FIELD OBSERVAION OF COOLING ENERGY SAVING BY THE HIGH REFLECTANCE PAINT

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ABSTRACT

Cooling energy savings in a building with the roof coated by high reflectance paint are examined. It is difficult to recognize the cooling energy savings by using the data observed every hour. It is assumed that factors affecting to cooling energy load are the internal heat generation, the set temperature, weather conditions, etc. From the analysis on the relationship between in-outdoor air temperature difference and electric power consumption for air conditioner, which are averaged and integrated into every day, the reduction of electric power consumption by high reflectance paint coating is estimated about 72Wh/m^2/day.

KEYWORDS

High reflectance paint, Cooling energy savings, Field observation

1 INTRODUCTION

Nowadays, high reflectance paint is becoming famous in Japan for the mitigation of heat island phenomenon. The evaluation method of high reflectance paint is established in the JIS (Japanese Industrial Standards) (1)(2). Although the mitigation effect for heat island phenomenon by high reflectance paint has been evaluated in many studies(3), the cooling energy saving in the building actually used by high reflectance paint is evaluated in few studies, because the cooling energy saving in the typical office or residential building with high thermal insulation performance is generally recognized small(4). However, it cannot be ignored in the building with low thermal insulation performance, such as factory, warehouse and gymnasium. In this study, we analysed the cooling energy saving by high reflectance paint in a building actually used.

The cooling energy saving in the building by heat island mitigation technologies, such as green wall, green roof, high reflectance paint has been studied by several researchers(5)(6). In those studies, they conducted controlled experiments using same two prefabricated houses without internal heat generation, in order to compare the difference of energy consumption with or without the heat island mitigation technologies in same weather condition. However, it is required by building owner or manager that the cooling energy saving by high reflectance paint in the building actually used on site.

Akbari et al analyzed the cooling energy saving in buildings actually used in California such as shop, school and refrigerated warehouse. They concluded that the savings are

70Wh/m^2/day, 42-48Wh/m^2/day, 57-81Wh/m^2/day, respectively, from measurement results in summer(7). We have carried out similar experiments in Japan.

It is recognized that introduction of high reflectance paint to buildings without high thermal insulation performance such as factory, warehouse, gymnasium is one of the energy saving measures. At that time, it is necessary to analyze the introduction effect for high reflectance paint. In this study, we analyzed the cooling energy saving in a building actually used based on measured results.

2 OUTLINE OF CASE STUDY BUILDING AND MEASUREMENT

General office buildings have relatively large window area ratio and small roof area ratio to the total envelope surface area. And, they have much internal heat generation from their apparatus and so on. So, the ratio of cooling load by heat conduction from roof is small in the total cooling load. In this study, the objective building is a small (floor area is 60m^2) two story research building (1st floor is piloti) in Kobe University (see Figure 1 and Table 1). It is expected that the objective building have large possibility to achieve cooling energy saving by high reflectance paint due to small window area ratio (15%) and large roof area ratio (25-30%) to total envelope surface area.

The experiment was carried out in rooms 1 and 2. The air conditioners in both rooms were continuously running for 24 hours. The roof consists of concrete slab (thickness is 100mm), above the ceiling (depth is 575mm) and ceiling (height from the floor is 2730mm) and it has no heat insulating material. We measured surface temperature of under and upper the slab and ceiling, room temperature (at 1200mm height), and power consumption of the air conditioner. Cross section of measurement point of temperature is shown in Figure 2. In order to avoid the influence of insolation, roof surface temperature was measured by infrared thermometer, and other measurement elements were measured by thermistor thermometer. The certificate cooling capacities of air conditioners in rooms 1 and 2 are 7.1 kW and 14.5 kW. Power consumption was measured by clamp type power meter (HIOKI3168-98) at the power distribution panel. We measured temperature and power data at one minute interval and averaged for temperature and integrated for power consumption over ten minutes.

