Assessing the retroreflectivity of white HDPE sprinkled roof sheets in a tropical climate

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Basic Information

Research Question

Do roof sheets applied with white HDPE microplastics possess retroreflective properties capable of reflecting solar radiation and lowering temperatures?

Keywords

HDPE, roofing, surface temperature, albedo, climate change

Badge Selection

- Be a Data Scientist
- Be an Engineer
- Make an Impact

See **Appendix A** for explanations.

Abstract

The warming effect of climate change, known as Urban Heat Island (UHI), led to a higher demand for polluting air conditioners. A potential alternative to cooling technologies are retroreflectors capable of lowering temperatures by retroreflecting solar radiation. High-density polyethylene (HDPE) microplastics are waste polymers that contribute to climate change. However, recycling HDPE plastics to produce retroreflectors shows promise, as HDPE shares similar properties with known retroreflectors.

In this study, the retroreflectivity properties of HDPE was assessed by applying the HDPE microplastics to roof sheets. The sheets' surface temperature was measured from 10 AM to 4 PM, and the albedo values were measured on solar noon. The study aimed to address climate change by: (1) finding an alternative to polluting air conditioning systems, and (2) recycling waste HDPE.

Results revealed that the surface temperatures of HDPE-applied roof sheets were higher than sheets without HDPE. The albedo values between the samples were also not statistically significant. This means that HDPE does not act as a retroreflector; instead, the plastics act as absorbers of solar radiation, which increase temperature. Thus, future studies may consider using our findings to test HDPE plastics as alternatives to heating technologies instead of cooling technologies, as both deposit greenhouse gases and contribute to climate change anyways.

Introduction. Climate change, variations in the climate and weather patterns of the planet, poses environmental risks to the regional and global level[1]. Existing literature has confirmed that climate change has significant impact on environmental indicators such as heatwaves, droughts, typhoons, temperature extremes, sea levels, floods, and other hydrological factors[1,2]. Another major effect of climate variations is the Urban Heat Island (UHI), where a metropolitan area has higher temperature levels as compared to surrounding suburban areas[3].

Due to the UHI, the demand for cooling technologies and air conditioning in urban areas has increased. However, air conditioning systems have been considered as one of the causal factors behind climate change and global warming[4], as most cooling technologies contain chlorofluorocarbons (CFCs), which previous studies have noted as "effective greenhouse gases (GHGs)" capable of causing climate variations[3,4].

One proposed solution to the increased demand of non-environment-friendly air conditioners is the application of retroreflective materials in roofing[5,6,7]. When applied in roof sheets, retroreflective materials can redirect the incident solar radiation towards a building, thus lowering or cooling the building's indoor temperatures[8,9]. Previous studies have confirmed that white paint, light-coloured paint, and glass beads have retroreflective properties capable of lowering surface temperature, cooling indoor temperatures, and producing thermal comfort[8,9,10].

High-density polyethylene (HDPE) microplastics are waste polymers that deposit GHGs and further contribute to global warming and climate change[11]. However, recycling HDPE plastics to produce retroreflectors may show promise. HDPE shares similar properties (index of refraction and transmittance values) with retroreflective glass beads[12,13]. Yet, no study has been conducted to assess the retroreflectivity of an HDPE microplastic.

The research aims to accomplish the following objectives:

1. Determine and compare the surface temperatures of roof sheets with and without applied HDPE microplastics over a period of time, and
2. Determine and compare the proportions of solar radiation (albedo values) reflected by the roof sheets with and without applied HDPE microplastics.

Moreover, the key findings of this research may be used to combat climate change by: (1) decreasing the demand for air conditioning and cooling systems that deposit CFCs and GHGs in areas with UHI, and (2) recycling potentially-polluting HDPE microplastic wastes into environment-friendly retroreflectors.

Review of Related Literature. Existing literature has established two major findings about retroreflectors.

First, retroreflective materials can be applied in roofing to lower surface and indoor temperatures [7,8,9,10]. A study by Suehrcke et al. (2008) concluded that a roofing's solar reflectance directly affects the thermal performance (surface temperatures and indoor air temperatures) of a building[9]. The same study derived an equation for the effect of roofing reflectance, and discovered that houses with light-coloured roof sheets have 30% lower temperatures than those with dark-coloured roofing[9]. Ismail (2011) supported these findings. The study compared the air temperatures in buildings with bare black roofs, white roofs, and light-coloured green roofs, and concluded that white roof sheets have significantly lower temperatures (27.95 °C to 30.50 °C) than black roofing (28.88 °C to 31.58 °C)[7].

