Study on the influence of different surface colors on energy consumption of mall in hot summer and cold winter areas

Siru Qian¹, Enshen Long*, Shurui Guo², Ying Zhang³, YanZhao⁴

MOE Key Laboratory of Deep Earth Science and Engineering, College of Architecture and Environment, Sichuan University, Chengdu, 610065, China

*E-mail: longes2@163.com

Abstract. China's energy consumption of building operation is increasing year by year. The characteristic of building envelope is an important factor affecting energy consumption, including color and material. This paper based on the analysis of the relationship between the heat balance of the enclosure structure and the solar radiation, the micro effects of different color on the daily and hourly air conditioning energy consumption of the building are studied, and the energy saving mechanism is further divided Analysis. We found that: through the simulation calculation, the cooling load accounts for a large proportion in the hypermarket, and the number of days with cooling demand accounts for 361 days, the cooling energy consumption from May to October accounts for 100% of the total energy consumption. When the color of the coating applied on the building surface is from deep to shallow, with the increase of daily cooling consumption, the larger the number of points in the energy saving of air conditioning, the more significant the energy saving effect. The change of paint color mainly affects the energy saving rate of air conditioning when there is solar radiation in the supermarket. From the micro dimension, with the increase of solar radiation, the trend of absolute energy saving and relative energy saving effect of building air conditioning cooling load is the same.

Keywords: Building surface; Solar radiation absorption coefficient; Energy consumption; Cooling energy saving amount/rate

1. Introduction

Influenced by the rapid growth of economy and urbanization, China's construction space is expanding rapidly, and the energy consumption of building operation is also increasing year by year. If the current energy consumption growth rate is maintained, China's total energy consumption will reach 6.6 billion TCE by 2020, which greatly exceeds the energy consumption ceiling set by energy supply and CO₂ emission reduction[1]. Architectural color
and architectural form constitute the main external expression of architecture, which is the embodiment of urban context, vitality and bearing capacity. Because of the intuitiveness and impact of color, it has the first impact on the urban landscape environment and the main impression. At the same time, the change of color has a direct impact on building energy consumption.

In recent years, researchers generally agree that the change of paint color will eventually affect the change of building energy consumption. However, the change of building energy consumption caused by paint color is not comprehensively considered according to meteorological conditions. Therefore, by grasping these factors and combining the change of solar radiation absorption coefficient, and discussing the influence of color on building cooling load and energy consumption from the micro perspective of day by day and time by time, we can explain the difference of building energy consumption change from the mechanism.

2. Research Objects and Methods

2.1 Simulation object

The building model used in this paper is a large-scale shopping mall with four floors above the ground and one underground floor facing north and south. The total height is 23.99m, the total building area is 92940m², the area of the enclosure structure is 91018.76m², and the volume is 420646.44m³, and the shape coefficient is 0.22. The building area of the first floor is 18588m². The first floor plan is shown in Figure 1. The second, third and fourth floor plan is basically the same as the first floor plan. The ratio of windows to walls in the southwest is 0.08 and 0.27 respectively. There is no external window in the northeast. The parameters of the building model are in Table 1.

![Figure 1. Building plan](image)

Table 1. Thermal characteristics and solar radiation absorption coefficient of enclosure
structure

| Enclosure structure | wall | window | frequency of ventilation | Solar radiation absorption coefficient |
|---------------------|------|--------|--------------------------|---------------------------------------|
| heat transfer       | 1    | 3      | 1.5 times/h              | Bright white 0.3                      |
|                     |      |        |                          | Meter white 0.45                      |
|                     |      |        |                          | Pearl Silver 0.55                     |
|                     |      |        |                          | Light gray 0.65                       |
|                     |      |        |                          | Black 0.75                            |

**2.2 Meteorological situation in hot summer and cold winter areas**

In this paper, the hot summer and cold winter area of Chengdu is selected as the research background, and the total solar radiation in Chengdu presents a wave like trend. Among them, December is the valley value, which is about 43.1KW/m², rising from February, reaching the peak value in August, which is about 130.718KW/m², and then gradually decreasing. And the distribution of solar energy resources in this area is relatively concentrated from May to August, all of which are above 100KW/m², reaching the peak in May; in January, February, November and December, solar energy resources are relatively scarce. In the high temperature period in summer, the solar radiation value is very high; in the cold season in winter, the solar radiation value is very low. The monthly average dry bulb temperature showed an upward trend from January to July, peaked in July and declined from August to December. Therefore, it is necessary to use solar energy resources flexibly according to the solar radiation value and temperature, and analyse the relationship between the climate environment and buildings dynamically according to local conditions in combination with other meteorological conditions.

