

Thermal insulation performance and service life prediction of some commercial solar heat-reflective coatings under natural weathering exposure

Doan Quy Hieu¹, Guzenkov Sergey Aleksandrovich^{1, 2}, Do Dinh Trung^{1*}

¹Institute of Tropical Durability, Joint Vietnam-Russia Tropical Science and Technology Research Center, 63 Nguyen Van Huyen, Nghia Do, Hanoi, Vietnam;

²A. N. Severtsov Institute of Ecology and Evolution Problems of the Russian Academy of Sciences, Laboratory of Tropical Technologies, 33, Leninskij prosp., Moscow, 119071, Russia.

*Corresponding author: trungdodinh.vrt@gmail.com

Received 15 Aug. 2025; Revised 30 Sep. 2025; Accepted 16 Oct. 2025; Published 18 Nov. 2025.

DOI: <https://doi.org/10.54939/1859-1043.j.mst.IMBE.2025.186-192>

ABSTRACT

This paper presents the results of natural climate-exposure tests conducted by Joint Vietnam-Russia Tropical Science and Technology Research Center on selected heat-resistant paints intended to reduce heat in warehouses, factories, and fuel storage tanks under Vietnam's tropical conditions. The paints examined include Intek, PCG Asuza AS132, and Dulux. The natural-exposure methodology was developed based on the JIS K 5675:2011 and TCVN 8785-2:2011 standards. Using a 24-month dataset collected from outdoor exposure, we evaluated the thermal insulation performance, decorative properties, protective capability, and service life of the three paints. The findings provide reference information for selecting heat-resistant coatings with potential for practical application in military settings.

Keywords: Natural climate exposure test; Weathering resistance; Heat-resistant paint; Thermal insulation performance; Protective capability; Service life prediction.

1. INTRODUCTION

Vietnam is located in a tropical monsoon climate zone. It is characterized by an abundant amount of annual solar radiation, about 5 kW/h/m²/day in the Central and Southern provinces and about 4 kW/h/m²/day in the Northern provinces. The number of sunshine hours is about 1500 - 1700 hours per year in the North. It is about 2000 - 2600 hours per year in Central and Southern Vietnam [1]. Especially in summer, it often has hot and intense heat with the high temperature affecting the preservation and maintenance of military weapons and technical equipment in warehouses, factories, and fuel tanks. The temperature on the corrugated iron roofs of warehouses, on the metal surfaces of weapons and technical equipment left outdoors can reach up to 60 °C - 70 °C, the temperature inside warehouses can reach up to 37 °C - 40 °C, being the factors that affect the lifespan of materials, equipment, storage environment and working conditions in warehouses. With the development of science, solar heat-reflective paints have been researched, developed and put into use to reduce temperature on the surface and inside of buildings, increasing environmental durability.

In the world, there are many paint brands from Japan, the US, Russia, Switzerland, Thailand... that have researched and produced types of solar heat-reflective paints [2, 3]. The paint brands in different countries often have different mixing formulas and insulation performance mechanisms kept secret and not widely publicized. Today, research projects on solar heat-reflective paint in the world are very few and rare. Verification of insulation performance, the decline in effectiveness over time, the protective and decorative characteristics of paint products, it is necessary to conduct climatic tests or accelerated tests.

There are also a number of domestic research projects on the manufacture and testing of solar heat reflective paint products. PhD. Thien Vuong Nguyen and his colleagues [4] have researched and manufactured solar heat-reflective paint samples from two types of pure acrylic emulsion resins, PRIMAL™ AC-261 and DIRTSHIELD™ K-2 and nano-TiO₂, nano-SiO₂ particles with

different mixing ratios to significantly increase the reflectivity, cooling insulation efficiency and weathering durability of solar heat reflective coating. In the article [5], PhD. Thien Vuong Nguyen and his colleagues have researched the use of non-destructive analysis methods, like IR and UV-Visible spectroscopy, 3D laser microscopy, SEM to monitor the formation of photo-oxidation products and the loss of the binder functional groups on a sample undergoing accelerated aging. In addition, this group of authors has researched optical absorbers to increase the weathering durability of acrylic polyurethane coatings [6]. The coatings showed no serious cracking, damage or chalking after 48 accelerated aging test cycles and after 5 years of climatic testing.

