JOURNAL OF RENEWABLE ENERGY AND SMART GRID TECHNOLOGY
Vol. 19, No. 1, January-June 2024

Evaluation of the Solar Absorption and Economics of Steel Roofs for Heat Sources

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Article info:

Received: 24 January 2024
Revised: 01 April 2024
Accepted: 23 April 2024
DOI:
10.69650/rast.2024.255517

Keywords:

Solar absorptance
Cooling load
Roof steel
Economic

ABSTRACT

Energy conservation in buildings and homes helps reduce energy use and save on energy costs. This study was to examine how the absorption of solar radiation (α) affects the amount of cooling load of colors steel roof. That impacts the energy costs of air conditioning compared to a tiled roof. The study used a spectrophotometer to analyze solar radiation's heat-absorbing properties in the 300-2,500 nm wavelength range. The roof uses a steel area of 1,000 m^2 with 10 metal roof coating colors (red, brown, gray, bluish-green, light-green, dark-green, orange, light-blue, dark-blue, and colorless). The result was found that gray, brown, dark-green, dark-blue, light-green, bluish-green, red, light-blue, orange and colorless metal roofs absorbed varying levels of heat from sunlight. Interestingly, colorless metal roofs had the least impact on heat absorption, resulting in the maximum energy saving effect in the air conditioning system, amounting to 125,085.32 baht per year. Furthermore, the break-even value was calculated to be 0.21 years.

1. Introduction

The energy use of buildings and homes for air conditioning is increasing at present and is trending to increase in the future. The public and private sectors are therefore increasingly interested in energy conservation in buildings. Energy conservation in buildings and homes is therefore a way to reduce energy use. It can reduce costs and energy expenses. Thailand has passed a law to increase energy conservation in buildings in the country for new or modified buildings. Building areas of 2,000 m^2 or more in 9 types of buildings (Educational institutions, Offices, department stores, Service establishments, Gathering buildings, Theaters, Hospitals, Hotels, and Condominiums) must have conservation energy in their designs and inspect and evaluate energy conservation building designs. Before requesting construction permission or permission to use the building, which is legally applicable to both government and private buildings [1-5].

There are many methods for conserving energy in buildings and homes that are popular and inexpensive, such as choosing construction materials that promote energy conservation (lightweight concrete [6] green glass that cuts light [4, 7] and heat insulation [8]) as shown in Fig. 1. The energy conservation must choose high performance equipment (Air conditioner number 5 according to EGAT standards), high efficiency energy saving air conditioning systems [2, 9] or high efficiency, energy saving and hot water production equipment according to DEDE standards. It is selecting renewable energy to help with the use of electrical energy in buildings (solar cells or solar collectors) [10-11] or even choosing to use roofs that have different colors. The color of the building has a very important role in heat absorption of solar radiation and thermal comfort of a building. Proper layers of color can prevent the occurrence of direct solar radiation against the roof each color has a different influence on the absorption of heat. Therefore, the influence of roof color is something that should not be forgotten about the thermal comfort of a building [12].

It will affect the heat summation. On average, a roof receives an average of 1,367 W/m^2 [9, 13] and is converted into heat energy, which affects the air conditioning within that area [14].

Fig. 1 Characteristics of steel roof sheets [15].

In previous research, the characteristics of color roofs have been studied to create the highest reflectivity [16]. But roofs come in a variety of colors at present. Therefore, it is interested in studying the characteristics of roof color that affect heat summation. This study aims to evaluate the efficiency and economic energy of steel roofs coated with different colors and the heat summation from steel roofs in households and factories in Thailand, which will affect the amount of heat summation. Choosing a steel roof color in relation to the amount of heat summation by each steel roof sheet.

Different colors offer guidelines for choosing the right color to reduce energy use in ventilation systems in factories or buildings.

2. Experimental detail

2.1 Experiment design

The experiment setup started with research studies for the analysis and evaluation of factors such as the absorption of solar radiation (α), assessing the heat summation, and calculating the electricity cost in baht per year. After that, the economic evaluation of the internal rate of return (IRR). Fig. 2 presents the summary of the study.

2.2 Material

Material use steel roofing sheets. That is rolled smooth in long rolls. When rolled, the steel roof will have 5 ridges, a standard corrugation shape, a width of 760 mm (measured from the left and right edges), a corrugation height of 24 mm, thickness of 0.47 mm and a tilt distance of 15. Length depends on the characteristics of the use Aluzinc is a rust-preventing agent and is highly resistant to corrosion shown in Fig. 3. Reduces corrosion caused by rainwater. and will help reduce scratches on the steel roof sheets.

