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Simulation of Energy Consumption of Radiant Refrigeration Coatings on Buildings

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Abstract: In recent years, radiation refrigeration materials have developed rapidly, and a lot of research has been carried out from simulation and experimental testing. In this paper, the radiation refrigeration coating is applied to a small residential container building in Chengdu area. The experimental results show that the radiation refrigeration coating can reduce the indoor temperature and improve the indoor thermal environment. Combined with the numerical simulation analysis, it is found that the radiation refrigeration coating is suitable for the roof of the building, which can reduce the energy consumption of 2.47 kWh/ m^2 per unit area per year.

Keywords: Radiation refrigeration coatings; Thermal environment improvement; Energy conservation.

1. Introduction

The radiant cooling material has high solar reflectivity and infrared emissivity, and is an energy-saving coating for cooling the building envelope in summer. Professor Yang Guirong[0] published a radiation cooling metamaterial in Science, which can achieve a maximum cooling effect of 150W/m^2, which has attracted wide attention from the academic community. Fang Hong et al. [2] conducted experiments on the model room of the ordinary tile roof and the radiation-refrigerated metamaterial roof, and found that the maximum temperature difference between the indicated temperature of the roof and the indoor temperature was 11.2℃ and 28.6℃. Nie X et al. [3] studied a polymer radiant refrigeration coating and found that it could save 2-12MJ /m^2 of energy per year for ordinary buildings through simulation. The cooling performance of the coating studied by Tang et al. [4] is significantly higher than that of the commercial coating, and the temperature is reduced by 5.5℃ at most. Through the simulation of application in different regions, it is found that the cooling performance increases with the increase of the ambient temperature.In this paper, containers in Chengdu (hot in summer and cold in winter) are taken as objects, and the envelope structure of the container is coated with radiant refrigeration coating. Through experimental tests and numerical simulation, the influence of radiant refrigeration coating on energy consumption in different orientations of buildings is discussed.

2. Experiment and Model Building

2.1. Coating experiment

Figure 1. Micro container for human occupancy

This experiment was conducted on a small building. The experimental building (Figure 1) is located on the roof of an experiment in Chengdu, Sichuan Province (a hot summer and cold winter area). This building is a miniature container building for human habitation. Select a time period in July 2023 to test the indoor temperature; Secondly, the coating experiment of radiating refrigeration materials is carried out on the roof of the container building, and then the indoor temperature after painting is tested, so as to sort out the obtained data and analyze and compare the temperature changes before and after painting the radiating refrigeration materials. The hourly temperature and average temperature in the room changed before and after painting. The average temperature before and after painting is 35.68℃ and 34.65℃ respectively, and the average temperature difference is 1.03℃. Whether from the point of view of hourly temperature and average temperature, radiation refrigeration coatings on the thermal environment of the building is improved, which has an impact on reducing building energy consumption.

2.2. Model Building

Figure 2. Radiating cooling coatings in different directions

Figure 2 shows the application of radiating refrigeration coatings in different directions. The size of the original model is 2660mm×2660mm×2500mm. The structure of the east, west, north and south walls and the roof are the same, and they are both 1mm iron sheet +70mm rock wool board +1mm iron sheet structure. The simulation was modified based on the original model, and the scene was set in a construction site in a hot summer and warm winter area (Chengdu), which was used as a boarding room for construction workers. The construction workers left the dormitory at 8:00 in the morning and returned to the dormitory at 6:00 in the evening. A total of five groups of simulation experiments were carried out, respectively, on the east, west, north, south walls and roof of the building using radiation refrigeration paint, and the remaining four surfaces using ordinary paint.

3. Numerical Simulation

3.1. Accuracy verification of numerical simulation

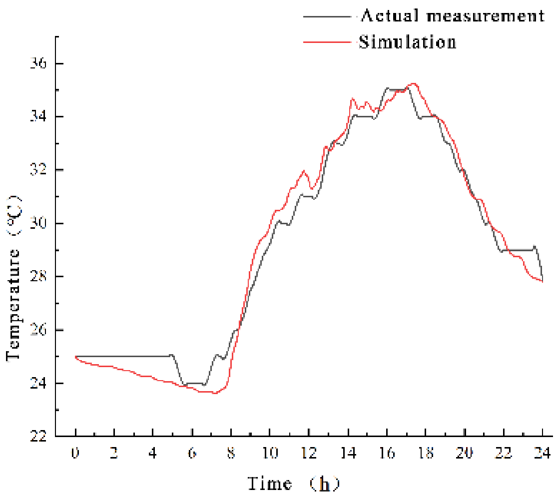

Figure 3. Comparison between the measured temperature and the simulated temperature