In this article, the research team performed climatic testing methods to evaluate the insulation performance, protective and decorative characteristics of solar heat-reflective paints on the market. The research conducted tests including: i) Measuring the temperature on the roof, and in the middle of the house with a corrugated iron roof coated with solar heat-reflective paint; ii) Measuring the temperature on the upper and lower surfaces of the corrugated iron sheet coated with solar heat-reflective paints in the laboratory. The paint samples were placed on a drying rack to evaluate changes in color, gloss, adhesion, dust adhesion, cracking, blistering, chalking, and rusting. After obtaining the test results, the process of evaluating and comparing the insulation performance, protective and decorative characteristics and service life prediction of solar heat-reflective paints.

2. RESEARCH METHODS

2.1. Test subjects

The research team selected 3 typical solar heat reflective paints on the market: Intek, PCG Asuza AS132, Dulux. These solar heat-reflective paints operate based on reflection and insulation mechanisms similar to other paint lines, with some outstanding features due to a special formula. The paint composition includes nano-ceramic particles and special reflective materials that effectively reflect UV and infrared rays from sunlight. This reduces the amount of heat absorbed by the surface, keeping the surface temperature significantly lower.

2.2. Test sample preparation

Prepare the sample surface according to TCVN 5670:2007 (abrasive method) [9]. Use a paint sprayer, nozzle size 1.3 mm, pressure 2.5 bar, ambient temperature 25–30 °C, relative humidity 70–80%. Number of coats: two coats with a drying time of 24 hours. The average coating thickness measured before and after exposure is in the range of 160–300 μm. The total number of samples is 300. Each test index consists of 3–5 samples according to the standard.

The outdoor insulation performance test model was built based on the model in reference [4]: 4 corrugated iron roof houses (with Length × Width × Height = 2 × 1 × 2 m) were built to test the insulation performance efficiency of 3 types of solar heat reflective paints on the market and 1 control roof house (The roof was not covered with any coating) (figure 1). The corrugated iron roof houses were sealed to reduce the influence of outside air, avoid heat convection of air from cold and hot sources. Hobo Onset UX 100 temperature and humidity sensors were placed inside the corrugated iron roof houses to monitor temperature. The Bosch GIS 500 Thermo Detector was used to measure the temperature on the upper surfaces of the corrugated iron roofs.

Temperature measurement was carried out inside the houses and on the upper part of the roofs with and without coated insulation performance paint at different times of the sunny day (8 am, 10 am, 12 pm, 1 pm, 2 pm, 4 pm, 6 pm). Assessment of the degree of deterioration in the insulation performance of paint over time. For test samples to evaluate protective and decorative characteristics: The samples are placed on a drying rack, periodically every 3 months, to measure the indicators of color change, gloss change, dust adhesion, blistering, chalking, cracking, and rust.

Measurement of paint film gloss is carried out by Trio Glossmeter 20°/60°/85° according to TCVN 2101:2016 (ISO 2813:2014) Standards [12]; Measurement of color change is carried out

by X-rite Ci62 according to ASTM D2244-16 Standard [13]; Measurement of Adhesion strength using TQC Sheen equipment according to TCVN 2097:2015 Standard [14].

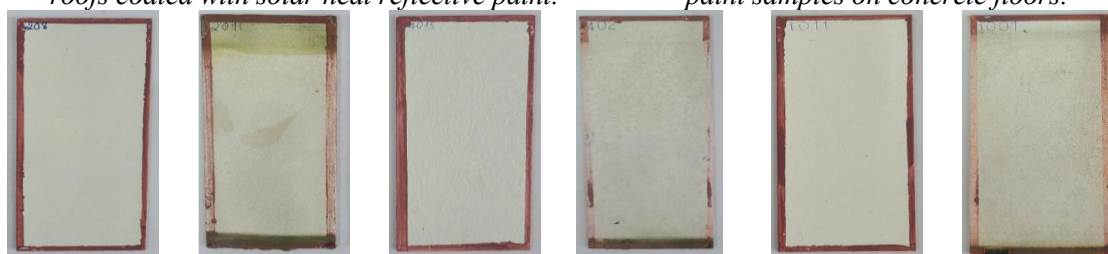
The color difference ΔE^* , ΔL^* , Δa^* , Δb^* between sampling cycles is calculated based on the measured L^* , a^* , b^* values according to the following formulas: $\Delta L^* = L^*_i - L^*_{i0}$; $\Delta a^* = a^*_i - a^*_{i0}$; $\Delta b^* = b^*_i - b^*_{i0}$; $\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$.



