The Horizon
The Official Scholarly Journal of High School Students
Colegio de San Juan de Letran - Manila
Volume 2 Issue 2

DEVELOPMENT OF A REFLECTIVE PAINT USING EGGSHELL POWDER FOR REDUCING INDOOR TEMPERATURES

Alexander Cagolcol[1], Tahnia Dalit[1], Lorraine Manrique[1], Lianne Athena Mariano[1], Dominic Galang[1], Geoffrey Garcia[1], Joseph De Mata[2], Jerkin Jexel Pedrosa[2]

[1]Student, Senior High Student, Colegio de San Juan de Letran-Manila
[2]Faculty Member, Colegio de San Juan de Letran-Manila
Corresponding author. Email: alexander.cagolcol@letran.edu.ph

ABSTRACT

This study investigates the development and thermal performance of an eco-friendly reflective paint utilizing eggshell powder as a sustainable, waste-derived pigment to mitigate heat accumulation in roofing materials. Three experimental paint formulations with 15%, 30%, and 50% eggshell concentrations were created and evaluated alongside a commercial reflective paint and an unpainted control roofing sheet. Statistical analysis using a One-Way ANOVA confirmed the overall efficacy of the eggshell coatings: a highly significant difference ($P<.001$) was found in the Cooling Differential when comparing all five treatments, demonstrating that the eggshell paint coatings successfully utilized the eggshell's calcium carbonate (CaCO3) to achieve high Solar Reflectance and significantly outperformed the unpainted control in reducing heat transmission. Crucially, an ANOVA comparing the three eggshell ratios (15%, 30%, 50%) revealed no significant difference in thermal performance ($P = 0.539$), indicating thermal equivalence across the concentrations; this means that increasing the eggshell ratio does not yield a statistically superior cooling effect. Descriptively, the 15% Eggshell Paint formulation recorded the highest mean cooling differential at 6.74°C, confirming its status as the most resource-efficient option. The study concludes that eggshell waste is a viable and effective additive for creating cool coatings. Future research is recommended to shift focus from basic thermal testing to quantifying the international standard Solar Reflectance Index (SRI) and assessing durability, adhesion strength, and rain performance to definitively determine the optimal formulation for long-term use.

Keywords: *Eggshell powder, reflective paint, solar reflectance, thermal performance, sustainable materials*

INTRODUCTION

Background of the Study

The continued rise in global temperatures and shifting weather patterns driven by climate change have created an urgent need for sustainable cooling solutions for every household. According to the Intergovernmental Panel on Climate Change (IPCC) in 2022, the global average surface temperature rose by about 1.1°C above pre-industrial levels, which in turn has intensified extreme heat events worldwide. In tropical countries like the Philippines, these extreme conditions are further heightened due to the country's climate, which allows heat to accumulate quickly inside homes. The World Health Organization (WHO, 2024) reported that indoor heat not only causes discomfort for many Filipinos but also poses health risks such as stress, fatigue, dehydration, and even heat stroke. Poor urban communities are especially vulnerable due to weak and low-quality housing materials.

Because of this, households and commercial buildings in the Philippines spend a large portion of their income on electricity for cooling appliances such as electric fans and air-conditioning units. During the dry season, residential electricity consumption in Metro Manila increases significantly due to greater use of cooling systems (DOE, 2025). However, this dependence on mechanical cooling also contributes to higher carbon emissions.

Various passive cooling technologies exist to help minimize indoor overheating, such as cool roofs, green walls, and reflective coatings. Among these, reflective paint stands out as the most economical and practical solution. Reflective paint reduces surface and indoor temperatures by reflecting more of the incoming solar radiation, preventing excessive heat from being absorbed by roofing and wall materials.

Global research demonstrates the effectiveness of reflective coatings in lowering temperatures. A pilot project in Singapore by NTU (2024) showed that applying reflective paint on building facades, rooftops, and even road surfaces resulted in surface and indoor temperatures up to 2°C cooler, with residents reporting that treated areas felt around 1.5°C more comfortable. Laboratory experiments further support these findings. Mishra et al. (2024), for example, created a TiO_2/PDMS reflective paint that achieved 94% solar reflectance, reducing temperatures by about 8°C inside aluminum test boxes coated with the material. These results highlight the strong potential of highly reflective paints to maintain cooler surfaces even under intense sunlight.

Aside from these technological advances, researchers are also exploring sustainable and eco-friendly additives to improve reflectance. One promising material is eggshell, an abundant household waste composed mainly of calcium carbonate ($CaCO_3$), a naturally white, highly light-scattering mineral. Composite material studies (Kamath & Chandrappa, 2021) emphasize that eggshell powder can enhance mechanical and reflective properties when incorporated into coatings. Tao et al. (2020) further noted that $CaCO_3$ increases whiteness and light scattering, key characteristics that enhance reflectance and surface brightness.

With the Philippine context in mind, this research is especially relevant given the robust growth of the poultry subsector, which produced over 185.26 thousand metric tons of eggs in 2023 according to the Philippine Statistics Authority (2023). This high consumption rate generates a massive volume of calcium-rich biowaste that traditionally ends up in municipal dumpsites, contributing to environmental degradation through leachate and greenhouse gas emissions (Baco et al., 2022). Repurposing this waste aligns with the Philippine Green Building Code and the Circular Economy Act, which promote the systemic recovery of resources. Situating this study within the local academic framework addresses a dual challenge: it provides a low-cost, passive cooling solution for "heat-stressed" urban areas while establishing a localized model for converting agricultural by-products into high-value functional coatings.

Despite the proven global effectiveness of reflective paints, many rely on imported or expensive components, limiting their accessibility in developing countries. In the Philippines—where poor insulation, thin roofing, and rising electricity costs intensify heat stress—there remains a lack of affordable reflective solutions made from locally available, sustainable materials. Given that eggshell waste is abundant nationwide, converting it into a reflective paint component offers a practical, eco-conscious approach.

Thus, this study aims to develop and test an innovative reflective paint using eggshell powder as a natural, recycled additive. The research focuses on reflectance and temperature reduction, evaluating how effectively the eggshell-based formulation lowers surface temperatures using infrared measurements. By doing so, the study addresses both the thermal discomfort experienced in many Filipino households and the growing need for sustainable, locally sourced cooling solutions.

Objectives of the study

This study seeks to develop and evaluate a sustainable reflective cooling paint using recycled eggshell waste to address indoor heat stress and promote environmentally responsible innovation.

According to the United States Environmental Protection Agency (2025) and Surface Optics Corporation (2025), among various journals, the secret to minimizing heat absorption is two characteristics: solar reflectance (the capacity to reflect sunlight, both visible and infrared radiation) and thermal emittance (the capacity to emit radiated heat back into the environment). A cool roof with high reflectivity and high emissivity substantially reduces roof and indoor temperatures.

Based on the empirical work of Wongmahasiri et al. (2024), enhancing roof solar reflectance has a significant impact, lowering cooling energy demand by 18–93% and peak cooling demand by 11–27% in air-conditioned buildings. The research also established that cool roofs lower maximum indoor temperatures by 1.2–3.3 °C and thermal discomfort hours by up to 100% in non-air-conditioned buildings.

These results show that high-performance reflective roofing paints provide significant mitigation from tropical urban heat stresses. By reducing roof heat absorption and promoting heat dissipation, reflective paints can lower indoor temperatures, providing not only thermal comfort but also saving in energy consumption. This makes the formulation of environmentally friendly reflective paint a realistic option, specific to the settings of the Philippines

The Role of Infrared Reflection and Direct Temperature Measurement

Reflective paint has emerged as a crucial passive cooling strategy to minimize heat accumulation in infrastructures and urban surfaces. These paints are composed of special pigments and additives that reflect large amounts of sunlight, particularly the invisible Near-Infrared (NIR) radiation, which accounts for approximately 53% of the total solar energy that causes heat buildup (Development of paints with infrared radiation reflective properties, 2025).

