area（m^2）.

In the cold area, the shape coefficient for building design is put forward to select a reasonable area of heat transfer for buildings with fixed volume, so that the heat losses through the building exterior structure are minimized and the energy consumption can be lowered under the influence of the temperature change, considering the area factor from the perspective of building area.

3. Effects of Shape Design of University Library Structures on Energy Conservation

The shape of university libraries is influenced by campus planning, historical context, technical conditions and design inspiration [4], thus the relationship between plane shape and building energy can be studied through the setting of building shape. Therefore, it is necessary to simplify the building plane of typical university libraries in Changchun area, analyze and study the relationship and change law between the plane shape, the volume and the shape coefficient through typical cases.

To ensure the representativeness and comparability of the discussed results, the common triangular plane, quadrilateral plane and circular plane, which are common in architectural design, will be discussed one by one to conclude the linear relationship between different plane shape, volume model and shape coefficient.

3.1 Shape Analysis of Buildings with Triangle Plane

In order to facilitate the calculation and further discuss the change law between the plane shape and the shape coefficient, the triangular plane of buildings is simplified into a triangular prism model with isosceles triangle at the bottom (Figure 1).

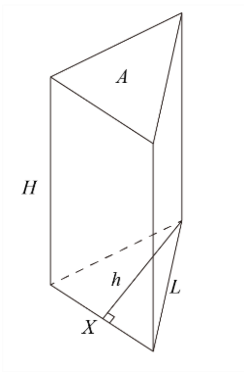

Figure 1. Triangular prism model.

The model parameters of triangular plane are set:

A is the bottom area of building model with triangle plane（m^2）;

X is the bottom side length (m);

h is the height of the bottom plane (m);

L is the perimeter of bottom plane (m);

H is the height of building model (m);

S is the shape coefficient of building model.

$$S = \frac{\left[X + 2\left(X + \sqrt{X^2 + 4h^2}\right)\right]H + \frac{Xh}{2}}{\frac{Xh}{2}H} = \frac{L}{A} + \frac{1}{H}$$

Assume that the bottom area of the triangle model is 10, 50, 100 m2, and by changing the model parameters, we can calculate the corresponding values of shape coefficient, S, according to different model heights (Table 1).

Table 1. Shape coefficient with volume.

The bottom area of building model A （㎡）		10	50	100
S	H =1m	2.442	1.645	1.456
	H =2m	1.942	1.145	0.956
	H =5m	1.642	0.845	0.656
	H =10m	1.542	0.745	0.556
	H =25m	1.482	0.685	0.496

3.1.1 Bottom Side and Shape Coefficient of Buildings with Triangular Plane. With X increasing, the change trend of shape coefficient, S, is: the early decline is more obvious (X = 2), then declines slowly to a minimum, and increases by a little. The higher the height of the building is, the smaller the influence of the bottom edge X on the shape coefficient is. The shape coefficient of different height models, S, all reduces to the minimum when the bottom plane is an equilateral triangle. And if the triangle edge changes, the value of S will increase (Figure 2).

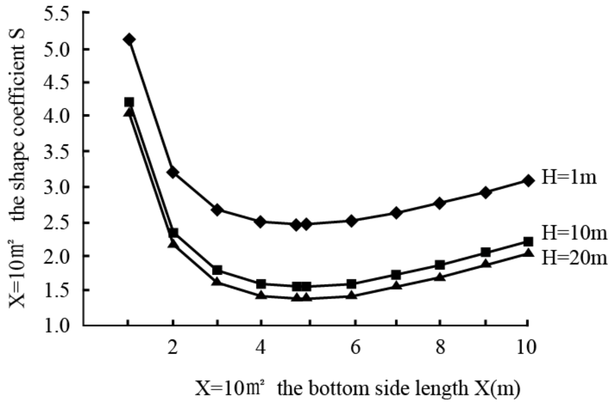

Figure 2. A=10 ㎡ Shape coefficient with hemline *X*.