Figure 1. House samples with corrugated iron roofs coated with solar heat reflective paint.



Figure 2. Drying racks for heat reflective paint samples on concrete floors.



Intek paint before testing. Intek paint after testing. PCG Asuza ASI32 paint before testing. PCG Asuza ASI32 paint after testing. Dulux paint before testing. Dulux paint after testing.

Figure 3. Solar heat reflective paint samples.

3. RESULTS AND DISCUSSION

3.1. Results of evaluating the solar heat-reflective paints

Outdoor insulation performance test: Climate, weather, and environmental characteristics are the causes of aging, reduction in insulation efficiency, and deterioration of the decorative and protective properties of paints [7, 8]. Meteorological and environmental statistics from the Climate Experimental Research Station (Hoa Lac) from July 2023 to July 2025 are presented in table 1.

Table 1. Meteorological and environmental statistics at Climate Experimental Research Station.

Solar radiation, MJ/m ² .year	Average temperature, °C	Average relative humidity,%	Total rainfall, mm
4218,56	24,85	88,95	2480,68

The results of measuring the temperature on the upper surface of the roof and inside the roof of the house with and without solar heat-reflective paint at different times of the day (8:00, 10:00, 12:00, 13:00, 14:00, 16:00, 18:00) in July 2023 are shown in figure 4 and figure 5. These graphs show that the solar heat-reflective paints give much better results than the uncoated control house. At hot times of the day (10:00 - 14:00), these paints reduce the temperature by 22 - 25 °C on the upper surface of the roof and by 8 - 10 °C inside the house. After 24 months of testing, by July 2025, the insulation performance has decreased to a certain extent. These paints reduce the temperature by 19 - 22 °C on the upper surface of the roof and by 7 - 9 °C inside the house. Intek paint brand has less reduction in insulation performance, PCG Asuza ASI32 and Dulux paints have more reduction in insulation performance.

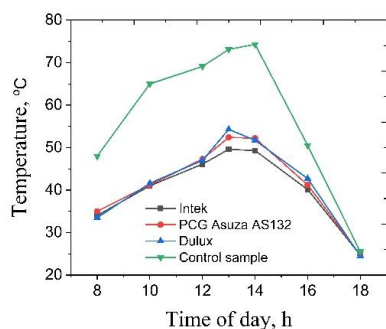


Figure 4. Temperature on the upper surface of the roof in July 2023.

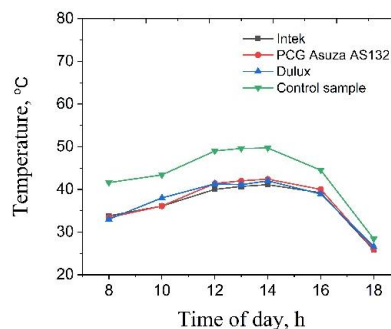


Figure 5. Temperature inside the house in July 2023.

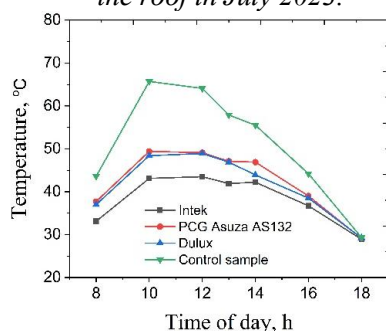


Figure 6. Temperature on the upper surface of the roof in July 2025.

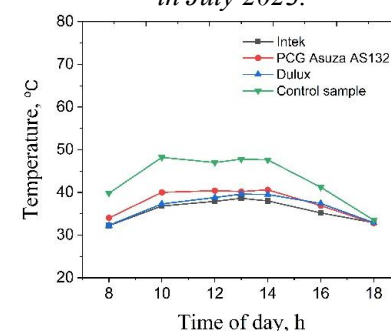


Figure 7. Temperature inside the house coated in July 2025.