Coatings formulated with special inorganic pigments are designed to reflect the radiation in the NIR spectrum, preventing the coating from absorbing heat and keeping objects cooler than they would be with conventional pigments of the same color (Mansour & Farha, 2025). This mechanism is critical because absorbed sunlight directly increases surface temperature, thereby increasing the need for cooling energy.

While standardized methods rely on laboratory equipment to measure solar reflectance and thermal emittance, a more direct and practical way to evaluate effectiveness is to measure the reduction in Surface Temperature under solar exposure using an infrared (IR) gun. This comparative approach, which measures the temperature differential achieved by painted samples, is a reliable method used in many studies to evaluate a material's practical heat-mitigation performance and to indicate whether a surface is primarily reflecting or absorbing heat. This methodology is directly validated by Wai et al. (2025), who utilised a thermal infrared camera to monitor surface temperature variations, demonstrating that the temperature differential serves as the authoritative performance metric for cool coatings. Furthermore, the relevance of this measurement is confirmed by Wongmahasiri et al. (2024), who showed that the surface temperature reduction achieved by reflective coatings directly translates into improved indoor thermal comfort and reduced cooling energy demand in hot, humid residential environments.

A high-performing coating will exhibit a significantly lower peak surface temperature than conventional materials, with reports indicating that reflective coatings can reduce roof surface temperatures by over 30% (LuminX, 2025). Thus, measuring surface temperature directly provides a reliable and practical measure of the coating's ability to mitigate heat gain.

Differences of Regular and Reflective Paint

Regular paint usually contains primary ingredients such as pigments, binders, solvent, and additives to improve various properties such as durability and drying time. Using these ingredients, the paint assures a long lasting and functional coating particularly in industrial and urban residences. According to Pravin (2024), reflective paints minimize heat absorption of surfaces exposed under direct radiation. While reflective paint shares the same primary ingredients as conventional paints, reflective paint includes special ingredients that make it more reflective.

According to StarShield Smart Paints & Coatings (2025), despite their similarities, reflective paints and regular paints differ in composition, performance, and durability. Common pigments and binders with minimal additives are less heat-resistant, and those are typically used in regular paints, resulting in poorer thermal performance. In contrast, reflective paints have high-tech materials like acrylic elastomeric polymers, ceramic microspheres, and infrared-reflective pigments being able to achieve high heat reduction capabilities, which can reduce roof surface temperatures by more than 30∘C

Advanced formulations are utilized in reflective paint production to enhance their ability to minimize heat intake. They are usually made out of epoxy resin or acrylic polymer matrices incorporating solar-reflective nanoparticles. As additives and pigments, the nanoparticles scatter and reflect solar radiation in the ultraviolet (UV), near-infrared (NIR), and visible spectrums. Due to its high refractive index, TiO_2 is significant in ensuring that solar reflectance is optimized and helps sustain cooler surface temperatures. Additionally, reflective paints contain pigments such as TiO_2 and Calcium Carbonate ($CaCO_3$) to enhance their reflectance, and specific binders to further improve weather resistance, durability, and adhesion.

Eggshells ($CaCO_3$) as a Reflective Material

Eggshells are typically regarded as non-reusable waste from homes and the food industry. Murakami et al. (2007), as cited in Aditya et al. (2021) emphasized that 94% of eggshells are composed of calcium carbonate, 1% of which is magnesium carbonate, 1% is calcium phosphate, and 4% is organic material. In which the calcium carbonate contributes significantly to the reflective properties of the eggshells. Calcium carbonate ($CaCO_3$) is a prevalent inorganic compound and serves as the most extensively utilized filler in polymeric materials, including plastics and rubber (Jahromi et al., 2017, as cited in Tao et al., 2020). Moreover, many studies have found that $CaCO_3$ has solar reflectivity. Tao et al. (2020) noted that its reflectivity in the visible spectrum is quite high, resulting in significant whiteness. In general, carbonates exhibit higher reflection in ultraviolet light and a shorter wavelength which means they reflect more UV radiation.

The hardness of the eggshells is said to be determined by the calcium carbonate. In paint, eggshells are used to reflect more light than ordinary paint. Roslan et al. (2020) discovered that eggshell-infused composite materials exhibit high strength when fused or bonded to a structure with various boundaries between them. As a result, it's an excellent alternative to synthetic paint composition. Eggshells, made of calcium carbonate polymers, are typically the load-carrying components; the surrounding egg membranes keep them in the proper position and protect them from environmental hazards such as high heat and humidity. (Roslan et al., 2020).

Eggshells can be found in different stores, and even in the comfort of our own homes, making it the easiest and most cost-effective way to minimize the heat in different house environments. Tao et al (2023) said that calcium carbonate ($CaCO_3$), is known to be affordable, easily accessible, and environmentally safe, making it a sensible option for sustainable applications. Thus, making $CaCO_3$ a safe addition to a variety of materials, such as reflective coatings. This ensures that the paint's components will not endanger the environment, human health, or animals in any way. Furthermore, $CaCO_3$ doesn't produce hazardous byproducts, which can help reduce environmental impacts. To add to that, its sustainability supports the rising demand for green materials. When it comes to reflective materials, using $CaCO_3$ derived from eggshells not only promotes resource efficiency and the 3Rs but also advances the development of sustainable substitutes for traditional reflective agents.

Reflective Paint Effectiveness in the Philippines

In a report prepared for the ASEAN Centre for Energy, Silitonga et al. (2024) noted that as the demand for more sustainable buildings grows, passive reflective techniques are becoming an increasingly viable alternative for cooling and ventilating indoor environments. Passive reflective techniques, unlike mechanical air conditioning systems, require little ventilation and prevent greenhouse gas emissions, reducing energy consumption in buildings by allowing indoor spaces to ventilate sustainably. Using reflective and insulating building materials will maximize the overall cooling efficiency in rural areas, especially in humid countries. The use of passive reflective processes, which employ natural means to regulate a building's thermal comfort without relying on high-energy-intensity mechanical or electrical systems, provides a relatively solid response to the rising demand for sustainability in building construction applications (European Commission, 2024, as cited in Tayag & Conejos, 2025).

The Philippines is situated in a hot, humid region, and its temperature fluctuations contribute to the extreme heat people experience. Last year, the temperature in Metro Manila reached 38.8 °C, resulting in an extreme heat index of 45 °C due to high humidity (Vera-Ruiz, 2024, as cited in Garcia, 2024). This is the highest record in the Philippines since 1915 and poses a problem, given the potential health risks to the general population. Garcia (2024) emphasized that the Philippines is not dealing with this phenomenon on its own; many Asian nations are facing unpredictable heatwaves, which makes this a more widespread regional emergency that needs strong responses.

Among the passive reflective methods discussed above is reflective paint. Mandal et al. (2020) noted that proponents of passive radiative cooling of buildings suggest that white paints, which are suitable for use on structures and have some radiative-reflective potential, could be improved to create highly effective radiative coolers for worldwide use. This will consistently keep indoor spaces cool, thereby mitigating the health risks posed by heat. Most reflective paints are expensive; therefore, marginalized communities don't have full access to them. Furthermore, its ingredients exacerbate the nation's greenhouse effect, further harming the environment. Recycled eggshells, however, can further lower embodied impacts and material costs; a recent research by Santamouris et al. in 2022 quantifies benefits across different kinds of construction and climates. In addition to comfort enhancements, city programs evaluating cool roofs frequently include the carbon emission releases, which will benefit the areas significantly.