3.1.2 Bottom Plane Perimeter and Shape Coefficient of Buildings with Triangle Plane. The relationship of perimeter and shape coefficient is linear (Figure 3), that is, no matter how the building height changes, the model's shape coefficient increases with the bottom surface perimeter increasing:

$$S = \frac{L}{A} + \frac{1}{H} = \frac{L}{10} + \frac{1}{H} \quad （\text{slope } K = \frac{1}{10}）$$

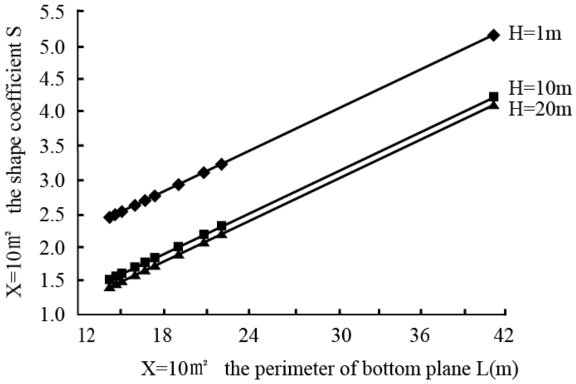

Figure 3. A=10 ㎡ Shape coefficient with perimeter L.

Similarly, when the bottom plane of the building is an equilateral triangle, the shape coefficient, *S*, of models with different heights is reduced to the minimum, and then the shape coefficient, *S*, will increase.

3.1.3Height and Shape Coefficient of Buildings with Triangle Plane. First of all, the analysis of Figure 4 verifies the previous analysis results. When L = 14.418m, the overall value of shape coefficient, S, of the building model is the smallest. With the increase of the L value, the shape coefficient increases gradually. At the same time, the vertical spacing of the curves in Figure 4 is relatively uniform, and S value increases proportionally with the value of L increasing, that is, the relationships between the triangle perimeter, L, and the shape coefficient of models is linear.

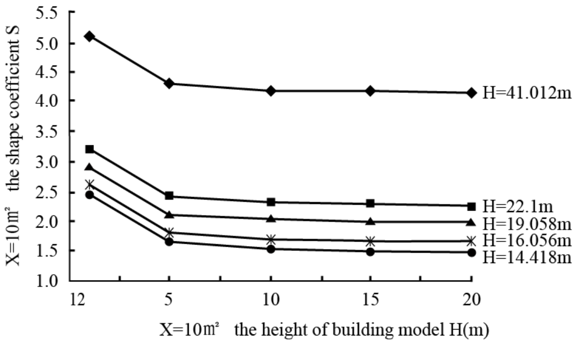

Figure 4. A=10 ㎡ Shape coefficient with highness *H*.

3.1.4 Change Law of Shape Coefficient of Buildings with Triangle Plane. (1) The shape coefficient, S, of rectangular building plane slowly reduces with the building height, H, increasing and finally tends to be a straight line.

(2) Similarly, the larger the building volume is, the smaller the shape coefficient is, in which the bigger the increase of body volume is, the smaller the impact of the volume changes is.

(3) When the building plane is square, its shape coefficient, *S*, is the smallest.

3.2 Shape Analysis of Building Shape with Rectangular plane

Rectangular plane is most widely used in the architectural design, and its guidance for the research object is typical (Figure 5). In the same way, by consuming the bottom areas, A, of the building model are 10, 50, 100 m2, we change the model height, *H*, to study the variation law of its shape coefficient, *S*, (Table 2).

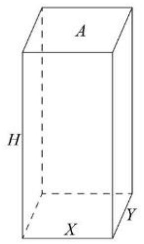

Figure 5. Rectangular plane model.

The parameter setting of building model with rectangular plane:
A is the bottom surface area of the building models with rectangular plane (m^2),
X is the bottom length (horizontal length) (m),
Y is the bottom width (vertical side length) (m),
L is the perimeter of the bottom surface (m),
H is the height of the model (m),
and S is the shape coefficient of the model.

Table 2. Shape coefficient with volume.