We conducted measurement from July 12 to September 26, 2011 and from July 12 to September 26, 2012. High reflectance paint was painted on August 2, 2011. Cooling energy saving is evaluated by the comparison of the measurement results of before and after painting. The albedo of objective paint is 86.9% (300 – 2500 nm wavelength, by JISK5602). The albedo measured by the pyranometer with white and black board which solar radiation is known was 16.9% before painting, 86.9% immediately after painting and 76.1% one year after painting(8). These are averaged value of measurement results at three points on the roof surface (east, middle and west point).

Measurement results of the temperature under the slab, upper and under the ceiling, in the room of room 1, outdoor air temperature and solar radiation are shown in figure 3. The temperature under the slab is from 40 to 27 deg. C and the maximum temperature is occurred around 18:00 due to the thermal storage of the slab. The temperature reduction on the roof surface is around 30 K at maximum after painting. Measurement results of the cooling energy consumption and solar radiation are shown in figure 4. It is difficult to recognize the cooling energy saving, based on the comparison in typical day even if solar radiation is similar to each other.

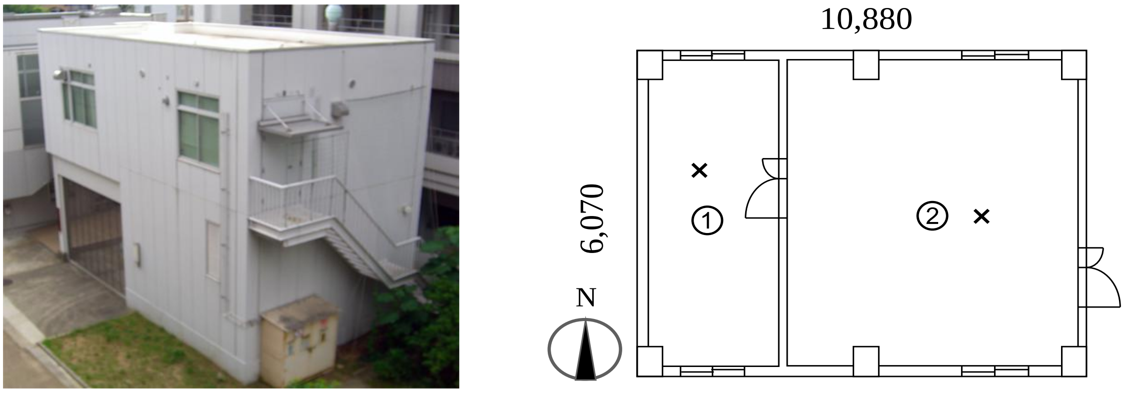

Table 1: Thermal load characteristics of objective rooms

	Roof ratio	Wall ratio	Window ratio	Heat generation	Set temperature
Room 1	25.3%	27.7%	6.4%	W/m^2	26 deg. C before 15:00, Aug. 8, 2011 25 deg. C after 15:00, Aug. 8, 2011 25deg. C through 2012
Room 2	29.7%	27.4%	3.9%	W/m^2	

Figure 1: Facade and plan (2nd floor) of objective building (x: measurement point in Figure 2)