3.2. Results of evaluating color change, gloss and adhesion assessment

The calculation results of the ΔE^* value - a measure that reflects the changes in all three parameters L^* , a^* , and b^* of the three types of coatings according to the testing cycle (ASTM D2244-16) - are shown in figure 8. The graph showed that the color change of the paint films increases over time. According to the standard ASTM D2244-16, the color change can be seen quite clearly with the naked eye when $\Delta E^* > 3$. The test of Dulux paint changed strongly after 3 months (with $\Delta E^* = 3.12$), PCG Asuza AS132 paint changed strongly after 6 months (with $\Delta E^* = 3.25$), Intek paint changed strongly after 9 months (with $\Delta E^* = 3.28$) and can be seen with the naked eye. The gloss change of the 3 paints over the testing time is shown in figure 9. The test results showed that Dulux paint had the highest gloss, Intek paint had the lowest gloss, however, after 24 months of testing, the gloss lose of all 3 paints is similar (Dulux and Intek paint both decreased by 29.03%, while PCG Asuza AS132 paint decreased by 28.40%). To evaluate adhesion, it is necessary to measure the paint film thickness and select the appropriate type of cutting knife for the test. The paint film thickness of three types of paint is shown in table 2.

Table 2. Paint film thickness and cutting knife types for the adhesion test.

Types of paints	Thickness before exposing the sample	Thickness before evaluating adhesion	Type of cutting knife
Intek	240,0	232,0	Knife No. 3
PCG Asuza AS132	114,0	108,7	Knife No. 2
Dulux	168,3	139,0	Knife No. 3

Regarding the adhesion of the paint films after 24 months of testing, the results showed that the Dulux paint film remained unchanged (grade 1), the Intek paint exhibited peeling marks, resulting in a grade 2 rating, and the PCG Asuza AS132 paint layer on the cut showed significant peeling when examined with a magnifying glass, also receiving a grade 2 rating. Figure 10 shows the surface of the adhesion test sample after 24 months of testing.

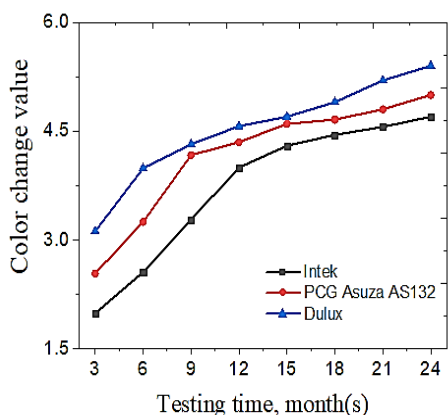


Figure 8. Graph of color change in ΔE^* value according to testing cycles.

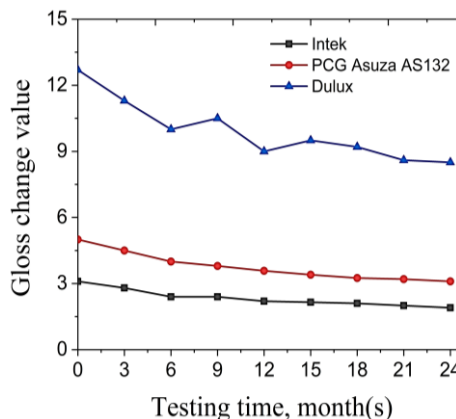
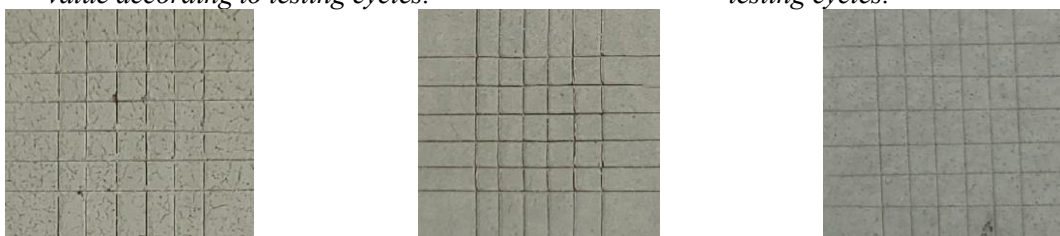


Figure 9. Graph of gloss change according to testing cycles.



Intek (Knife No. 3).

PCG Asuza AS132 (Knife No. 2).

Dulux (Knife No. 3).

Figure 10. Paint film adhesion after 24 months of testing.

3.3. Results of dust adhesion, cracking, blistering, chalking, and rust assessment of paints

The results of dust adhesion, cracking, blistering, chalking and rust after 24 months of climatic testing are shown in table 3.

Table 3. Results of dust adhesion, cracking, blistering, chalking, and rust of paints.

Types of paints	Dust adhesion	Cracking	Blistering	Chalking	Rust
Intek	1	3	0	2	0
PCG Asuza AS132	1	0	0	1	0
Dulux	1	0	0	1	0

The results in table 3 showed that all 3 types of solar heat reflective paint do not blister or rust. The remaining indicators, such as dust adhesion, can be observed with the naked eye. All types of paint had light dust adhesion at a scale of 1. Intek paint had cracks at a scale of 3 and chalking at a scale of 2.