Aside from simply applying paint on roofing, retroreflectors can also be used to further increase the solar reflectance or albedo values of roof sheets[10,14]. Albedo is the proportion of light reflected off a surface[14]. Some of the known retroreflective materials are glass beads and light-coloured shells. Zhang et al. (2010) concluded that glass beads are highly effective in reflecting incident solar light[10]. As Apdon et al. (2019) adds, sprinkling retroreflector shells on white paint can also increase a roofing's albedo[14].

The second key finding established by past studies is the similarity of properties between known and empirically confirmed retroreflectors (such as glass beads) and HDPE microplastics. The indices of refraction and transmittance values of glass and HDPE plastics are close in value[12,13]. Index of refraction and transmittivity are common properties used to initially assess a potential of a material to act as a retroreflector[15].

	Glass bead	**HDPE plastics**
Index of refraction (n)[12]	1.52	1.54
Transmittivity[13]	0.72	0.84

Table 1. Preliminary retroreflective properties of glass and HDPE plastics.

Therefore, existing literature has already confirmed that retroreflectors (white paint, glass beads, reflective shells) can lower surface and indoor air temperature. Studies by Lin et al. (2013) and Ndegwa et al. (2014) have also confirmed that glass beads and HDPE plastics have closely related preliminary retroreflective properties, indicating a potential for HDPE microplastic to act as an effective retroreflector[12,13].

However, no existing study has evaluated the retroflectivity of HDPE plastics, as the albedo and surface temperature of roofing with applied HDPE has not been assessed. Thus, there is no confirmation whether a significant difference exists between the solar reflectance and temperature of roof sheets without HDPE and roof sheets with applied HDPE microplastics. This is the knowledge gap that the research intends to address and investigate.

Methods. HDPE (High-Density Polyethylene) plastics were obtained from a junk shop. The HDPE plastics were then pre-shredded into chunks of microplastics.

HDPE microplastic preparation. Prior to pulverization, the microplastics were rinsed in distilled water for an hour, soaked overnight in a soap solution, to clean the plastics and remove extraneous factors that are attached to the HDPE (e.g. dirt). The plastics were sun-dried the following day.

Using an industrial blender, the chunks of plastics were pulverized to a powder-like form. The HDPE powder was filtered with a size 10 sieve. The powdering and sieving process continued until sufficient material was produced for the following densities: 0.25 kg/m^2, 0.30 kg/m^2, and 0.35 kg/m^2. These densities were adopted from a prior study[16].

Roof sheets preparation. Corrugated galvanized iron (G.I.) roof sheets were used as the roofing medium where the paint and HDPE plastics were applied. The metal roof sheets had a thickness of 0.4 mm, a length of 500 mm, and a width of 450 mm (surface area: 2475 cm^2). The dimensions were based on a previous study[17].

Using a hand-held roller, the roof sheets were coated in two layers of water-based acrylic paint[14]. The first layer was dried for an hour before the second coating. Immediately after the second coating, the HDPE powder was sprinkled evenly onto the roof sheets using a sieve[14]. The application process of the HDPE microplastic powder (sprinkling) is also based on the studies of Apdon et al. (2020) and Heineck et al. (2010)[14,18].

Each subject density (0.25 kg/m^2, 0.30 kg/m^2, and 0.35 kg/m^2) had three replicates; a control sample that had no sprinkled HDPE was also included. Thus, a total of twelve roof sheets were dried overnight, before exposure to sunlight on the following day.

Experimental set-up. The roof sheets were situated on a rooftop, evenly distanced from one another[19]. They are positioned in direct sunlight to ensure incident solar radiation will be received by the sheets[19].

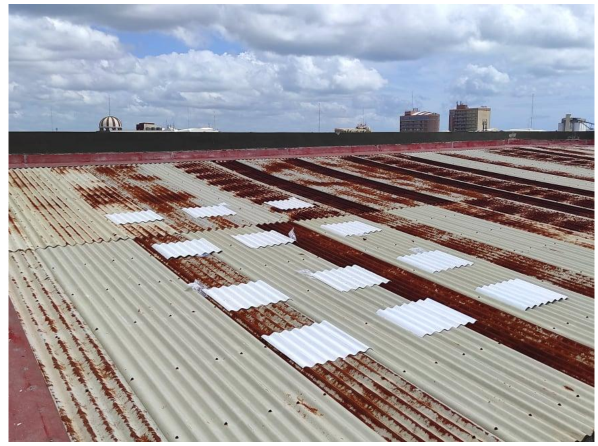

Figure 1. Experimental set-up of roof sheets.

Measurement of Surface Temperature and Albedo. A hand-held thermogun was used for measuring surface temperature (Pulse Oximeter infrared thermometer scanner calibrated by using a water-temperature test). The roof sheets' temperatures were recorded every 30 minutes from 10:00 AM to 4:00 PM (GMT+8 time zone). Times of observation were contextualized and modified from an existing study by Apdon et al. (2020)[14].