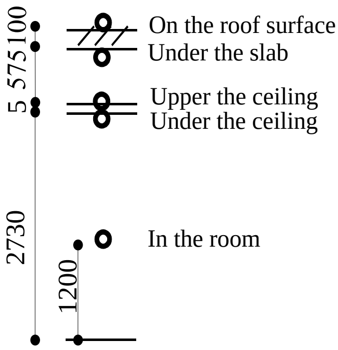

Figure 2: Cross section of measurement point of temperature

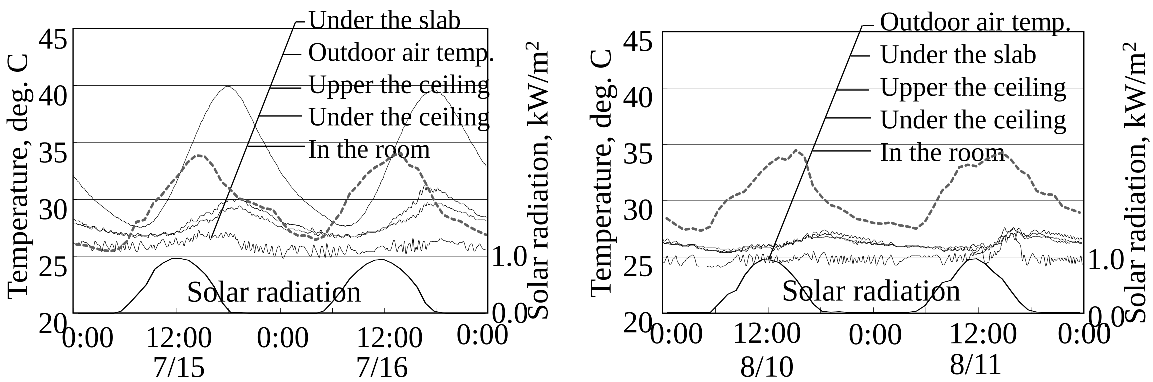

Figure 3: Measurement results of the temperature under the slab, upper and under the ceiling, in the room of room 1, outdoor air temperature and solar radiation (left: before painting, right: after painting)

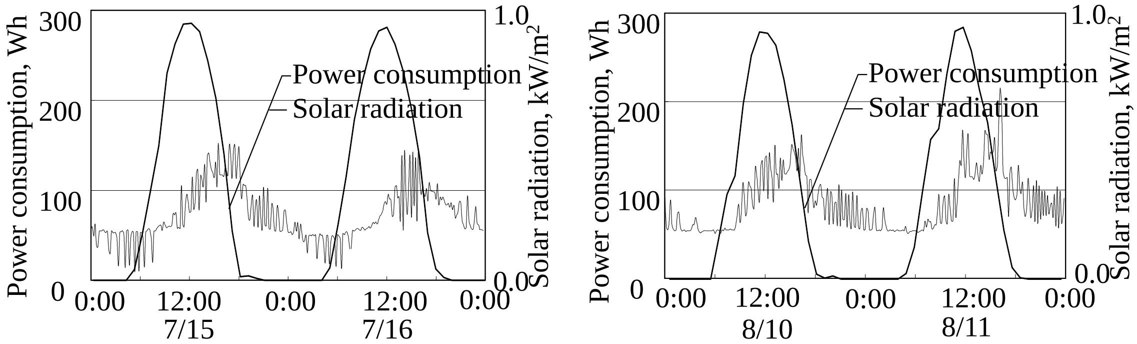

Figure 4: Measurement results of the cooling energy consumption and solar radiation (left: before painting, right: after painting)

3 EVALUATION METHOD OF COOLING ENERGY SAVING BY HIGH REFLECTANCE PAINT

We analyse the cooling energy saving with difference of cooling power consumption between before and after painting. Every hour relationships between outdoor to room air temperature difference and cooling power consumption are shown in figure 5. The data of before painting is black point, and that of after painting is white point. The sol–air temperature changes larger after painting influenced by solar radiation, but power consumption doesn’t change so much after painting. Air temperature difference is averaged in one hour and power consumption is integrated in one hour. Since the temperature under the slab reaches maximum around evening, it is difficult to recognize the relationship between temperature difference and power consumption by every hour data.

We analyse the relationship between daily averaged outdoor to room air temperature difference and daily integrated cooling power consumption, by referring to the method of Akbari et al. The evaluation of cooling energy saving by high reflectance paint is mainly influenced by following factors.

・internal heat generation

・set temperature of air conditioner

・weather condition (air temperature, solar radiation)

Because the object of this study is the evaluation of cooling energy saving in the building actually used, we didn’t instruct the users how to use the room. Accordingly, the measurement results are affected by above three factors. However, the differences of internal heat generation and set temperature of air conditioner are not so large.