The bottom area of building model *A* （㎡）		10	50	100
S	*H* =1m	2.265	1.566	1.400
	H =2m	1.765	1.100	0.900
	H =5m	1.465	0.766	0.600
	H =10m	1.365	0.666	0.500
	H =25m	1.305	0.606	0.440

3.2.1 Bottom Length and Shape Coefficient of Building Bottom Surface with Rectangular plane. It is found that the change of the shape coefficient, S, according to those of the bottom side length, X, is similar to a parabola with an opening upward, but it is not a simple linear relation (Figure 6).

$$S = \frac{2(X+Y)H + XY}{XYH} = 2\left(\frac{X}{10} + \frac{1}{X}\right) + \frac{1}{H}$$

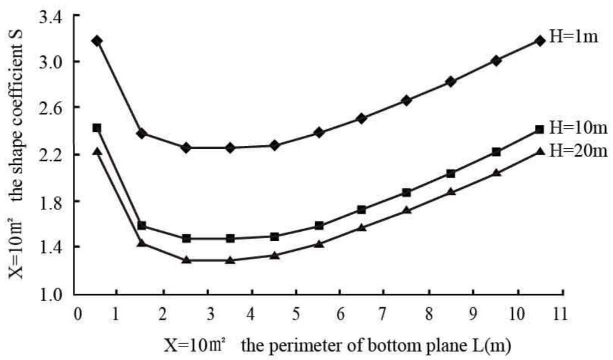

Figure 6. A=10 ㎡ Shape coefficient with highness H.

In order to get the minimum body shape coefficient S, derive the above formula,

$$\frac{dS}{dx} = \frac{d\left(2\left(\frac{X}{10} + \frac{1}{X}\right) + \frac{1}{H}\right)}{dx} = 2\left(\frac{1}{10} - \frac{1}{X^2}\right)$$

Let $\frac{dS}{dx} = 0$

Namely $2\left(\frac{1}{10} - \frac{1}{X^2}\right) = 0$

Obtain $X = \sqrt{10} \approx 3.16$

It is found that, when the bottom plane is a square (X = 3.16m), the shape coefficient of the model is the smallest, which is considered as an energy-saving building shape. At the same time, no matter how the building height changes, the changes of shape coefficient are almost the same as the changes of the side length, which sharply drop to a minimum at first, and then increase by a little.

As for buildings with the bottom rectangular plane, the relationship between the bottom width and the shape coefficient is the same as that between the length and shape coefficient.

3.2.2 Bottom Length and Shape Coefficient of Building Bottom Surface with Rectangular plane. According to the analysis, it is found that no matter how the building height, H, changes, the relations between shape coefficient, S, and the perimeter, L, in the building model are linear (Figure 7):

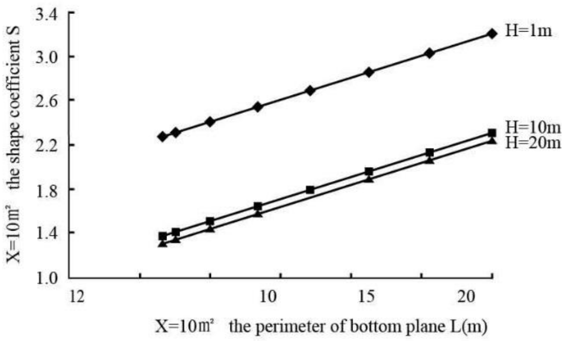

Figure 7. A=10 ㎡ Shape coefficient with perimeter L.

When the model bottom X = Y = 3.16m, the rectangular plane is a square and the shape coefficient, S, of building model is the smallest.

3.2.3 Height and Shape Coefficient of Buildings with Rectangular Plane. First of all, by comparing the curves between Figure and Figure 8, it is found that when L = 12.648m, the overall shape coefficient, S, of the prism model is the smallest, and the value of S increases with the length L increasing. The changes of shape coefficient, S, of the model are almost the same as those of the model height, H, which sharply fall to a certain value (H = 5m), then slowly reduce, and tend to a straight line.

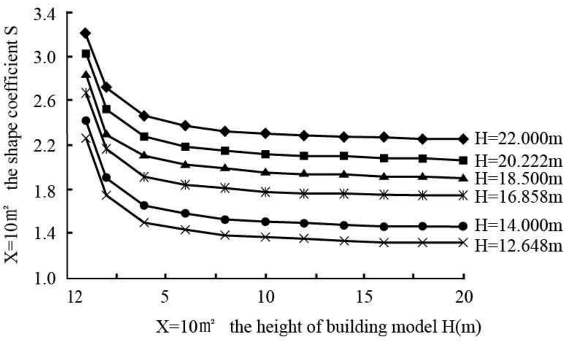

Figure 8. A=10 ㎡ Shape coefficient with highness H.