Research Framework

Theoretical Framework

This research is grounded on the concept of Reflection of Light, which describes the behavior of surfaces when dealing with solar radiation. Reflective coatings reduce heat absorption by reflecting a significant percentage of incoming light, thereby lowering surface and indoor temperatures. This concept is reinforced by the Theory of Heat Transfer. According to Jack Holman (2001), as cited by Zu et al. (2021), this theory focuses on the mechanisms of radiation and conduction in controlling thermal energy flow along building surfaces. Additionally, Song et al. (2025) discuss the Albedo Theory (Light Scattering), further explaining how sunlight is scattered and reflected by surfaces.

rom a sustainable development approach, the study is based on the Theory of the Circular Economy that advocates for the utilization of recycled and natural materials in a manner that avoids waste and protects resources. This is complementary to the utilization of eggshell waste as a principal reflective material in paint formulation. Wu et al. (2023) also complement this using the Optical Scattering Theory (Light Scattering), which rationalizes the reflectivity of materials. Similarly, the Green Building Theory places this innovation on the right track for sustainable design, focusing on energy efficiency and the reduction of carbon emissions in building processes. And finally, Rathinavel et al. (2023) explore the Thermal Conductivity Theory (Low Thermal Conductivity), which highlights minimizing indoor heat to improve comfort, health, and productivity.

By combining these theories, the current study aims to develop reflective paint as a practical, science-driven innovation that enhances environmental sustainability and social health.

Conceptual Framework

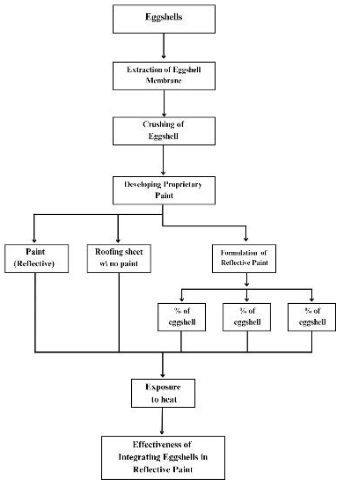

Figure 1. Conceptual Framework of the Study on Eggshell-Based Reflective Paint

The conceptual framework of this study is designed to evaluate the effectiveness of chicken eggshells as an additive in reflective paint. The process starts with the collection of eggshells, removal of the membrane, and crushing into fine particles to ensure consistency. These particles were then incorporated into a formulated reflective paint at three specific concentrations—15%, 30%, and 50%—which serve as the Independent Variable. The formulated paint samples were applied to standardized substrates and compared against a Negative Control (unpainted roofing sheet) and a Positive Control (commercially available reflective paint). All samples were simultaneously subjected to heat exposure. The results were then analyzed by measuring the surface temperature reduction using a non-contact Infrared Thermometer to determine the effectiveness of the eggshell additive in reducing overall heat absorption

Scope and Limitations

The present study aims to develop and test the thermal performance of the reflective paint made from recycled eggshells. It aims to determine whether the paint effectively reduces surface temperature and, consequently, indoor heat, while remaining eco-friendly. It compared the performance against conventional commercial paint and commercial reflective paint. The experiments examined surface temperature reduction, thermal properties, and physical properties through small-scale application on controlled test substrates using an infrared thermometer (IR gun). The study's ability to measure intrinsic reflectivity is limited to the direct correlation between surface temperature and solar reflection under testing conditions.

The research is limited to small-scale tests on specific substrates and does not extend to large-scale applications on actual buildings or long-term weather exposure. It also does not consider aesthetic aspects like color, finish, or texture. Issues related to industrial production, supply chain, and compliance with manufacturing standards are beyond its scope. Additionally, drying time was only measured under controlled testing conditions and may vary in real-world, full-scale settings. The study also did not evaluate cost efficiency or economic feasibility of the paint.

METHODOLOGY

Research Design

This research will utilize a true experimental design that is quantitative, specifically the post-test-only control group design, to assess whether an eco-friendly reflective roof paint made from eggshell waste is effective. As J. and D. Creswell (2018) explained in "Research Design: Qualitative, Quantitative, and Mixed Methods Approaches," a true experimental design establishes cause-and-effect relationships through the random assignment of participants to groups, which reduces bias and strengthens internal validity. As opposed to iterative methods involving multiple tests across successive rounds, this research adopts a non-iterative design in which data are gathered once following exposure to the controlled conditions. This is such that the results directly represent the treatment effect, free from interference from repeated testing.

There are two groups in the experimental design: the experimental and control groups. The experimental group consisted of roof panels coated with newly developed reflective paint containing varying concentrations of eggshell-derived calcium carbonate ($CaCO_3$). The control group consisted of two subgroups: one coated with commercially produced reflective paint and the other left unpainted. Roof panels were randomly assigned to these groups to ensure unbiased distribution and reliable results.

Preparation consists of washing, drying, and grinding eggshells into a powder, then adding them to paint mixtures at various ratios. The same formulation batch was applied evenly to the roof panel samples to ensure reproducibility. Following application and curing under standard conditions, the panels were exposed to natural sunlight or artificial heat lamps in a controlled laboratory setting to replicate outdoor heating.

Thermal regulatory efficacy was measured primarily by the Surface Temperature Reduction achieved by the experimental paints, an established benchmark that assesses a surface's capacity to reflect sunlight and shed absorbed heat. Surface temperature reduction values are directly correlated with a material's ability to remain cool in response to solar radiation, which underpins the Solar Reflectance Index (SRI) as defined by ASTM International. Research by Zahra Jandaghian et al. (2025) validates that the thermal performance of a coating is directly determined by the temperature differential observed under solar exposure. Dark, non-reflective roofs usually exhibit high surface temperatures, whereas highly reflective coatings show significantly lower temperatures. By determining the surface temperature of each panel, the surface temperature reduction is the standardized assessment of the eggshell-based paint's reflective capacity.

The data obtained will be statistically analyzed to ensure that differences in surface temperature reduction are significant between treatments. This method is supported by research, such as that of the U.S. Department of Energy (2025), which shows that high-solar-reflective cool roofs can lower surface temperatures by as much as 28°C compared with standard dark roofs. A rigorous experimental analysis by Wai et al. (2025), which used a thermal infrared camera to monitor surface temperature variations, validates the use of surface temperature differential as a reliable indicator of cooling efficacy in cool roof coatings. Likewise, Wongmahasiri et al. (2024) discuss the role of solar absorption in influencing thermal comfort and energy consumption in homes and thereby advocate for the use of reflective coatings in tropical regions.

Overall, this experimental design provides a valid and reliable method for testing the thermal regulation capability of eggshell-based reflective paint. Through the application of a post-test-only control group design and by measuring performance via surface temperature reduction, the research provides evidence on whether recycled eggshells can be adopted as a sustainable, cost-effective substitute for commercially available reflective paints.

Procedure

The procedure utilizes the following materials: chicken eggshells ($CaCO_3$), sodium silicate ($mNa_2O{\cdot}nSiO_2{\cdot}xH_2O$), zinc oxide (ZnO), titanium dioxide (TiO_2), iron(III) oxide (Fe_2O_3), sodium hexafluorosilicate (Na_2SiF_6), and water (H_2O). The required equipment includes measuring containers for accurate proportioning, a stirring rod for thorough mixing, a bucket for combining the materials, and a designated curing space to allow the mixture to properly set and achieve the desired properties.

Table 1. Materials and Functions in Reflective Paint Development

Component Function	Material/Compound
Binder	$mNa_2O{\cdot}nSiO_2{\cdot}xH_2O$
Solvent	H_2O
Filler	$CaCO_3$
UV stabilizer	Fe_2O_3
Reflective Pigment	TiO_2
Pigment and Microbial Resistance	ZnO
Hardener/setting agent	Na_2SiF_6
Additives	—

Table 2. Preparation of Chicken eggshells as an additive

Step	Procedure
1	Collect chicken eggshell waste
2	Boil the eggshells to sanitize and for easy removal of the inner membrane
3	Remove the inner membrane
4	Rinse and allow them to dry completely
5	Crush and grind eggshells into fine powder
6	Pass the ground materials through a sieve for a consistent particle size.