Cooling power consumption influenced by internal heat generation, set temperature of air conditioner and weather condition is shown as follows.

$$E=A\times I+ B\times \Delta T + C \qquad (1)$$

where E is the daily integrated cooling power consumption (Wh/day), I is the daily integrated solar radiation (Wh/day), ΔT is the daily averaged temperature difference between outdoor and room (K), A is the coefficient related to absorptivity, B is the coefficient related to thermal condauctiance, and C is the internal heat generation. In the case that these coefficients are large, cooling power consumption becomes large. Strictly speaking, we should use the difference of enthalpy instead of ΔT and consider the coefficient of performance of air conditioner. In this study, we measured E, I, ΔT. It is assumed that B and

C don't change by painting. The influence by set temperature of air conditioner is reflected in ΔT and the influence by weather condition is reflected in ΔT and I. In following chapter, we will analyze measurement results using equation (1).

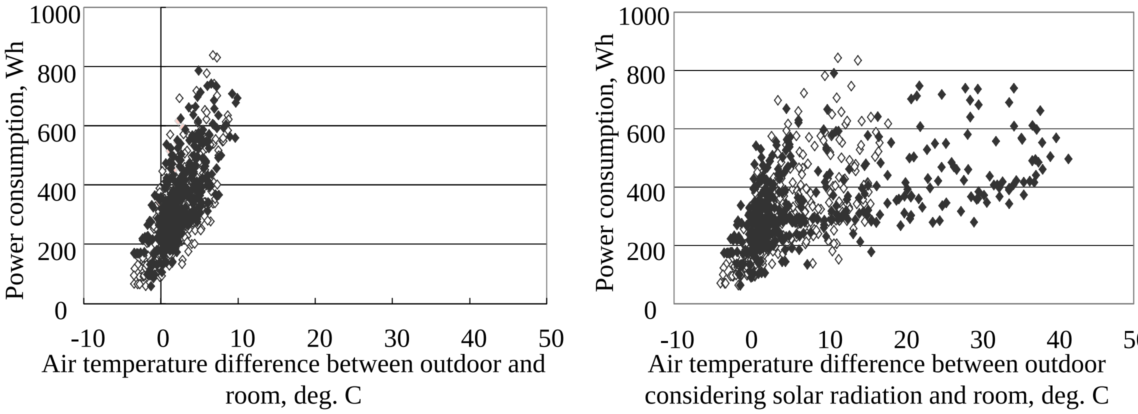

Figure 5: Every hour relationship between outdoor to room air temperature difference and cooling power consumption (black: before painting, white: after painting) (left: air temperature difference without considering solar radiation effect, right: air temperature difference with considering solar radiation effect)

4 EXAMINATION OF COOLING ENERGY SAVING BY HIGH REFLECTANCE PAINT

Every day relationship between outdoor to room air temperature difference and cooling power consumption is shown in left of figure 6. Since both slopes of regression equations of before and after painting are similar, cooling power consumption is influenced by outdoor air temperature. And, it is also influenced by set temperature of air conditioner, which was changed during measurement period. Every day relationship between solar radiation and the intercept of regression equation in left of figure 6 is shown in right of figure 6. Cooling power consumption doesn't change after painting even if the daily integrated solar radiation is large. When the daily integrated solar radiation is relatively large, the cooling energy saving is about 1.6kWh/day (72Wh/m^2/day).

The coefficient B before painting is as mostly same as that after painting in left of figure 6, so it is assumed that the influences by ΔT to power consumption are similar before and after painting. The coefficient A after painting is nearly 0 in right of figure 6, so it is assumed that the influence by solar radiation to cooling power consumption may be neglected after painting. Since the internal heat generation was not controlled during measurement, the coefficient C is not similar before and after painting in right of figure 6. We only have information on the use of the rooms shown in Table 1. Even if using the data measured in the building actually used, the analysis results have captured the approximate characteristics of cooling energy consumption.

Regression equations of cooling power consumption by air temperature difference between outdoor and room before, after and one year after painting in rooms 1 and 2 are shown in Table 2. Cooling power consumption and its saving in table 2 are divided by floor area (room 1 is 22.5m^2, room 2 is 43.5m^2). Because slopes of regression equation (coefficient B) of before, after and one year after painting are relatively similar in each room, the influences by ΔT to cooling power consumption are similar in each room. In room 1, coefficients B are almost similar both after and one year after painting. Cooling energy saving in room 2 is smaller than that in room 1. The internal heat generation ratio to the total cooling load in room 2 is larger than that in room 1, because floor area in room 2 is approximately twice as large as room 1. Since slopes of regression equation (coefficient B) in room 2 are smaller than room 1, it is not so much influenced by external weather condition in room 2.

