Influence of Heat Reflective Wall on Air Conditioning Energy Consumption of Office Buildings in Chongqing

ZhongYu Hao, DaChuan Shi, Hou QianKun and ZhiQiang Wang

National Centre for International Research of Low-carbon and Modular Garden Buildings, Chongqing University, China
Email: zhongyuhaoyu@126.com

Abstract. As the main channel of heat and humidity exchange between the building and the external environment, the improvement of the thermal insulation performance of the external wall is crucial to reduce the building energy consumption. However, the influence of heat reflective exterior walls on the energy consumption of air conditioning is rarely studied. This paper aims to study the effects of heat reflective walls on air conditioning energy consumption (ACEC) through testing and simulation. The measured results show that the heat reflective exterior walls will reduce the summer ACEC of the room and increase the ACEC of the room in winter, but the contribution rate is higher in summer than in winter. At the same time, the ACEC simulation results show that the energy saving per unit area of the heat reflective wall of the office building is 0.0149 kWh/(m²•a) for the west outer wall, 0.0131 kWh/(m²•a) for the east outer wall, 0.0121 kWh/(m²•a) for the south outer wall, and 0.0113 kWh/(m²•a) for the north outer wall. These provide a useful reference for the research and application of heat reflective walls in Chongqing.

1. Introduction
The application research of high reflection heat insulation coating mainly focuses on roof, road and so on. Among them, cold roof research first began in the 1980s. In the late 1990s, the U.S. department of energy and the environmental protection agency launched the cold communities’ project [1], which aims to reduce energy use and improve urban living conditions by utilizing a regional environmental system of high-reflectivity roofing and pavement materials as well as shade. The cold roof research centre, the green building association, green earth, energy star and other organizations in the United States have developed relevant standards, and proposed regulations on the reflectivity limit of cold roofs, which has promoted the promotion and application of cold roofs [2]. Levinson et al. [3][4][5][6][7] of Lawrence Berkeley laboratory in the United States have conducted long-term research on the application of high-reflection materials in building roofs, showing that cold roofs can alleviate urban heat island effect and reduce building energy consumption by improving urban albedo. The application of highly reflective materials can reduce the cooling load and peak cooling energy. Through the study of cold roof, Haberl and Cho [8] found that the energy saving rate brought by the application of cold roof in residential and commercial buildings was up to 44%. Levinson et al. [9] studied the application effect of highly reflective materials on non-residential buildings in warm climate, and the results showed that building energy consumption decreased by 10–30% on air conditioning days in summer. Akabari et al. [10] compared the energy saving efficiency of a traditional dark roof with a reflectivity of 0.1 and a cold roof with a reflectivity of 0.4 at different temperatures, indicating that energy saving could be 250kWh per year in a mild climate and 1000kWh per year in a hot climate. Pablo J Rosado1 and Ronnen Levinson used various types of buildings in...
California as a model to perform a full-scale simulation to obtain energy savings for buildings using cool walls. [11]

Through the above research, it is found that the thermal reflection coating performance and application research started earlier, especially the development of cold roof technology has been very mature. However, there are few researches on cold wall, so it is urgent to carry out relevant researches to promote the popularization and application. Therefore, we will conduct the following research. This paper takes the office building in Chongqing as the object, tests the relevant thermal parameters of the heat reflective wall in summer and winter, and obtains the measured effect of the heat reflective wall on the ACEC of the room.

Based on the climatic characteristics of Chongqing area, this paper uses the measured office building as a model to simulate the annual ACEC of each heat-reflecting exterior wall, and obtains the influence of different heat reflective walls on building energy saving.

2. Methodology

2.1. The experiment site
As shown in Figure 1 and Figure 2, the experimental site is an office building of a factory in Jiangjin district of Chongqing. The building location is 106°26'38" east longitude and 29°29'37" north latitude, with a total of four floors. Two rooms on the west side of the third and fourth floors are selected as the measured objects. The west wall of the fourth floor room is not treated, the west wall of the third floor room is sprayed with heat reflective coating. The office building is surrounded by an open space that does not block the building.

2.2. The experimental scheme
Room 1 and 2 were selected as measured rooms, and the indoor layout was shown in Figure 3. The length, width and height of the rooms were 6.0×3.6×3.3 m. The two rooms are basically the same except for the different surface characteristics of the west wall. The air conditioner is set at 26 ℃ in summer and 20 ℃ in winter. The measurement time is 8:00~18:00 and the test time interval is 1h. The main thermal environment parameters tested include indoor and outdoor air temperature, inner and outer surface temperature of the west wall, room air conditioning power consumption and other parameters. The outdoor temperature measurement points are arranged under the shade around the building, the indoor air temperature measurement points are arranged on the diagonal three equal points of the room, and the inner and outer surface temperature measurement points are arranged on the outer wall three equal points. All measuring points are 1.5 meters above the ground.