3.4. Predicting the service life of solar heat reflective paints

In figure 8, we have the ΔE^* color change value data of 3 types of paint in 24 months. Using the exponential nonlinear regression method, the 3 types of paint have the following function values in table 4. Solve the equation when the value $y = 10$ (When ΔE^* exceeds 10, the paint is almost expired). The predicted value of the usage time of the 3 types of paint is shown in the table. All 3 types of paint have a predicted usage time of 39 to 50 months. Thus, Dulux paint has the longest predicted usage time.

Although ΔE is a widely accepted indicator of overall color change, it does not fully capture other degradation mechanisms such as gloss loss, adhesion loss, chalking, or cracking. Therefore, the current model is considered a first-order approximation of service life under tropical conditions. Further research will integrate multiparametric approaches – combining color, gloss, adhesion, and surface integrity – to establish a more comprehensive and reliable predictive model.

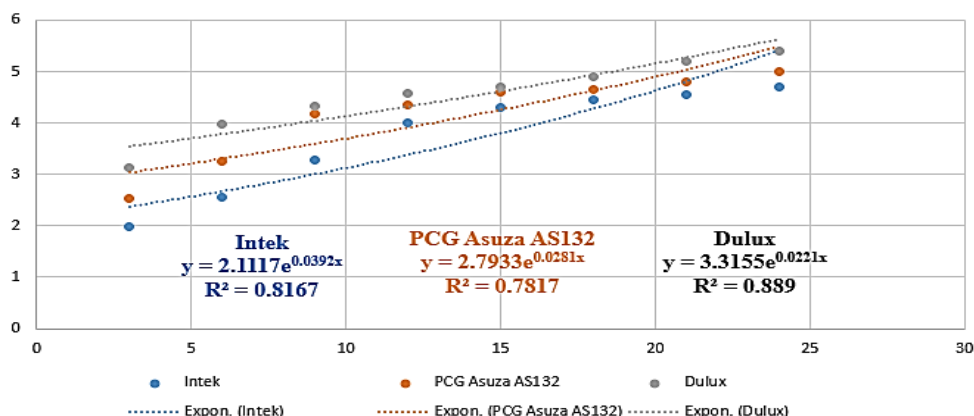


Figure 11. Nonlinear exponential regression graph of 3 types of paint.

Table 4. Results of predicting the service file for solar heat reflective paints.

Types of paints	Nonlinear Regression	Predicted service file
Intek	$y = 2,1117 \cdot e^{0,0392x}$	39,6 (months)
PCG Asuza AS132	$y = 2,7933 \cdot e^{0,0281x}$	45,3 (months)
Dulux	$y = 3,3155 \cdot e^{0,0221x}$	50,0 (months)

The new current life expectancy predictions are based on natural climate experiment data. This is valuable practical information, but to increase scientific reliability, in the next study, the team will add accelerated experiments to compare and verify with real climate data.

4. CONCLUSIONS

1. After 24 months of natural climate exposure testing at the Hoa Lac Station (Hoa Lac Commune, Hanoi), the thermal insulation performance, protective and decorative properties, and service life of three solar heat-reflective paints were evaluated. Intek demonstrated strong insulation performance with minimal degradation over time.

2. All three paints (Intek, PCG Asuza AS132, and Dulux) met the protective performance requirements specified in JIS K 5675:2011 and TCVN 8785-2:2011 [10, 11]. However, their decorative properties showed varying degrees of deterioration, most notably in color change, gloss reduction, dust adhesion, cracking, and chalking. Other appearance-related indicators remained largely stable. PCG Asuza AS132 and Dulux exhibited better overall decorative durability compared to Intek.

3. Long-term testing at the Hoa Lac Station will continue over the 3-year, 5-year, and 10-year milestones. The results of this study provide a practical basis for selecting suitable solar heat-reflective paints to reduce temperatures in warehouses, factories, and fuel storage facilities, thereby helping to extend the service life of military equipment and improve working conditions in military facilities.

Acknowledgments: This article is the product of "The climatic testing for insulation performance evaluation and decorative protective characteristics of the solar heat-reflective paints on the market" project. The authors would like to express special appreciation and thanks to the heads of the Institute of Tropical Durability, Joint Vietnam-Russia Tropical Science and Technology Research Center, for facilitating this research.