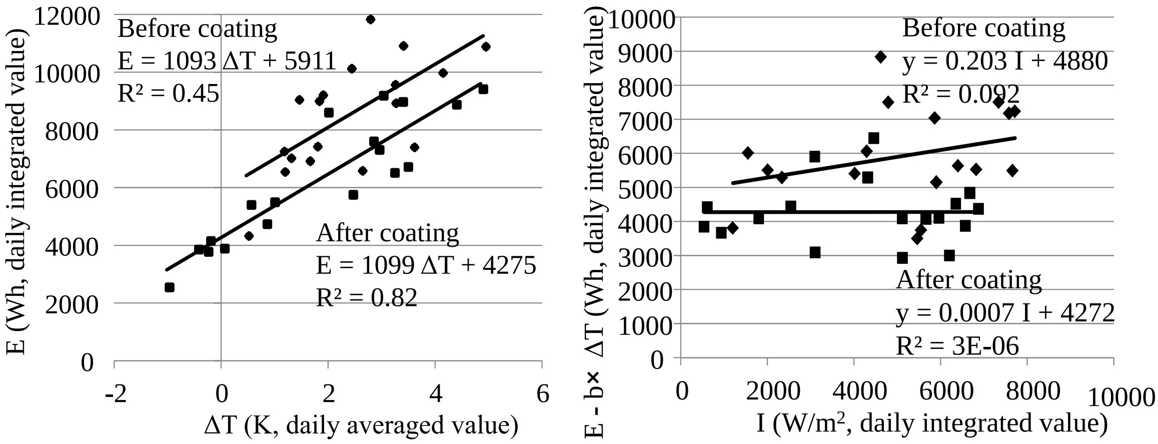

Figure 6: Relation per day between air temperature difference between outdoor and room and cooling power consumption(left), Relation per day between the integrated of the day solar radiation and cooling consumption(right)

Table 2: Regression equations of cooling power consumption by air temperature difference between outdoor and room before, after and one year after painting in rooms 1 and 2

		Regression equation	Energy saving
Room 1	Before painting*	$E=48.6\Delta T+262.7$ ($R^2=0.45$)	-
	After painting**	$E=50.3\Delta T+190.8$ ($R^2=0.82$)	72Wh/m^2/day
	One year after painting***	$E=48.0\Delta T+171.6$ ($R^2=0.82$)	91Wh/m^2/day
Room 2	Before painting*	$E=26.7\Delta T+151.3$ ($R^2=0.54$)	-
	After painting**	$E=27.6\Delta T+116.6$ ($R^2=0.60$)	35Wh/m^2/day
	One year after painting***	$E=26.9\Delta T+142.8$ ($R^2=0.77$)	9Wh/m^2/day

*before painting: from July12 to July 31, 2011
**after painting: from August 3 to September 26, 2011
***one year after painting: from July 12 to September 26, 2012

5 CONCLUSION

In this study, we analyzed the cooling energy saving by high reflectance paint in a building actually used based on measured results. It is assumed that factors influencing on cooling energy are the internal heat generation, set temperature of air conditioner, and weather condition. Considering these factors, we analyzed the relationship between daily integrated solar radiation and cooling power consumption, and the relationship between outdoor to room daily averaged temperature difference and cooling power consumption.

By analysis of the relationship between outdoor to room daily averaged temperature difference and cooling power consumption, cooling power consumption saving by high reflectance paint is estimated around 1.6kWh/day (72Wh/m^2/day). Similar result is confirmed one year after painting. Even if we use results measured in a building actually used, we could evaluate approximate energy savings. However, under the condition in that ΔT is relatively large, cooling power consumption tends to be more larger. Therefore, we may have to consider change of the coefficient of performance of the air conditioner.

6 ACKNOWLEDGEMENTS

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