Table 3. Procedure for Formulating Reflective Roof Paint

Step	Procedure
1	Gather all required components: binder($mNa_2O.nSiO_2.xH_2O$) and extender pigments including ZnO, TiO_2, Fe_2O_3, $CaCO_3$, Na_2SiF_6, and H_20.
2	Mix the extender pigments (ZnO,TiO_2, Fe_2O_3, $CaCO_3$, Na_2DiF_6, and additives)
3	Stir at room temperature for 20 minutes
4	Combine the extender pigments with $mNa_2O.nSiO_2.xH_2O$
5	Stir for another 20 minutes
6	Add water to dissolve the powders, creating a liquid state of paint.

Materials and Experimental Procedure

Both chemical and natural constituents were used in the reflective roof paint. The binder was sodium silicate ($mNa_2O{\cdot}nSiO_2{\cdot}H_2O$), and the solvent was distilled water (H_2O). The fillers included calcium carbonate ($CaCO_3$) and powdered chicken eggshells, which are expected to provide structural stability to the paint. Iron(III) oxide (Fe_2O_3) served as a UV stabilizer, titanium dioxide (TiO_2) as a reflective pigment, and zinc oxide (ZnO) for color stability and biostatic microbial resistance. The hardener and setting agent was sodium hexafluorosilicate (Na_2SiF_6). All chemicals were of analytical grade, and sourcing from verified suppliers ensured the credibility of the experimental procedure (Le & Lê, 2021). Safety precautions will also be observed during formulation and testing. Since the paint mixture contains both natural and chemical additives, some ingredients may cause allergic reactions upon skin contact or inhalation. Therefore, researchers used protective equipment such as gloves, masks, and lab coats, and ensured proper ventilation throughout the process.

The eggshells were collected from household food waste and local bakeries, ensuring that the study reuses materials that would otherwise contribute to solid waste. After processing (boiling, drying, and grinding), any unusable residues, such as membranes, were disposed of in biodegradable waste bins. Chemical byproducts, if any, were handled in accordance with laboratory waste management protocols to prevent environmental contamination.

The main components of the reflective roof coating included sodium silicate, zinc oxide, titanium dioxide, calcium carbonate, ferric oxide, and sodium hexafluorosilicate. All chemicals were high-grade and purchased from Merck to ensure consistency and purity.

The experimental process involved preparing an extender pigment mixture with sodium silicate to form a stable coating solution. Initially, the extender pigments (ZnO, TiO_2, Fe_2O_3, $CaCO_3$, Na_2SiF_6) were measured and added to the sodium silicate solution, followed by continuous stirring at room temperature until a semi-dry mixture was obtained. To achieve uniformity, the resulting powder was refined by ball milling for 1 hour. After milling, the mixtures were left to cure under room temperature conditions for 24 hours to ensure complete hardening before application.

The prepared paint samples were then applied onto identical roofing substrates and allowed to dry for 24–48 hours. Once dried, the samples were exposed to natural sunlight for a 3-day testing period. Temperature readings were taken at three intervals each day—10:00 AM, 12:00 noon, and 2:00 PM—to capture morning, peak, and afternoon heat levels. Surface temperature, indoor temperature, solar reflectance, and thermal absorption were recorded consistently throughout the testing period.

Thermal regulatory efficacy was measured directly via the Surface Temperature Reduction achieved by the experimental paints. Testing was conducted on-site at the residential property (the testing location) by applying the paint samples to standardized substrates (test panels) and exposing them to natural solar radiation.

Surface temperatures were recorded using a non-contact infrared thermometer, model NJYT T600A. This instrument enabled precise, non-invasive capture of instantaneous surface temperatures across all test panels at predetermined intervals throughout the day. The maximum temperature differential achieved between the formulated paints and the control groups was established as the primary measure of effectiveness.

Following the collection of surface temperature data, the results underwent statistical analysis. Specifically, a one-way Analysis of Variance (ANOVA) was employed to determine whether there were statistically significant differences in the average surface temperature reduction (ΔT) among the eggshell-based reflective paint groups (15%, 30%, and 50% concentrations), the commercial reflective paint, and the traditional non-reflective paint groups. This analysis establishes the reliability of the findings, determines the optimal concentration of eggshell powder, and assesses whether there are statistically significant differences among the eggshell-based reflective paint, the commercial reflective paint, and the roofing sheet with no paint groups.

Process of testing the Solar Reflectance and Thermal Absorption of Eggshells-integrated Reflective Roof Paint

The process of testing the solar reflectance and thermal absorption of the eggshell-integrated reflective roof paint began with the preparation of samples. Three paint groups with varying concentrations of eggshell-based reflective paint were prepared and applied to identical metal roof panels in triplicate, ensuring uniform thickness and proper curing under controlled conditions. Following this, the panels were arranged in an outdoor environment with unobstructed exposure to natural sunlight. All samples were positioned adjacent to one another, oriented identically, and inclined at the same angle to ensure equal solar incidence across all test surfaces.

Surface temperature measurements were then obtained using an infrared thermometer (NJTY T600A) at specific time intervals: 10:00 a.m., 12:00 noon, and 3:00 p.m. The maximum temperature differential (ΔTmax) was determined by identifying the largest observed temperature difference between materials, typically recorded during peak solar radiation at midday. In this study, ΔTmax was used to compare the difference between the non-reflective control and the test reflective samples (ΔTmax = Non-reflective control − test reflective sample). After data collection, the results were analyzed and compared across all paint groups using the Analysis of Variance (ANOVA) statistical method.

Sampling Method

The researchers used random assignment as the sampling method for this study to ensure objectivity and reduce bias. Roof panels coated with eggshell-based reflective paint, commercial reflective paint, and traditional non-reflective paint were randomly assigned to treatment and control groups. This approach guaranteed that each panel had an equal chance of being assigned to any group, thereby enhancing the validity of the results.

Random assignment is a probability-based technique in which participants or samples are allocated by chance rather than by choice. According to Creswell and Creswell (2018), random assignment strengthens the internal validity of experimental research by ensuring that observed effects can be attributed to the treatment itself rather than to pre-existing differences between groups.

The objective of this research is to test the effectiveness of the eggshell-incorporated reflective paint in reducing surface temperature and indoor temperatures. By randomly assigning roof panels to different paint conditions, the study ensured that any differences observed in surface and indoor temperature reduction and solar reflectivity are the direct result of the paint formulations tested, thereby supporting the study's goal of evaluating the reflective potential of eggshell-based additives.

Research Instrument

The SRI Testing Observation Sheet is designed to record and evaluate the Solar Reflective Index (SRI) results of the formulated eggshell-based cooling paint compared with commercial reflective and non-reflective paints. The SRI is a standard measure that combines both solar reflectance and thermal emittance to indicate how well a surface stays cool when exposed to sunlight. By documenting the surface temperature and SRI values of each paint sample under identical laboratory conditions, this instrument helped assess the experimental paint's thermal regulation effectiveness.

Commercial Paint Samples

The commercial paint samples consisted of two categories used as baseline comparisons in the study. Paint sample 0 served as the control and was identified as a metal panel with no paint applied. Paint sample 1 consisted of a commercially available reflective paint. For both samples, data were collected based on the date of testing, hours of exposure to sunlight, front and back panel temperatures (°C), and the computed temperature difference, with corresponding remarks recorded for each trial.

Eggshell Paint Samples

The eggshell-based paint samples were categorized according to varying concentration ratios. Paint sample 2.1 consisted of eggshell paint with a 15% eggshell ratio, sample 2.2 had a 30% ratio, and sample 2.3 had a 50% ratio. Similar to the commercial samples, each was tested under controlled conditions, with data gathered on the date of testing, duration of sunlight exposure, front and back panel temperatures (°C), and the resulting temperature difference. Observations and remarks were also documented for each experimental run to support comparative analysis.