2.3. Simulation
Based on the actual measurement of office buildings, the weather data were selected as CSWD, and the energy consumption simulation software DesignBuilder v5.0 was used to analyse the annual ACEC of heat reflective coating on different exterior walls. The average reflectance setting values of the outer wall surfaces with different orientations are varied from 0.2 to 0.8, respectively, simulating the changing trend of ACEC under the corresponding conditions. In order to make the simulation result
more representative of the actual situation, and reference to the error control selection in IPMVP, 20% is adopted. [12]

3. RESULT

3.1. Analysis of the measured
It can be seen from table 1 that during the summer test, the room 1 (heat reflective west wall) air conditioner consumes an average of 10.42 kWh/d, and the room 2 (ordinary west wall) air conditioner consumes an average of 11.86 kWh/d. By comparison, the use of thermal reflective coatings can reduce the cooling power consumption of the room in summer by 1.43 kWh/d. During the winter test, the room 1 air conditioner consumes an average of 10.25 kWh/d, and the room 2 air conditioner consumes an average of 10.07 kWh/d. By comparison, in the room with a thermal reflective wall, the heating power consumption in winter increased by 0.18 kWh/d. Because the test data cannot reflect the annual energy consumption, and the measured data will have certain errors due to the influence of roof heat transfer, this paper takes the measured room data on the third floor as the boundary condition to simulate and analyse the annual air conditioning energy consumption under different reflectance of the building's external wall.

| DATE | Room2 ACEC (kWh·d⁻¹) | Room1 ACEC (kWh·d⁻¹) | Difference between ACEC of R1 and R2 (kWh·d⁻¹) | Energy savings per square meter(kWh·d⁻¹·m⁻²) |
|------|-----------------------|-----------------------|-----------------------------------------------|--------------------------------------------|
| 8.23 | 12.39                 | 10.77                 | 1.62                                          | 0.08                                       |
| 8.25 | 13.34                 | 11.58                 | 1.76                                          | 0.08                                       |
| 8.26 | 12.82                 | 11.24                 | 1.58                                          | 0.07                                       |
| 8.27 | 13.07                 | 11.04                 | 2.03                                          | 0.09                                       |
| 8.28 | 13.65                 | 12.01                 | 1.64                                          | 0.08                                       |
| average | **13.054**           | **11.328**            | **1.726**                                    | **0.08**                                   |
| 1.17 | 10.85                 | 11.03                 | -0.18                                         | -0.008                                     |
| 1.18 | 10.82                 | 11.25                 | -0.43                                         | -0.020                                     |
| 1.19 | 10.85                 | 10.96                 | -0.11                                         | -0.005                                     |
| 1.20 | 11.34                 | 11.49                 | -0.15                                         | -0.007                                     |
| 1.21 | 11.08                 | 11.16                 | -0.08                                         | -0.004                                     |
| average | **10.988**           | **11.178**            | **-0.19**                                    | **-0.009**                                 |

3.2. Simulation analysis
Figure 4 reflects the trend of air conditioning refrigeration energy consumption and heating energy consumption after the use of thermal reflective coatings on different walls of the office building. It can be seen from the figure that as the reflectivity of each wall increases, the energy consumption of air conditioning refrigeration decreases, the heating energy consumption increases, and the overall linearity changes. It can be seen from the simulation results that the reduction of air-conditioning refrigeration energy consumption per unit building area of the outer wall is 2.49kWh/ (m² • a) for the western wall, 4.52 kWh/ (m² • a) for the south wall, 2.18 kWh/ (m² • a) for the east wall, and 4.00 kWh/ (m² • a) for the north wall. Due to the different areas of the walls of the building, the wall area of the east and west is 130.5 m², and the wall area of the north and south is 265.5 m². Therefore, the energy consumption reduction of air-conditioning refrigeration per square meter of wall is: western wall 0.0191kWh/ ((m²)² • a), south wall 0.0170 kWh/ ((m²)² • a), east wall 0.0167 kWh/ ((m²)² • a), and north wall 0.0151 kWh/ ((m²)² • a). Therefore, the ability to save energy for the summer cooling of the building from different walls is West Wall > South Wall > East Wall > North Wall.

In winter, the energy consumption of air-conditioning heating in each unit area of the outer wall is 1.31kWh/ (m² • a) in the south wall, 0.54 kWh/ (m² • a) in the west wall, 1.01 kWh/ (m² • a) in the north wall, and 0.47 kWh/ (m² • a) in the east wall. The reduction of air conditioning and refrigeration
energy consumption per unit area of the external wall is 0.0048 kWh / ((m²)² • a) for the south wall, 0.0041 kWh / ((m²)² • a) for the west wall, 0.0038 kWh / ((m²)² • a) for the north wall, and 0.0036 kWh / ((m²)² • a) for the east wall. Therefore, the increase in ACEC of the building in winter is South Wall > West Wall > North Wall > East Wall. Based on the above analysis, it can be seen that the application of heat reflective coating towards different walls can reduce cooling energy consumption of the office buildings in summer, but at the same time increase the heating energy consumption in winter. Therefore, for the energy saving effect of the whole year, it is still necessary to consider the combined influence of the thermal reflective wall on the cooling energy consumption and the heating energy consumption of air conditioning.