TRNSYS is used for numerical simulation in this simulation. Before the simulation, the model will be verified in order to ensure the accuracy of the simulation. The indoor temperature monitored by the residential container on July 28, 2022 was taken as the test data, and the constructed container calculation simulation model was verified in combination with the field measured environmental data. The comparison between the field measured indoor temperature and the simulated indoor temperature data was shown in Figure 3.

As can be seen from the figure, the overall temperature variation trend of the measured indoor temperature and the simulated indoor temperature is basically the same, and the temperature difference is less than 1.2℃. Considering the errors and deviations in the measured and simulated processes, the calculated simulation model constructed can be approximately regarded as accurate and reliable.

3.2. Simulated Result

The author takes the load change caused by the unit area of radiation refrigeration coating as a reference, and establishes the formula:

$$R = \frac{\Delta Q}{A} \quad (1)$$

Where: R represents the load change rate caused by unit area after coating, kWh/ m^2/m^2;

ΔQ represents the difference between the load after painting and the load before painting, kWh/ m^2;A represents the area of radiant refrigeration coating, m^2.The variation rules of R value in different orientations are obtained through calculation of Formula 1. The calculation process is shown in Table 1 and Table 2.

Table 1 Calculation results of cooling load R

Orientation	Computational Formula	ΔQ_C (kWh/ m²)	A (m²)	R (kWh/ m²/m²)
Roof	$R_R = \frac{\Delta Q_C}{A_R}$	37.36	9	4.15
East	$R_E = \frac{\Delta Q_C}{A_E}$	20.40	8.4	2.43
West	$R_W = \frac{\Delta Q_C}{A_W}$	20.84	8.4	2.48
South	$R_S = \frac{\Delta Q_C}{A_S}$	15.01	7.32	2.05
North	$R_N = \frac{\Delta Q_C}{A_N}$	15.49	8.4	1.84

Table 2 Heat load R calculation results

Orientation	Computational Formula	ΔQ_H (kWh/ m²)	A (m²)	R (kWh/ m²/m²)
Roof	$R_R = \frac{\Delta Q_H}{A_R}$	-15.09	9	-1.68
East	$R_E = \frac{\Delta Q_H}{A_E}$	-8.84	8.4	-1.05
West	$R_W = \frac{\Delta Q_H}{A_W}$	-8.69	8.4	-1.03
South	$R_S = \frac{\Delta Q_H}{A_S}$	-9.55	7.32	-1.32
North	$R_N = \frac{\Delta Q_H}{A_N}$	-7.22	8.4	-0.86

As can be seen from Figure 4, after the roof is coated with radiant refrigeration coating, the cooling load difference ΔQ is as high as 37.36kWh/m^2, indicating that the cooling load of the coating applied on the roof will be reduced by 37.36kWh/m^2 throughout the year, and the cooling load reduction rate reaches 10.64%. The difference of cooling load on the east side ΔQ is 20.40kWh/m^2, and the cooling load reduction rate is 5.81%. The west cooling load difference ΔQ is 20.84kWh/m^2, and the cooling load reduction rate is 5.93%. The ΔQ of the south side is 15.01kWh/m^2, and the cooling load reduction rate is 4.27%. The ΔQ of the north side is 15.49kWh/m^2, and the cooling load reduction rate is 4.41%. The roof reduces the cold load the most, followed by the east and west side, and the south and north side the least, but as mentioned above, because each orientation area is not the same, and the south side has a window, can only further analyze the heat load and the heat load R value.