To ensure accuracy in the infrared temperature testing, all roofing sheet samples were prepared and coated under identical conditions. Each panel was exposed to a controlled infrared heat source at a fixed distance to simulate prolonged thermal exposure. An infrared thermometer was used to measure the surface temperature at the front of the panel and the temperature behind the panel to determine heat transfer. All measurements were taken at 4-hour, 6-hour, and 8-hour exposure periods.

Each test will be repeated at least three times to ensure consistency, and the recorded values will be averaged to minimize experimental error. Laboratory personnel conducting the heating and measurement procedures followed standardized protocols, while the researchers independently analyzed the collected data to avoid bias.

Statistical Treatment

The study's thermal data, called the Cooling Differential, was initially analysed using basic figures known as descriptive statistics. The average performance for all developed paint mixes, the commercial reflective paint, and the control panel, which has no paint, were calculated. The standard deviation was also determined. This number showed how consistent the cooling results were during the testing period. These simple calculations summarised the typical performance and reliability of each paint.

To determine whether the differences in cooling performance among the groups are meaningful, an advanced statistical test was used. The One-Way Analysis of Variance (ANOVA) was conducted to compare the average cooling across all paint groups simultaneously. If the ANOVA test shows that an overall difference exists, a second, more detailed test is required: the Tukey's Honestly Significant Difference, or HSD, test. This test involves comparing every single paint mixture against every other one. This direct comparison confirmed which specific paint mixture was statistically superior, allowing the researchers to identify the optimal eco-friendly formulation that performs significantly better than both the commercial paint and the unpainted control.

Ethical Considerations

The study did not involve any human or animal subjects, as it focused solely on paint formulation and thermal testing of inanimate objects, specifically roofing sheets. The preparation of the paint strictly followed standard laboratory safety guidelines to ensure the safe and proper handling of materials. All materials used, especially eggshell waste, were collected and managed responsibly as part of environmental stewardship, promoting upcycling and preventing unnecessary waste or ecological harm.

After formulation, the testing phase was conducted in a real house setting or in a sunlight-exposed environment to accurately assess heat and thermal performance under natural conditions. The procedures were carried out carefully and honestly, with all observations and measurements recorded accurately. All waste materials were disposed of properly in accordance with environmental regulations, ensuring no harm to humans, animals, or the environment. Throughout the study, the researchers upheld transparency and integrity in data collection, ensuring that the results are reliable and that the research contributes responsibly to the field of sustainable materials.

RESULTS AND DISCUSSION

Result for Unpainted Roofing Sheet

The thermal exposure results for the unpainted roofing sheet show clear changes in surface heat and heat transfer across the three testing dates. The temperatures taken every three hours reflect how the bare metal reacted directly to sunlight and the weather.

On 13 November, the front temperature ranged from 40.8°C to 41.8°C, while the back temperature varied from 36.6°C to 39.3°C. The cooling difference was at most 5.2°C, indicating only minimal heat reduction. By 16 November, temperatures rose significantly, with the front reaching 46.8°C and the back 46.7°C, resulting in a negligible cooling difference of 0.1°C. This suggests that nearly all the heat passed through the metal, supporting studies that indicate bare metal roofs transfer heat easily and offer poor insulation (Bansal et al., 2020). On 18 November, a larger temperature difference of 7.5°C was observed in the morning, but during midday and afternoon, the heat reduction remained minimal.

Overall, the unpainted yero absorbed and passed on heat easily. This supports the need for reflective coatings, as past research shows these coatings can help lower heat by reflecting more sunlight (Kim & Kim, 2022; Medina et al., 2021).

Table 4. Unpainted Roofing Sheet Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	40.8	39.3	1.5
	12:00	41.3	38.3	3
	2:00	41.8	36.6	5.2
16-Nov	10:00	43.8	39.3	4.5
	12:00	45.9	45	0.9
	2:00	46.8	46.7	0.1
18-Nov	10:00	39.3	31.8	7.5
	12:00	39.3	39	0.3
	2:00	40.8	40.5	0.3

Result for Commercial Paint

The results for the commercial reflective paint show that it reduced the behind-panel temperature more effectively than an unpainted sheet. Across all testing dates, the cooling differential remained between 2.4°C and 5.7°C, indicating that the coating helped block some of the heat before it reached the back of the panel.

This performance matches what the literature explains about the difference between regular and reflective paint. Regular paints primarily use basic pigments and binders that are not designed to withstand heat. As a result, they allow more heat to pass through (StarShield Smart Paints & Coatings, 2025). In contrast, reflective paints include special ingredients such as ceramic microspheres, infrared-reflective pigments, and acrylic polymers, which make them more effective at reflecting sunlight and reducing heat absorption. These advanced materials can significantly lower surface temperatures, sometimes by more than 30°C (Pravin, 2024; StarShield Smart Paints & Coatings, 2025).

The commercial reflective paint's consistent cooling effect, as shown in the results, supports this. The higher cooling differential during peak hours, such as 5.7°C at 2:00 PM on November 18, shows how reflective pigments work more effectively when sunlight is strongest. This is also in line with the idea that reflective paints use TiO_2 and $CaCO_3$ pigments, which help scatter light across UV, NIR, and visible spectrums, keeping the surface cooler.

Table 5. Commercial Paint Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	40.4	37.2	3.2
	12:00	40.9	37.5	3.4
	2:00	42.55	38.1	4.45
16-Nov	10:00	39.4	36.2	3.2
	12:00	42.5	38.7	3.8
	2:00	40.5	38.1	2.4
18-Nov	10:00	39.4	35.8	3.6
	12:00	38.9	36.5	2.4
	2:00	43.5	37.8	5.7

Result for Eggshell Paint (15%)

The analysis of the raw thermal data collected for the Eggshell Paint (15%) formulation, as presented in Table 8, establishes this ratio as the descriptively highest-performing experimental group.

The 15% formulation demonstrated superior heat mitigation, achieving a peak Panel Temperature Difference of 11.0°C when the surface temperature reached 47.0°C. This successful thermal resistance limited the behind-panel temperature to only 36 °C during that peak solar exposure. Furthermore, the overall mean Cooling Differential for the 15 group was the highest among all eggshell formulations at 6.74°C. This performance provides strong empirical evidence that the 15 concentration is highly effective at disrupting the flow of solar heat, directly addressing the research objective of formulating a high-performing reflective paint.

This finding is well-supported by existing literature on sustainable thermal management; studies on reflective coatings in hot climates, such as those by Hernández-Pérez et al. (2021), have reported that light-colored cool roofs achieved a substantial reduction in daily heat gain, resulting in temperature differentials that validate the principle of using high-reflectance materials to interrupt heat transfer and improve indoor thermal comfort. The magnitude of the cooling differential achieved by the 15% eggshell formulation is comparable to, and in some peak instances exceeds, the typical 6% - 8% reductions cited in literature for effective cool coatings in tropical environments by Xian Rong et al, thereby validating the use of the eco-friendly eggshell additive as a viable, sustainable component for passive cooling.

Table 6. Eggshell Paint (15%) Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	39.4	35.2	4.2
	12:00	40.9	35.5	5.4
	2:00	43.2	36.2	7
16-Nov	10:00	42.4	36.2	6.2
	12:00	47	36	11
	2:00	44.9	36.5	8.4
18-Nov	10:00	37.9	31.8	6.1
	12:00	38.9	33.5	5.4
	2:00	43.5	37.8	5.7

Result for Eggshell Paint (30%)

The roofing panel coated with 30% eggshell reflective paint consistently reduced its surface temperature across all trials. The cooling values for the 30% eggshell coating ranged from 4.7°C to 8°C, indicating that the mixture reduced heat on the panel even as sunlight intensity varied throughout the day. The mean drop of 5.88°C indicates steady performance, although this ratio was not the most effective among all mixtures. The largest drop, which reached 8°C at midday, suggests that the coating becomes more responsive as solar radiation increases.