3.2.4 Change Law of Shape Coefficient of Buildings with Rectangular Plane. (1) Under the condition that the building bottom area, A, and the building height, H, are a fixed value, the relation between the changes of shape coefficient, S, and the changes of height is similar to a parabola with a upward opening rather than a simple linear, whose change process is that it falls sharply, slowly reduces to a minimum, and finally lifts by a little.

(2) The shape coefficient, *S*, of rectangular building plane slowly reduces with the building height, *H*, increasing and finally tends to be a straight line. Similarly, the larger the building volume is, the smaller the shape coefficient is, in which the bigger the increase of body volume is, the smaller the impact of the volume changes is.

(3) When the building plane is square, its shape coefficient, *S*, is the smallest.

3.2.5 Analysis of Building Shape with Round Plane. From the perspective of building construction technology, the buildings with round plane does not meet the development requirements of the building industrialization, but according to the trend of international popular design, the frequency of such a building form is still very high (Figure 9) [5].

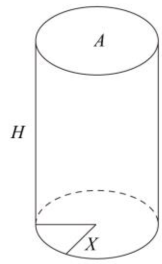

Figure 9. Round plane model.

The parameter setting of building model with round plane:

A is the bottom area of building models with round plane (m^2),

X is the round radius (m),

L is the perimeter of the bottom surface (m),

H is the height of the model (m),

S is the shape coefficient of the model.

The bottom area $A = \pi X_2 = 3.14X^2$ (π is 3.14),

and the perimeter of the bottom surface $L = 2\pi X = 6.28X$ (π is 3.14).

The shape coefficient of the model: $S = \frac{LH + A}{AH} = \frac{6.28X}{3.14X^2} + \frac{1}{H} = \frac{4}{X} + \frac{1}{H}$

In the same way, by fixing the bottom areas of building model: 10, 50, 100m^2, we can get the corresponding values of the model shape coefficient, *S*, by changing the model height (Table 3).

Table 3. The changes of the shape coefficient, S, of buildings with round plane.

the bottom area of building models *A*(m2)		10	50	100
the round radius *X*(m)		1.785	3.990	5.643
the perimeter of the bottom surface *L*(m)		11.210	25.057	35.438
S	*H* =1m	2.121	1.501	1.354
	H =2m	1.621	1.001	0.854
	H =5m	1.321	0.701	0.554
	H =10m	1.221	0.601	0.454
	H =25m	1.161	0.541	0.394

(1) The shape coefficient, S, of round buildings is inversely proportional to the building height, *H*. When the building height, *H*, increases to a certain value, the value of body shape, S, tends to be a fixed value,4/*X*;

(2) When the height of building, *H* is fixed, the shape coefficient of round buildings, *S* reduces according to the increasing of bottom perimeter, *L*, of buildings, and tends to be a same value.

Comparison of the building plane shape:

by comparing the relations between various parameters of the prism, prism and cylindrical model and the shape coefficient, it is found that no matter how the model plane areas change, the shape

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coefficient, S, of models is inversely proportional to the model height, *H*, and finally tends to be a same value. When the height of the model is the same, the shape coefficients of models are: $S_{\text{Triangular prism}} > S_{\text{Quadrangular prism}} > S_{\text{Cylindrical cylinder}}$ —— that is, when the building plane is a regular polygon, the more the number of edges is, meaning the regular polygon tends to become a circle, the smaller the shape coefficient is, thus the build is an energy-saving one.

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Reasonable shape design can reduce heat exchange between buildings and the outside. The study shows that the shape coefficient increases by 0.01, the energy consumption of buildings will correspondingly increase by about 25%. Therefore, building graphic design should be simple and complete and avoid too many uneven outlines —— that is a proper length-width ratio should be selected.

4. Conclusion

The sustainable development approach of university library construction should not only focus on the design of architectural images, but also pay more attention to research of the architectural technology improvement and development, because the innovation of building technology is the life source for sustainable development of architecture. [6]

The sustainable development design of university libraries requires the architect not only to be the creator of the architectural images, but also to have the spirit of scientific research and exploration, who should own a clear idea for the architectural design, abandon the technical or artistic prejudice, and, based on build technology, create architectural images meeting the requirements of social development, thus make great contributions to the inheritance and development of university library construction.

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