Preparation of a sample steel roofing sheets are commonly used in homes and industrial plants. Samples are cut into squares of 10 colors, which include red, brown, gray, bluish-green, light-green, dark-green, orange, light-blue, dark-blue, and colorless, as shown in Fig. 4.

2.3 Experiment setup

Sample preparation for testing involves cutting steel roofing sheets to a size of 1×1 cm and testing them using a UV-3101PC Ultraviolet-Visible-Near Infrared Spectrophotometer. The specification is wavelength of 190-3,200 nm, absorbance of 4-5 Abs, transmittance of 0-999.9%T and reflectance: 0-999.9%R. To find the reflection value (reflectance) properties of each color as shown in Fig. 5.

2.4 Characterizations

The spectrophotometer is used to determine the amount of light reflection in the wavelength range of 300–2,500 nm. Therefore, the absorption of solar radiation by steel roofing sheets is considered according to the solar radiation standard ASTM G173-03 Air Mass [17] according to the following relationship equation (1) [18].

$$\text{Solar absorptance, } \alpha = \frac{\int_{0.3\,nm}^{2.5\,nm} I_{sol}\,\lambda\,(1-R(\lambda))\,d\lambda}{\int_{0.3\,nm}^{2.5\,nm} I_{sol}\,(\lambda)\,d\lambda} \quad (1)$$

Where λ is wavelength (nm), I_{sol} is the normal spectral irradiance, (W·m^2/nm) and R is reflection of solar radiation.

2.5 Economic analysis

The economic worthiness of reducing the use of air conditioning systems in homes and industrial plants. It can find the amount of heat in the steel roof as shown in equations (2) and (3) [19].

$$(1-R_R)xI = E_R x \varepsilon x(T_R^4 - T_S^4) + h_0 x(t_R - t_0) + Q \quad (2)$$

$$Q = \frac{((1-R_R)xI) - (E_R x \varepsilon x(T_R^4 - T_S^4) - h_0}{t_R - t_0} \quad (3)$$

Where R_R is reflection of solar radiation, I is radiant intensity = 800 W/m^2, ER is radiance (0.25), ϵ is tefan-Boltzman (5.67x10^{-8} W·m^2/K^4), t_R is roof surface temperature (45 °C) , T_R is 273 + t_R (318 °K), t_s is sky temperature = 43.5 °C , T_s is 273 + t_s (316.9 K), h_0 is heat transfer (6 W·m^2/K), t_0 is outside temperature (30 °C) and Q is heat (W/m^2)

Payback Period (PB) is period of investment in which the net cash inflows from the project are exactly equal to the net cash outflows, or the investment has no profits and no losses. The payback period is a tool for evaluating the feasibility of an investment, as shown in equations (4) [19-20].

$$PB = \text{Year before breck - even} + \frac{\text{Unrecovered amount}}{\text{Cash flow in recovery year}} \quad (4)$$

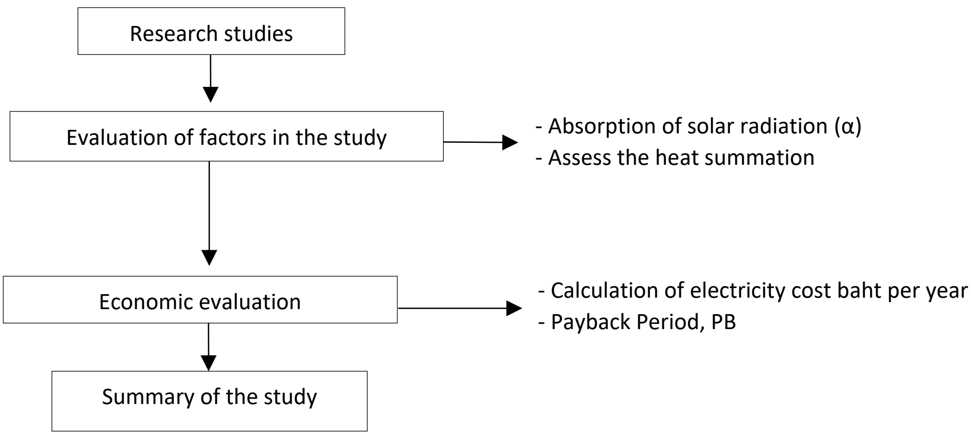

Fig. 2 Diagram of experimental.