REFERENCES

- [1]. H. A. Nguyen, "Climate and Solar Radiation in Northern and Southern Vietnam", New Energy Journal, Vol. 47(1), pp. 12–18, (2020).
- [2]. Davidson S., "SkyCool – extraordinary paint on a hot tin roof", ECOS (CSIRO publication), Iss. 119,

- p. 12, (2004).
- [3]. John Pockett, Martin Belusko, "A Review of Heat-reflective Paints", Sustainable Energy Centre, University of South Australia, Mawson Lakes SA5095, (2010).
- [4]. T. V. Nguyen, P. H. Dao, T. A. Nguyen, V. P. Mac, T. V. Do, T. M. L. Dang, M. N. Ha, H. N. Trinh, T. L. Le, D. L. Tran, T. D. Nguyen, P. N. Tri, "Effects of nano-TiO₂ and nano-SiO₂ particles on the reflective and weathering durability of solar heat reflective coating", Journal of Photochemistry and Photobiology A: Chemistry, Vol. 442, 114752, (2023).
- [5]. T. V. Nguyen, P. N. Tri, T. D. Nguyen, R. E. Aidani, V. T. Trinh, C. Decker, "Accelerated degradation of water borne acrylic nanocomposites used in outdoor protective coatings", Polymer Degradation and Stability, Vol. 128, pp. 65–76, (2016). <https://doi.org/10.1016/j.polymdegradstab.2016.03.002>
- [6]. T. V. Nguyen, X. H. Le, P. H. Dao, C. Decker, P. N. Tri, "Stability of acrylic polyurethane coatings under accelerated aging tests and natural outdoor exposure: The critical role of the used photo-stabilizers", Polymer Degradation and Stability, Vol. 128, pp. 65–76, (2016).
- [7]. C. C. Nguyen, H. L. Nguyen, D. M. Le, N. T. Phan, V. D. Dang, "Outdoor weathering for determination of decorative and protective properties of some emulsion paints being used in Vietnam's tropical climate", Journal of Tropical Science and Technology, No. 25, pp. 81–94, (2016).
- [8]. M. T. Chu, "Choosing steel protection paint products suitable for tropical climate area", Journal of Tropical Science and Technology, No. 25, pp. 95–104, (2016).
- [9]. TCVN 5670:2007 (ISO 1514:2004). "Paints and varnishes – Standard panels for testing".
- [10]. JIS K 5675:2011. "High Solar Reflectant Paint For Roof".
- [11]. TCVN 8785:2011. "Paint and coating for metal protection – Method of tests – Exposed to weathering conditions".
- [12]. TCVN 2101:2016 (ISO 2813:2014). "Paints and varnishes — Determination of gloss value at 20°, 60° and 85°".
- [13]. ASTM D2244-16. "Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates".
- [14]. TCVN 2097:1993 (ISO 2409:1992). "Paints and varnishes – Cross-cut test".

TÓM TẮT

Hiệu suất cách nhiệt và dự báo tuổi thọ của một số loại sơn chống nóng trong điều kiện khí hậu Việt Nam

Bài báo trình bày một số kết quả thử nghiệm khí hậu tự nhiên của một số loại sơn chống nóng tại Trung tâm Nhiệt đới Việt - Nga nhằm đảm bảo giảm nhiệt cho các kho, nhà máy, bể chứa nhiên liệu trong điều kiện khí hậu nhiệt đới Việt Nam. Các loại sơn được nghiên cứu bao gồm: Intek, PCG Asuza ASI32, Dulux. Phương pháp nghiên cứu thử nghiệm tự nhiên được xây dựng dựa trên tiêu chuẩn JIS K 5675:2011 và TCVN 8785-2:2011. Trên cơ sở dữ liệu 24 tháng thử nghiệm khí hậu tự nhiên thu được, tiến hành đánh giá hiệu suất hiệu suất cách nhiệt, tính chất trang trí, khả năng bảo vệ và tuổi thọ của 03 loại sơn. Kết quả thử nghiệm có thể được sử dụng làm cơ sở để lựa chọn một số loại sơn chống nóng có tiềm năng ứng dụng thực tế trong quân đội.

Từ khóa: Thử nghiệm khí hậu tự nhiên; Độ bền khí hậu; Sơn chống nóng; Hiệu suất cách nhiệt; Khả năng bảo vệ; Dự báo tuổi thọ.