Figure 4. The reflectivity of heat reflective coating on the surface of the east, west, north and south walls changes from 0.2 to 0.8, and the trend of building refrigeration (heating) energy consumption.

Figure 5 reflects the trend of the total annual ACEC after the use of thermal reflective coatings on different walls of the office building. It can be seen from the figure that as the reflectivity of each wall increases, the overall ACEC of the building shows a decreasing trend and changes linearly. It can be seen that the reduction of air-conditioning refrigeration energy consumption per unit building area is 1.95 kWh/ (m² • a) for the western wall, 3.21 kWh/ (m² • a) for the south wall, 1.71 kWh/ (m² • a) for the east wall, and 2.99 kWh/ (m² • a) for the north wall. By calculating the energy saving per unit area of the wall, the west wall is 0.0149 kWh / ((m²)² • a), the east wall is 0.0131 kWh / ((m²)² • a), the south wall is 0.0121, and the north outer wall is 0.0113 kWh / ((m²)² • a). Therefore, the reduction of the total ACEC of the building for different walls is West Wall > East Wall > South Wall > North Wall. The use of heat reflective coatings can significantly reduce the total ACEC of the building throughout the year. Therefore, the thermal reflecting exterior wall is a very effective energy-saving measure for the energy-saving renovation of office buildings in Chongqing.

Figure 5. The reflectivity of the heat reflective coating on the surface of the east, west, north and south walls changes from 0.2 to 0.8, and the trend of ACEC in buildings throughout the year.

4. Conclusion
Through the construction of the thermal reflection wall measurement platform, this paper carries out the measurement of ACEC in the summer and winter seasons of the office building heat reflective wall and ordinary wall in Chongqing. Combined with the annual ACEC simulation results, the energy-
saving effect of the heat reflective wall of office buildings is obtained. The main findings are summarized as follows:
The measurement of the use of heat reflective coatings on the west wall of the office building in Chongqing shows that the summer heat reflective wall saves an average of 0.066 kWh/d, but in winter it increases the average energy by 0.008 per day. In general, the heat reflective western wall can reduce the ACEC in summer, and the increased ACEC in winter only accounts for 12.12% of the ACEC in summer.
By simulating the ACEC with different heat reflective walls, it can be seen that the east, west, south and north of the office buildings in Chongqing use heat reflective walls to reduce the ACEC of the whole year. The energy saving per unit area is 0.0149 kWh / ((m²)² • a) for the west wall, 0.0131 kWh / ((m²)² • a) for the east wall, 0.0121 kWh / ((m²)² • a) for the south wall, and 0.0113 kWh / ((m²)² • a) for the north wall. Therefore, the energy-saving ability of different facing heat reflective walls is West Wall > East Wall > South Wall > North Wall.
5. References
[1] http://www.coolcommunities.org/what_is_cool_communities.htm
[2] http://en.wikipedia.org/wiki/Cool_roof#Across_the_U.S._Federal_Government
[3] Levinson R, Akbari H, Konopacki S, Bretz S. Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements. Energy Policy. 2005;33(2):151-70.
[4] Levinson R, Berdahl P, Akbari H, Miller W, Joedicke I, Reilly J, et al. Methods of creating solar-reflective nonwhite surfaces and their application to residential roofing materials. Solar Energy Materials and Solar Cells. 2007; 91(4):304-14.
[5] Levinson R, Akbari H, Reilly JC. Cooler tile-roofed buildings with near-infrared-reflective non-white coatings. Building and Environment. 2007;42(7):2591-605.
[6] Levinson R, Akbari H, Berdahl P. Measuring solar reflectance-Part I: Defining a metric that accurately predicts solar heat gain. Solar Energy. 2010;84(9):1717-44.
[7] Levinson R, Akbari H, Berdahl P. Measuring solar reflectance-Part II: Review of practical methods. Solar Energy. 2010;84(9):1745-59.
[8] Haberi J, Cho S, Literature Review of Uncertainty of Analysis Methods (Cool Roofs), Report to the Texas Commission on Environmental Quality, Energy Systems Laboratory, Texas A&M University, College Station, TX, 2004.
[9] Levinson R, Berdahl P, Berhe AA, Akbari H. Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane. Journal of Atmospheric Environment. 2005;39(40):7807-24.
[10] Akbari H, Konopacki S. Calculating energy-saving potentials of heat-island reduction strategies. Energy Policy. 2005;33(6):721-56.
[11] Rosado PJ, Levinson R. Potential benefits of cool walls on residential and commercial buildings across California and the United States: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy and Buildings. 2019;199:588-607.
[12] Committee I. International performance measurement and verification protocol: concepts and options for determining energy and water savings, volume I. Office of Scientific & Technical Information Technical Reports. 2001.