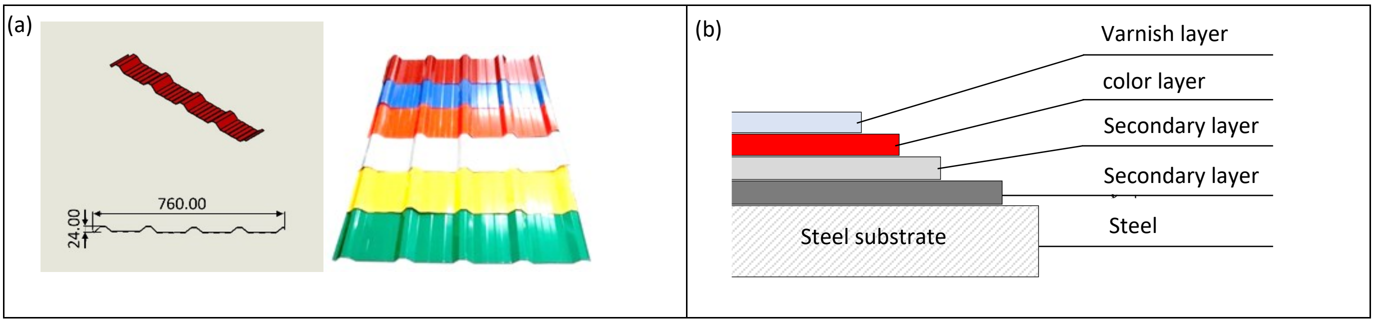

Fig. 3 (a) Characteristics of steel roof folding and (b) Characteristics of steel roof coating layers.

Fig. 4 The color of the steel roofing sheets used in the study.

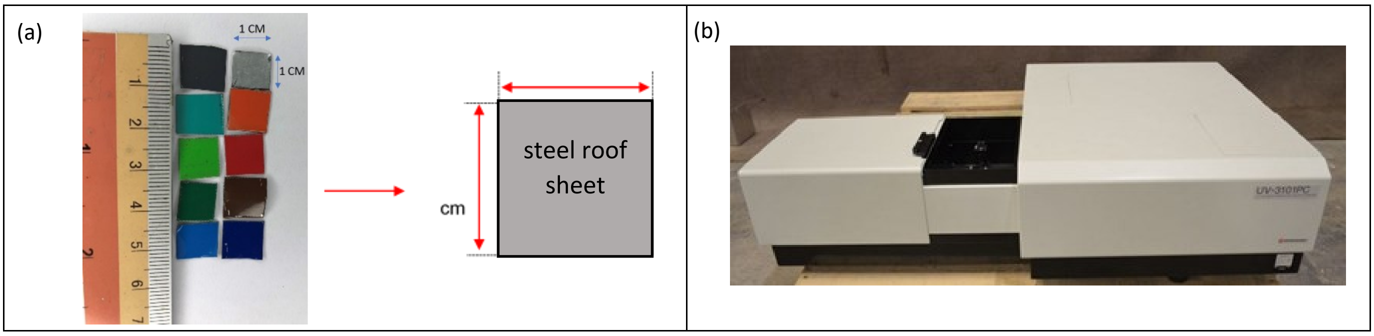

Fig. 5 sample preparation (a) Sample characteristics for analysis (b) UV-3101PC Ultraviolet-Visible-Near Infrared Spectrophotometer.

3. Result and discussion

The experimental results with the relationship in equation 1 and the ASTM G173-03 Air Mass solar radiation standard, the solar radiation absorption value is close to the ASTM G173-03 Air Mass solar radiation standard value of 1.5. The average absorption of solar radiation throughout the wavelength range is shown in Fig. 6. Grey and brown had high absorptance, while colorless had low absorptance. The dark-green, bluish-green, light-green, red, dark-blue, light-blue and orange had nearly absorptance in the range 1,000-2,500 nm. In the UV range at 200–400 nm, the curve has tended to decrease slightly and continue to decrease. The wavelength behavior has decreased again in the NIR range, at wavelengths 800–2,500 nm, and decreased to the lowest in the range around 1,900 nm, then increased and gradually decreased. Different colors have affected the absorption of different light and heat intensities. Light colors have lower absorption than dark colors, depending on the electromagnetic waves that are absorbed and reflected by each color. Each color of light has a different wavelength and has different penetration and absorption capabilities. The order of colors based on their ability to absorb solar heat is from the highest to the lowest: black, green, red, purple, yellow, pink, blue, and white. The black color has good heat absorption [21].

Table 1 shows that the cost-effectiveness of choosing energy-saving steel roof colors will vary depending on the brightness of each color, as shown in Fig. 6. If the color is very bright, it causes a lot of reflection causing the absorption value of solar radiation to be low. As a result, the low heat content can save energy costs more than darker colors. But the cost for each color of metal roof is the same. Choosing a roof color that is highly reflective affects energy savings in the building that uses. It can be seen from the calculation of colorless and gray that if you choose to use colorless, it will electricity cost of 125,085.32 baht per year. It can save on electricity costs by comparing the air conditioning temperature of the building. The break-even point or payback period of a steel roof in an area of 1,000 m^2. The price of a steel roof per square meter is 207 baht in an area of 1,000 m^2, an investment of 207,000 baht. The payback period of colorless is 0.21

years, dark-green 0.32 years, bluish-green 0.29 years, light-green 0.3 years, red 0.29 years, gray 0.42 years, dark-blue 0.31 years, brown 0.39 years, light-blue 0.29 years, and orange 0.28 years, as shown in Fig. 7. The color with the fastest payback period is colorless. The information can be used to compare steel roof colors to provide alternatives and comparisons in selecting steel roof colors to meet the objectives desired by the user.