This outcome is supported by previous literature, as Hernández-Pérez (2021) explained that calcium-carbonate–based coatings tend to reflect more solar radiation because the mineral is naturally bright and thermally stable, and this characteristic likely contributes to the behavior observed in the 30% mixture. Additionally, National Science Open (2024) found that mineral fillers can enhance the way reflective paints scatter incoming sunlight, thereby reducing the heat absorbed by coated surfaces. However, the pattern in the present study shows that increasing the amount of additive does not automatically lead to improved thermal performance, which aligns with Lu et al. (2023), who reported that waste-derived reflective additives perform best only at certain concentration levels rather than improving continuously as more material is added.

While the 30% eggshell formulation provided reliable cooling, it did not outperform the other ratios; nevertheless, it still demonstrates potential as an affordable and environmentally sustainable coating for reducing heat on roofing panels, especially under conditions where solar intensity fluctuates throughout the day.

Table 7. Eggshell Paint (30%) Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	38.4	32.9	5.5
	12:00	40.1	35.4	4.7
	2:00	42	36	6
16-Nov	10:00	41.4	35.9	5.5
	12:00	47	39	8
	2:00	44.1	38.4	5.7
18-Nov	10:00	38.2	31.4	6.8
	12:00	38.1	33.4	4.7
	2:00	41	35	6

Result for Eggshell Paint (50%)

The data presented in Table 10 provide strong evidence for the thermal-regulation capacity of the 50% eggshell paint formulation. The consistent cooling differential, ranging between 5.3 °C and 6.8 °C, demonstrates the paint's reliable ability to reduce heat transfer under various solar conditions.

The highest cooling differential of 6.8◦C was recorded twice, both at 10:00 am. This suggests the paint is most effective at reducing heat transfer when the front of the roofing sheet is at a relatively lower temperature, between 39.7◦C and 38.2◦C. This 50% formulation implies greater efficiency under morning sun conditions or before peak heat. In contrast, the lowest temperature differential of 5.3 °C was recorded multiple times, specifically during peak solar exposure periods. This reduction in cooling performance corresponds to periods of higher front-panel temperatures, suggesting a minimal decrease in the coating's thermal-regulation effectiveness under high solar intensity or elevated ambient heat. Nonetheless, the absolute highest front-panel temperature of 47.6◦C yielded a differential of 6.5◦C, indicating that the paint can still maintain strong thermal regulation even under peak heat conditions.

Overall, the results demonstrate that the 50% eggshell formulation reliably moderates thermal gain, particularly during morning exposure, and shows strong potential as a passive cooling coating. The mean cooling differential of 6.11 °C supports the limited heat-transfer effectiveness of eggshell powder. This interpretation aligns with the findings of Song et al. (2025), who state that finely ground eggshell powder can enhance solar reflectance in coating systems. Although different materials are used in the present study, the similar outcomes demonstrate the promise of eggshell-based additives as effective cooling components in coating formulations.

Table 8. Eggshell Paint (50%) Data

Date of Test	Time of Exposure	Front Panel	Behind Panel	Temperature Differential
13-Nov	10:00	39.7	32.9	6.8
	12:00	40.7	35.4	5.3
	2:00	42.6	36.7	5.9
16-Nov	10:00	42.7	36.9	5.8
	12:00	47.6	41.1	6.5
	2:00	44.7	39.4	5.3
18-Nov	10:00	38.2	31.4	6.8
	12:00	38.7	33.4	5.3
	2:00	41.6	35.1	6.5

Table 9 then presents the ANOVA results for differences among the five roofing treatments in temperature reduction. To determine if significant differences exist in their thermal performance, the Null hypothesis (H0) states that there is no significant difference in the mean surface temperatures of the roofing sheet across the various paint formulations, while the Alternative hypothesis (H1) states that there is a significant difference in the mean surface temperatures among the different paint formulations.

The front-panel temperature indicates no statistically significant difference among the five treatments (F = 0.485, *p* = 0.747). This indicates that, when exposed to direct sunlight, all roof panels absorb the same amount of heat at the surface, regardless of their coating. The temperature behind the panel results indicate a statistically significant difference among treatments (F = 4.690, *p* = 0.009). This demonstrates that the five paint types directly affect the amount of heat transferred through the substance. The cooling differential is the most significant metric for assessing reflective performance, as it indicates the actual thermal protection the paint provides. The ANOVA reveals a highly significant difference (F = 12.067, $p < 0.001$), suggesting that the treatments' capacities to lessen heat penetration differ significantly.

The result is consistent with research showing that incident solar radiation dominates direct surface heating, such that even reflective coatings would first heat up before exhibiting their cooling effects through reduced heat transfer (Wai et al., 2025). This explains that the actual performance of reflective coatings does not become apparent until heat begins to pass through the material, which accounts for the non-significant result for front-panel temperatures. According to research on CaCO3 cool-roof technologies by Wongmahasiri et al. (2024), eggshell-based coatings are effective in limiting conductive heat transfer, as evidenced by notable decreases in the p-values for behind-panel temperature and cooling difference.

Table 9. Significance result of Eggshell paints(15%, 30% and 50%) with commercial and unpainted roofing sheets

Variables	F-value	*p-value*	Decision	Conclusion
Front of panel	0.485	0.747	Do not Reject Ho	Not Significant
Behind of panel	4.690	0.009	Reject Ho	Significant
Cooling Differential	12.067	<.001	Reject Ho	Significant

Note: Significant at 5% level

ANOVA result for Eggshell paints(15%, 30% and 50%)

Table 9 shows the ANOVA comparison of the three eggshell paint concentrations 15%, 30%, and 50% to evaluate their thermal performance and the analysis indicates that the differences are non-significant. The front-panel temperature (*p*=0.851), behind-panel temperature (*p*=0.845), and cooling differential (*p*=0.539) all have high p-values. Because each p-value exceeds the 0.05 significance level, the null hypothesis is not rejected.

This result confirms that the different concentrations do not yield a distinct cooling effect, indicating that all three formulations are comparably viable for reducing surface heat. The main cooling mechanism is attributed to the Solar Reflectance of the eggshell's primary component, which is calcium carbonate, which successfully reflects the sun's heat. The successful cooling observed across all eggshell paint samples validates the study's premise of using eggshell as a reflective pigment to reduce roof heat (Tao et al., 2021).

These findings also resonate with the work of Shang et al. (2024), in which composite inorganic coatings applied to walls improved thermal insulation by increasing heat-flux reflectivity. Their study highlights how carefully engineered coating formulations, rather than simply more filler, can drastically enhance reflective performance and reduce heat absorption. This parallels our results, implying that increasing eggshell ($CaCO_3$) concentration doesn't necessarily yield proportional gains in cooling, and that coating composition and dispersion are arguably more important.

However, the 15% Eggshell Paint formulation achieved the highest mean cooling differential of 6.74 °C. This data point, combined with the ANOVA's finding of statistical equivalence, suggests that 15% concentration is the optimal formulation from a resource-efficiency standpoint.

Table 10. Significant results for Eggshell paints (15%, 30% and 50%)

Variables	F-value	*p-value*	Decision	Conclusion
Front of panel	0.163	0.851	Do not Reject Ho	Not Significant
Behind of panel	0.170	0.845	Do not Reject Ho	Not Significant
Cooling Differential	0.646	0.539	Do not Reject Ho	Not Significant

Note: Significant at 5% level

ANOVA result of Eggshell paints (15%, 30% and 50%)

The mean cooling differential results show that the 15% eggshell-based reflective paint provides the greatest thermal protection among the three formulations. The results show an average temperature difference of 6.74°C between the front and back of the panel, compared with 6.02°C and 5.88°C for the 50% and 30% eggshell-based paint, respectively. Therefore, indicating that the 15% formulation keeps the back pane cooler than the higher eggshell concentrations under the same solar exposure by preventing more heat from flowing through the roofing sheet.