**2.3 Computing method**

The outdoor meteorological parameters of Chengdu City in the hot summer and cold winter climate area are taken from the Energy Plus meteorological database. Assuming that the thermal characteristics of the building envelope meet the energy-saving design standard[2], the air change frequency is taken as 1.5/h, the indoor environment design temperature, the indoor heating temperature in winter is set as 18 ℃, and the indoor air conditioning temperature in summer is set as 26 ℃. The solar radiation absorption coefficient of the coating is 0.3 (bright white), 0.45 (meter white), 0.55 (pearl silver), 0.65 (light gray),0.75 (black)[3], and the exterior wall coating of five colors is simulated. Using the characteristic temperature method[4], we can reveal the relationship between room (building) cooling (heating) load or energy consumption and other factors. The reliability of this method is verified by experiments and software comparison in a large number of literature[5][6]. Based on the indoor characteristic temperature $T_{\infty} = 26$ ℃ in Chengdu area, the influence of different color coatings on building energy consumption is considered.

**3. Differences in the impact of building energy consumption**

**3.1 Proportion of monthly cooling consumption**

When the building characteristic parameters and meteorological conditions are identical, changing the solar radiation absorption coefficient of the building skin can respectively simulate and predict the changes of hourly load, daily, monthly and even annual energy
consumption, which includes both heat consumption and cooling consumption. Figure 2 shows the proportion of monthly cooling consumption in total energy consumption. It can be seen from the figure that the proportion of cooling consumption in the whole year has exceeded 50% in 12 months, showing an upward trend from January to May, 100% in January to October, and a downward trend from November to December. It can be seen that the cooling consumption accounts for a large proportion of the total energy consumption in the hypermarket, and the air conditioning energy consumption from May to October accounts for 100% of the total energy consumption.

![Figure 2. Change of monthly cooling consumption proportion](image)

3.2 Micro energy-saving mechanism of different color

In order to explain the difference of energy-saving effect caused by different paint colors, this paper reveals the microscopic texture under the phenomena from the daily and hourly micro-level, combined with meteorological factors.

Figures 3 and 4 show the changing rule of daily energy saving with the daily cooling consumption when building skin is coated with light gray paint ($\alpha =0.65$) and bright white paint ($\alpha =0.3$).

![Figure 3. The change of cooling energy saving amount with daily cooling consumption when applying light gray paint](image)

Figures 3 and Figures 4 show that there are four points of energy saving in building skin
paint color, no matter from black to light gray or bright white, which means that the days with cooling demand are 361 days. The change range of daily cooling consumption is similar when different color coatings are applied, and the law of increasing energy saving of air conditioning also shows a great degree of similarity. The individual law is that when the color of coatings painted on building skin changes from light gray to bright white, it is not only from deep to shallow, but also with the increase of daily cooling consumption, the larger number of points in energy saving of air conditioning will be distributed, and the more remarkable energy saving effect will be achieved.

![Figure 4](image.png)

**Figure 4.** The change of cooling energy saving amount with daily cooling consumption when applying bright white paint.

Figure 5 and Figure 6 shows the changing rules of energy saving rate of air conditioning with light gray paint ($\alpha=0.65$) and bright white paint ($\alpha=0.3$) applied on building surface. It can be found from the figure that when four different paint colors are applied on the building surface, the change of paint color mainly affects the air conditioning energy rate of the research model at several moments after sunrise in the morning and before sunset in the evening. The shallower the paint color is, the lower the solar radiation absorption coefficient is, the more time the paint color affects the energy saving rate of the research model, the greater the contribution of energy saving rate is. Comparatively speaking, light gray paint ($\alpha=0.65$) concentrates on the time interval of 9-21 hours, mainly in the 0.01%-4.8% area; bright white paint ($\alpha=0.3$), the energy-saving rate of the main distribution area increased to 5%-21% and the broadest value of energy-saving rate distribution was the largest. Thus, with black paint as the contrast parameter, the contribution of light gray paint to energy saving rate is slight, and bright white paint has the greatest impact on energy saving rate.
Figure 5. Hourly cooling energy saving rate when applying light gray paint.

Figure 6. Hourly cooling energy saving rate when applying bright white paint.