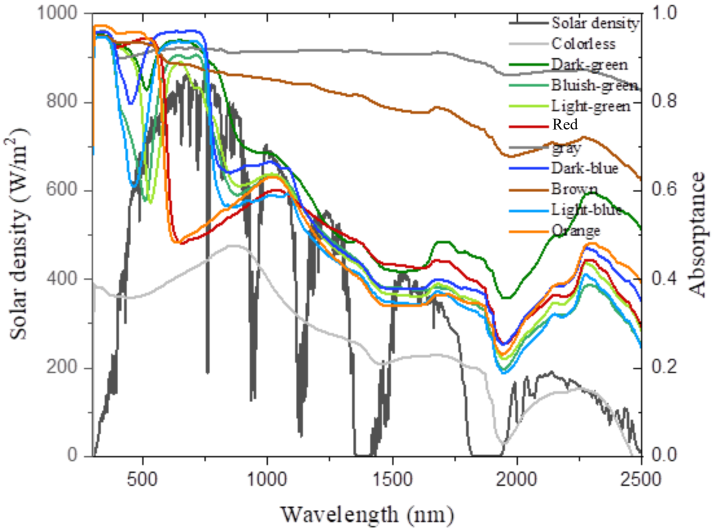

Fig. 6 Absorption of solar radiation.

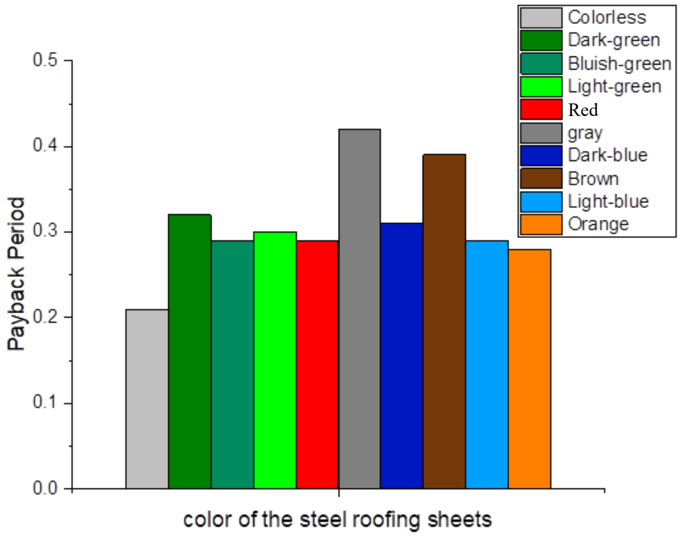

Fig. 7 The payback period of the steel roofing sheets used.

Table 1 Economic value.

Colors	R_R	Q (W/m^2)	Electricity cost to be paid per year (Baht)	Payback period (year)
Colorless	0.68	17.1043	125,085.32	0.21
Dark-green	0.3337	35.8030	261,830.27	0.32
Bluish-green	0.4168	31.3710	229,418.68	0.29
Light-green	0.4112	31.6696	231,602.85	0.30
Red	0.4263	30.8643	225,713.38	0.29
Gray	0.0885	48.8803	357,465.93	0.42
Dark-blue	0.3754	33.5790	245,565.97	0.31
Brown	0.1611	45.0083	329,149.66	0.39
Light-blue	0.4299	30.6723	224,309.27	0.29

4. Conclusion

The different colors of steel on the roof had different absorptions of solar radiation. Gray, brown, dark-green, dark-blue, light-green, bluish-green, red, light-blue, orange and colorless metal roofs absorbed varying levels of heat from sunlight. Interestingly, colorless metal roofs had the least impact on heat absorption, resulting in the maximum energy saving effect in the air conditioning system, amounting to 125,085.32 baht per year. Furthermore, the break-even value was calculated to be 0.21 years.

Acknowledgements

The author would like to thank Rattanakosin College for Sustainable Energy and Environment (RCSEE), Rajamangala University of Technology Rattanakosin for providing educational opportunities to develop knowledge and create experience in renewable energy. That leads to the development of quality of life in operations, society, and the nation.

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