This pattern implies that there is an ideal eggshell concentration where light scattering and reflectance are maximized without sacrificing the paint matrix's stability. Tao et al. (2020) found that $CaCO_3$-enhanced reflective films achieved the highest albedo at moderate filler loadings, while excessive $CaCO_3$ reduced reflectance due to particle crowding.

Moreover, Wu et al. (2023) proved that when the particles are evenly distributed rather than excessively concentrated, eggshell-derived $CaCO_3$ enhances radiative cooling throughout the day. Thus, this emphasizes that the ideal microstructure and particle behavior are the foundation of the 15% eggshell-based reflective paint's exceptional cooling performance in your study. Eggshell-derived CaCO3 particles are abundant enough to improve scattering at this concentration, but not dense enough to group together or obstruct the reflecting pathway. Furthermore, particle aggregation and binder insufficiency, observed in both studies, begin to degrade the coating's optical and thermal properties as the concentration increases to 30% and 50%.

Table 11. The Mean Cooling Differential of the 15%, 30%, and 50% Eggshell Paint Formulations

	Group	Mean
Front	1	41.87
	2	41.14
	3	41.83
Behind	1	35.12
	2	35.27
	3	35.81
Difference	1	6.74
	2	5.88
	3	6.02

Note: Significant at 5% level

Interpretation of ANOVA: Comparison of All Treatments

The ANOVA compared all five treatments (This ANOVA compared the thermal performance of all five roofing treatments: the three eggshell concentrations (15%, 30%, 50%), the commercial paint, and the unpainted roofing sheet. For the Front of the panel temperature, the analysis showed no significant difference (F = 0.485, P = 0.747), indicating that all surfaces absorbed heat similarly when directly exposed to the sun. However, a significant difference was found for the Behind of Panel temperature (F = 4.690, P = 0.009). This crucial finding suggests that the various coatings were not equally effective at insulating and reducing heat transfer to the substrate beneath the panels. This disparity was confirmed by the Cooling Differential (Front minus Behind), which showed a highly significant effect (F = 12.067, P < .001), indicating that the treatments differed substantially in their ability to lower the temperature beneath the roofing sheets.

Table 12. ANOVA: Comparison of All Treatments

Variables	F-value	df1	df2	*p-value*
Front	0.163	2	16.0	0.851
Behind	0.170	2	14.7	0.845
Difference	0.646	2	14.0	0.539

Summary of Findings

The experimental evaluation of the developed reflective paint demonstrated significant cooling efficacy across all tested concentrations. Statistical analysis using a One-Way ANOVA confirmed a highly significant difference (P< .001) in heat reduction when comparing the eggshell-coated roofing sheets to the unpainted control. This confirms that the high concentration of calcium carbonate (CaCO3) found in eggshells effectively scatters solar radiation and limits heat transmission into the structure.

The following table summarizes the performance of each treatment qualitatively to provide an overview of the thermal trends observed:

Table 13. Summary of Thermal Performance Trends Across Treatments

	Performance Summary	Thermal Result
15% Eggshell Paint	Demonstrated the highest overall reduction in heat transmission among all tested samples.	Optimal Cooling
30% Eggshell Paint	Provided significant cooling that was statistically identical to the 15% formulation.	High Efficacy
50% Eggshell Paint	Maintained a consistent cooling effect comparable to the lower eggshell concentrations.	High Efficacy
Commercial Paint	Successfully reduced heat compared to bare metal but was surpassed by the eggshell formulations.	Moderate Cooling

CONCLUSION

The study successfully achieved its objective of formulating and evaluating the thermal performance of eco-friendly reflective paints using varying concentrations of eggshell powder. Based on the statistical analysis, several key conclusions were drawn. First, the eggshell paint formulations, when considered as a group, were found to be highly effective in mitigating heat transfer. A highly significant difference in cooling differential (F = 12.067, $p < 0.001$) was observed when comparing all five treatments, including the three eggshell-based paints, the commercial reflective paint, and the unpainted control. This result confirms that the application of paint coatings significantly improved thermal performance compared to the unpainted roofing sheet.

Furthermore, the analysis of the three eggshell concentrations (15%, 30%, and 50%) showed no statistically significant difference in their ability to reduce surface temperature, as indicated by a p-value of 0.539. This suggests that all three formulations provided comparable cooling effects, and increasing the proportion of eggshell powder does not necessarily result in better thermal performance. Lastly, based on descriptive analysis, the 15% eggshell paint formulation emerged as the most resource-efficient option, achieving the highest mean cooling differential of 6.74°C. This makes it the most practical and promising concentration for further development and potential application.

Recommendations

The study recommends that, given the conclusion of thermal equivalence among the tested formulations, future research should move beyond basic temperature differential measurements and instead focus on material performance and durability assessment. The 15% eggshell paint formulation should be established as the baseline for subsequent studies, as it demonstrated the highest mean cooling effect while remaining the most resource-efficient option.

Further investigations should aim to determine the paint's true cooling efficiency by adopting international standards, particularly through the measurement of solar reflectance and thermal emissivity to compute the Solar Reflectance Index (SRI). In addition, durability and longevity tests are essential to ensure sustained performance over time. These should include evaluations of water resistance to assess performance under rain exposure, adhesion strength to prevent peeling or chipping, and accelerated weathering tests to simulate prolonged ultraviolet exposure and determine any loss in reflectivity.

Moreover, future studies should focus on optimizing the overall coating quality by refining the manufacturing process. This includes examining the ideal eggshell particle size and distribution to achieve better uniformity and surface finish, as well as assessing application properties such as drying time to ensure the paint's practicality and ease of use in real-world conditions.

REFERENCES

Aditya, S., Stephen, J., & Radhakrishnan, M. (2021). Utilization of eggshell waste in calcium-fortified foods and other industrial applications: A review. *Trends in Food Science & Technology, 115*, 422–432. https://doi.org/10.1016/j.tifs.2021.06.047

Baco, J., et al. (2022). Environmental impact of agricultural biowaste: Case studies on eggshell disposal in municipal landfills. *Journal of Philippine Environmental Management, 14*(2), 112–128.

Bansal, N. K., Goel, V., & Singh, R. (2020). Thermal behavior of metal roofing materials under solar exposure. *Journal of Building Physics, 44*(3), 215–234. https://doi.org/10.1177/1744259120921096

Chandrappa, R. K., & Kamath, S. S. (2021). The eggshell as a filler in composite materials—a review. *Journal of Mechanical and Energy Engineering, 4*(4), 335–340. https://doi.org/10.30464/jmee.2020.4.4.335

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Department of Energy Philippines. (2025). *DOE urges public to adopt energy efficiency measures as summer begins*. [suspicious link removed]

Garcia, M. B. (2024). Physical school closures as a public health response to high heat index in the Philippines: A critical perspective. *Journal of Public Health and Emergency, 8*, 30. https://doi.org/10.21037/jphe-24-33

Goh, J. (2024, April). *Authorities eye reflective paint for buildings as NTU pilot shows it can cool urban areas by 2 deg C*. Nanyang Technological University. https://www.ntu.edu.sg/erian/news-events/news/detail/authorities-eye-reflective-paint-for-buildings-as-ntu-pilot-shows-it-can-cool-urban-areas-by-2-deg-c

Hernández-Pérez, P., Xamán, J., Flores-Prieto, J. J., & Rincón, D. F. (2021). Influence of traditional and solar reflective coatings on the heat transfer of building roofs in Mexico. *Applied Sciences, 11*(7), 3263. https://doi.org/10.3390/app11073263

Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate change 2022 – Impacts, adaptation and vulnerability: Working group II contribution to the sixth assessment report of the IPCC*. Cambridge University Press.