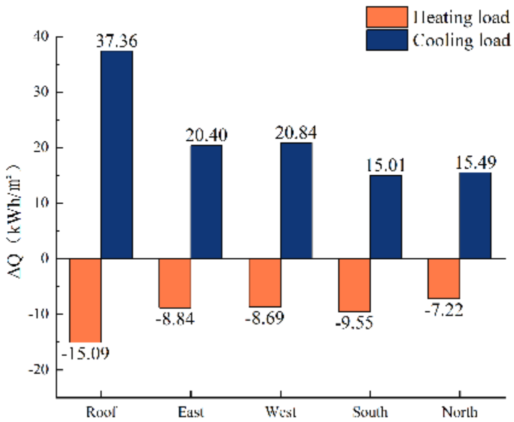

Figure 4. Difference between the load after painting and the load before painting in different directions

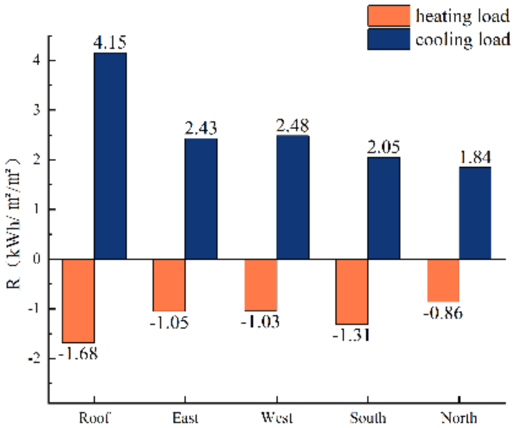

Figure 5. Load change rate of unit area caused by different orientations of coating

As can be seen from Figure 5, after the application of radiating refrigeration coating, the cooling load variation rate R caused by the roof per unit area is as high as 4.15 kWh/ m^2, and the cooling load reduction effect is the most obvious, followed by 2.48 kWh/ m^2/m^2 in the west, 2.43 kWh/ m^2 in the east, and 2.05 kWh/ m^2/m^2 in the south. North side 1.84kWh /m^2 /m^2; From the reduced cooling load effect, the roof is undoubtedly the best choice, followed by the east and west sides, and the south and north sides. However, due to the characteristics of the radiation refrigeration material itself, it will also be cooled on the heating day, so it will lead to a slight increase in heating energy consumption in winter; As can be seen in Figure 5, the variation rate of roof cooling load R is -1.68kWh /m^2/m^2, indicating that each unit square meter of coating will increase the cooling load by 1.68kwh/m^2; the second value of R is -1.31kWh/m^2/m^2 in the south, -1.05kWh /m^2 in the east, and -1.03kWh /m^2 in the west. North side -0.86 kWh/ m^2/m^2.

In order to get the best coating direction, the cold and heat load must be considered comprehensively. Because the change of cold load caused by the coating is greater than the change of heat load, the author defines a formula:

$$R_J = |R_C| - |R_H| \quad (2)$$

Where: R_J represents the change rate of net load caused by unit area after coating, kWh/ m^2/m^2;R_C represents the rate of change of cooling load caused by unit area after coating, kWh/ m^2/m^2;R_H represents the rate of change of heat load caused by unit area after coating, kWh/ m^2/m^2;

According to Formula 2, the R_J value of the roof is 2.47 kWh/ m^2/m^2, the R_J value of the east side is 1.38 kWh/ m^2/m^2, the R_J value of the west side is 1.45kWh/ m^2/m^2, and the R_J value of the south side is 0.74kWh/ m^2/m^2. The R_J value of the north side is 0.98 kWh/ m^2/m^2; It can be seen that even if the heat load of the roof increases the highest, but it brings the highest net load change rate, can bring the thermal environment improvement is still the most obvious, the coating of radiation refrigeration paint on the roof is the best choice, followed by the east and west side, the south and north side of the last consideration. In view of all factors, when the user chooses only one side of the building painting, the roof is undoubtedly the best choice, followed by the east and west side, and the north and south are relatively unfavorable; If the user chooses more coating surface, it can be selected according to different needs.

4. Conclusion

By coating the radiative refrigeration coating on the roof of a small residential container in hot summer and cold winter zone for temperature test, it was found that the radiative refrigeration coating achieved a good cooling effect on the container, which can effectively improve the indoor thermal environment of the container building. Based on the experiment, numerical simulation was carried out to simulate the energy-saving effect of the radiative refrigeration coating in the five directions of the building, and finally found that Radiant refrigeration coating is suitable for the roof, when the user needs to paint multiple walls, it can be used according to the situation.

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