Figure 7 shows the Hourly cooling energy saving amount when applying bright white paint. Generally consistent, in order to avoid redundancy, take $\alpha = 0.3$ (bright white) as an example, and also based on the comparison of building painting with black paint. It can be seen from the observation chart that 5401 points with energy saving rate are concentrated in the time interval from 8:00 to 21:00. There are 361 energy-saving points in the 9 hours of 10-18, and the energy-saving rate is mainly distributed in 5% - 21% area. This shows that the change of paint color mainly affects the air conditioning energy saving rate of the research model after sunrise and several moments before sunset in the evening. The lighter the paint color, the lower the solar radiation absorption coefficient, the more time the paint color affects the energy saving rate of the research model, and the greater the contribution of energy saving rate.
Figure 7. Hourly cooling energy saving amount when applying bright white paint.

It can be seen from the observation chart that the moment with the highest energy-saving rate occurs at 11 a.m., and the points with higher energy-saving rate are mainly distributed between 10 a.m. and 4 p.m., which are basically the same as the trend of solar radiation and energy-saving. According to the calculation formula of energy saving rate:

\[ R = \frac{L_1 - L_2}{L_1} \times 100\% \]  \hspace{1cm} (1-1) \]

\( R \) = Cooling energy consumption change rate;  
\( L_1 \) = Cooling load or energy consumption when applying black coating;  
\( L_2 \) = Cooling load or energy consumption when applying other coating.

At noon, the solar radiation is large, and the cooling load demand of air conditioning is also large. However, the ratio of energy saving rate is not necessarily corresponding to it. The scatter points in the Figure 8 shows an upward trend with the increase of solar radiation. The scatters with zero or low solar radiation represent the morning and evening before sunrise from the dimension of each day, and the scatters with high solar radiation represent the noon. From a wide time dimension, the scatter with zero or low solar radiation value also represents cloudy or rainy days, and the scatter with high solar radiation value represents sunny days, so there will be a large number of overlapping scatter in the figure. The characteristics of the figure is as follows: the scatter of cooling load in Figure 9 increases less with the increase of solar radiation. That is to say, with the increase of solar radiation, the increase of cooling load energy saving as a molecule is large, and the increase of cooling load as a denominator is small, and the ratio energy saving rate will still show the same trend as the energy saving. From the perspective of time-by-time, with the increase of solar radiation, the trend of absolute energy saving and relative energy saving effect of building air conditioning cooling load is the same.
Fig 8. Hourly cooling load changes with total solar radiation

4. Conclusions

In this paper, the micro effects of different colors on the daily and hourly air-conditioning energy consumption of the building are studied, and the energy-saving mechanism is further divided Analysis:

1. Results showed the proportion of cooling consumption in total energy consumption in shopping malls is very large throughout the year. The cooling energy consumption from May to October accounts for 100% of the total energy consumption.

2. Through simulation calculation, there are 361 days of cooling load demand in the mall. When the color of the coating applied on the building surface is from deep to shallow, with the increase of daily cooling consumption, the larger the number of points in the energy saving of air conditioning, the more significant the energy saving effect.

3. The change of paint color mainly affects the energy-saving rate of air conditioning when there is solar radiation in the research hypermarket. The lighter the paint color, the lower the solar radiation absorption coefficient, the more time the paint color affects the energy-saving rate of the research model, and the greater the contribution of energy-saving rate.

4. From the micro dimension, with the increase of solar radiation, the trend of absolute energy saving and relative energy saving effect of building air conditioning cooling load is the same. Because with the increase of solar radiation, the increase of molecular cooling load energy saving is large, and the increase of denominator cooling load is small, the ratio energy saving rate will still show the same trend as energy saving. So there will be the same change trend among the three.

References

[1] Chen Peng, Determination of the Upper Limit of Building Energy Consumption in China. Construction technology, 2015. (In Chinese)

[2] Ministry of housing and urban rural development, Energy saving design standard of residential buildings in hot summer and cold winter areas, China Construction Industry Press, 2010. (In Chinese)

[3] Shunjie Sun, Study on the preparation and properties of color heat reflection and heat insulation coating, Beijing Technology University, 2013. (In Chinese).
[4] E.S. Long, Gene Theory of Building Energy Consumption and Building Energy Conservation Practice, Science Press, Beijing, 2009. (In Chinese).

[5] E.S. Long, Regression equations of annual electric fare ratio of ice-storage to conventional cooling scheme for commercial buildings, Build. Environ. (2005).

[6] E.S. Long, Y. Wang, Are the relative variation rates (RVRs) approximate in different cities when the same energy-efficiency reform is taken to the same building, Build. Environ. 40 (4) (2004) 473–480.