Kim, S., & Kim, J. (2022). Effectiveness of high-albedo reflective coatings in reducing roof surface temperature. *Energy and Buildings, 258*, 111822. https://doi.org/10.1016/j.enbuild.2022.111822

Le, H. T. V., & Lê, D. T. (2021). Green synthesis of silver nanoparticles and their application in catalytic reduction of 4-nitrophenol. *Materials Chemistry and Physics, 272*, 124976. https://doi.org/10.1016/j.matchemphys.2021.124976

Li, X., Peoples, J., Huang, Z., Zhao, Z., Qiu, J., & Ruan, X. (2020). Full daytime sub-ambient radiative cooling in commercial-like paints with high figure of merit. *Cell Reports Physical Science, 1*(10), 100221. https://doi.org/10.1016/j.xcrp.2020.100221

Lu, X., Fan, J., et al. (2023). Diatomite-based recyclable and green coating for efficient radiative cooling. *Sustainable Materials and Technologies, 38*, e00788. https://doi.org/10.1016/j.susmat.2023.e00788

LuminX. (2025). *LuminX cool roof coatings*. https://lumincoat.com/pages/roof-cooling-paint-in-philippines

Mandal, J., Yang, Y., Yu, N., & Raman, A. P. (2020). Paints as a scalable and effective radiative cooling technology for buildings. *Joule, 4*(7), 1350–1356. https://doi.org/10.1016/j.joule.2020.04.010

Mansour, S. A., & Farha, A. H. (2025). A review of near-infrared reflective nanopigments: Aesthetic and cooling properties. *Crystals, 15*(3), 271. https://doi.org/10.3390/cryst15030271

Mishra, B. R., Sundaram, S., & Sasihithlu, K. (2024). Design of radiative cooling paint coating and insights into its sub-ambient cooling behaviour. *Scientific Reports, 14*, 6745. https://doi.org/10.1038/s41598-024-57356-9

National Science Open. (2024). Radiative cooling for long-term building energy efficiency: An experimental comparison of seven coatings. National Science Open, 3, 20230065. https://doi.org/10.1360/nso/20230065

Philippine Statistics Authority. (2023). *Chicken egg situation report, July-September 2023*. https://psa.gov.ph/statistics/livestock-poultry-egg

Pravin, M. (2024). *Reflective solar cooling paint*. Bannari Amman Institute of Technology. https://www.bitsathy.ac.in/reflective-solar-cooling-paint/

Raihan, M. (2023). Thermal and environmental performance of cool roof materials under different weather conditions: A systematic review. *Case Studies in Thermal Engineering, 45*, 102927. https://doi.org/10.1016/j.csite.2023.102927

Rathinavel, N., Kannadasan, K., Ismail, A. A. M., Mammo, W. D., & Alagar, M. (2023). Impact of eggshell powder on the mechanical and thermal properties of lightweight geopolymer. *Advances in Civil Engineering, 2023*, Article 6655921. https://doi.org/10.1155/2023/6655921

Rong, G., Yan, J., & Liu, X. (2020). Research on the efficiency of urban development towards urban shrinkage. *International Journal of Urban Planning and Development, 15*(2), 45–59.

Rong, T., Tang, Y., Wu, B., & Zhang, W. (2020). A study on the driving forces of energy-related carbon emissions in tropical nations and regions. *Science of The Total Environment, 703*, 135061. https://doi.org/10.1016/j.scitotenv.2019.135061

Rong, X., Jiao, L., & Kong, X. (2020). Research on low-brightness and high-reflective coatings suitable for buildings in tropical areas. *The Open Construction and Building Technology Journal, 14*(1), 829–839. https://doi.org/10.2174/1874836802014010829

Roslan, M. H., & Mohamad, Z. (2020). Investigation of mechanical and physical properties of eggshell reinforced with different type of resin. *Journal of Mechanical Manufacturing and Materials Engineering, 1*(1), 160–169.

Rossi, S., Lindmark, H., & Fedel, M. (2020). Colored paints containing NIR-reflective pigments exposed to accelerated ultraviolet radiation aging with possible application as roof coatings. *Coatings, 10*(11), 1135. https://doi.org/10.3390/coatings10111135

Santamouris, M., et al. (2022). Cool roofs cost benefit analysis volume 1 - Cool roofs: International progress, technology, market, and legislative frame. UNSW Sydney.

https://www.unsw.edu.au/content/dam/pdfs/ada/built-environment/research-reports/2022-04-high-performance-architecture-research-cluster/2022-04-Volume-1.pdf

Shang, J., Wang, M., Wang, P., Li, G., Yang, M., & Li, Y. (2024). Study on thermal reflection characteristics and mechanism of composite inorganic coatings. *Preprints*. https://doi.org/10.20944/preprints202407.0473.v1

Silitonga, R. J. P., Anh, V. T. D., Ramadan, I., & Setiabudi, N. I. Z. (2024). *Passive cooling strategies*. ASEAN Centre for Energy. https://aseanenergy.org/wp-content/uploads/2024/09/Passive-Cooling-Strategies-Report.pdf

Song, Q., Kubacki, E., Berger, A., & Retsch, M. (2025). Cool kitchen: Processing starch and eggshell powder into sustainable coatings for passive daytime cooling. *Advanced Functional Materials*. https://doi.org/10.1002/adfm.202513897

StarShield Smart Paints & Coatings. (2025). *The difference between heat reflective paint and regular paint: What you need to know*. https://starshieldpaints.com/blogs/news/the-difference-between-heat-reflective-paint-and-regular-paint-what-you-need-to-know

Surface Optics Corporation. (2025, February 20). *Solar reflectance of cool roofing and paving materials*. https://surfaceoptics.com/solar-reflectance-cool-roofing-paving-materials/

Tao, Y., Mao, Z., Yang, Z., & Zhang, J. (2020). $CaCO_3$ as a new member of high solar-reflective filler on the cooling property in polymer composites. *Journal of Vinyl and Additive Technology, 27*(2), 275–287. https://doi.org/10.1002/vnl.21801

Tayag, C. R. C., & Conejos, S. (2025). Passive cooling in tropical residential buildings using thermal and energy performance analysis. *IOP Conference Series: Earth and Environmental Science, 1500*(1), 012060. https://doi.org/10.1088/1755-1315/1500/1/012060

U.S. Department of Energy. (2025). *Cool roofs*. https://www.energy.gov/energysaver/cool-roofs

Wai, C. Y., Chau, H.-W., Paresi, P., & Muttil, N. (2025). Experimental analysis of cool roof coatings as an urban heat mitigation strategy to enhance thermal performance. *Buildings, 15*(5), 685. https://doi.org/10.3390/buildings15050685

Wang, Z., Xie, Y., Mu, M., Feng, L., Xie, N., & Cui, N. (2022). Materials to mitigate the urban heat island effect for cool pavement: A brief review. *Buildings, 12*(8), 1221. https://doi.org/10.3390/buildings12081221

World Health Organization (WHO). (2024, May 28). *Heat and health*. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

Wongmahasiri, R., Wongvorachan, T., Thampanichwat, C., & Bunyarittikit, S. (2024). Impact of wall paint solar absorptance on CO_2 emissions in residential buildings: A case study from Bangkok. *Buildings, 14*(12), 3958. https://doi.org/10.3390/buildings14123958

Wu, H.-J., et al. (2023). Passive radiative cooling using eggshell-based coatings. *Energy & Buildings*. https://energyzhao.github.io/pdf/Wu%20et%20al.%202023%20eggshell.pdf

Zahra Jandaghian, Lacasse, M., & Gaur, A. (2025). Solar reflectance index of building envelope materials: A comparative review of North American and European standards and long-term performance. *Buildings, 15*(6), 888. https://doi.org/10.3390/buildings15060888