Albedo values and cloud data were measured on the same day. The roof sheets' albedo or proportion of light reflected were measured using the Albedo: A Reflectance App.

Use of GLOBE data. GLOBE data was used to characterize the cloud data of the experiment site, as these parameters can measure or assess the weather conditions during the experiment. Weather conditions can affect the amount of solar radiation received by the roofing sheets[7,8,9,10].

Data analysis. The surface temperature difference between the samples were analyzed using one-way analysis of variance (ANOVA) to visualize the significant trends. One-way ANOVA was also used to analyze the albedo values of the subject densities.

Additionally, the Tukey or post hoc test was used to determine whether there is a statistically significant difference between the results. Two software applications (SPSS Statistics and R version 4.1.3) were used for processing the methods above.

Results and Discussion. - The researchers assessed GLOBE cloud data to describe the weather conditions during the data gathering. The high cloud cover was shown to be overcast, and only few middle clouds were observed.

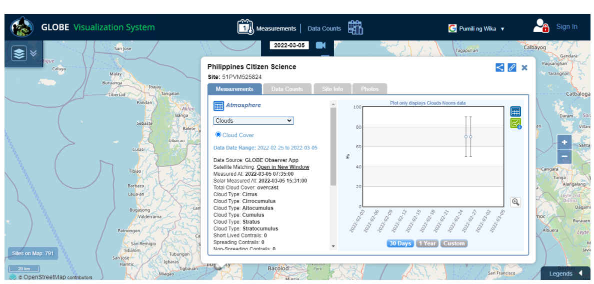

Figure 2. GLOBE visualization page showing the submitted cloud data to GLOBE.

Surface temperatures data. The one-way ANOVA results show that the difference between the initial surface temperature and the temperature measured every 30-minute interval of each density is statistically significant, except during the 150-minute and 270-minute onwards timeslot (see Table 2 next page).

This proves that applying HDPE plastics affect the surface temperature of a roof sheet, as there are significant changes in the surface temperature measurements of the roof sheets except at 12:30 PM and 2:30 PM. (During these time frames, atmospheric cloud cover was wider, which may have affected the radiation received by roof sheets).

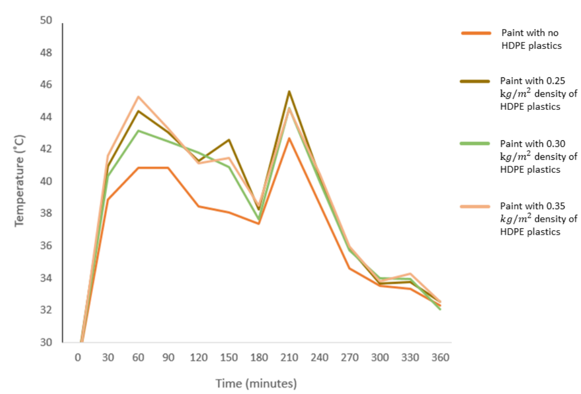

Figure 3. Graph showing the change in the average surface temperatures of the roof sheets over time.

It was also shown that the average surface temperature of the roof sheets with no HDPE plastics is lower compared to the samples with HDPE plastics. For all samples, the temperature decreased on the 90-minute interval and 210-minute interval onwards. The highest peak can also be seen during the 210-minute interval, except for the sample with 0.35 kg/m^2 of HDPE plastics, having the 60-minute interval as its highest.

Furthermore, the Tukey post hoc test revealed that the temperature difference of the 0.25 kg/m^2, 0.30 kg/m^2, and 0.35 kg/m^2 samples is significantly higher than the 0 g/m^2 sample for all time intervals, with the exception of the 0-time interval.

This means that HDPE plastics cannot lower temperatures or retroreflect solar radiation. On the contrary, HDPE acts as an absorber; the microplastics increase temperature and absorb solar radiation.

Table 2. The calculated one-way ANOVA of the surface temperature differences of the roof sheets.

Time Intervals	P-value
$temp_{30\ min}$ - $temp_{0\ min}$	0.013
$temp_{60\ min}$ - $temp_{30\ min}$	0.000
$temp_{90\ min}$ - $temp_{60\ min}$	0.010
$temp_{120\ min}$ - $temp_{90\ min}$	0.002
$temp_{150\ min}$ - $temp_{120\ min}$	0.005
$temp_{180\ min}$ - $temp_{150\ min}$	0.238
$temp_{210\ min}$ - $temp_{180\ min}$	0.000
$temp_{240\ min}$ - $temp_{210\ min}$	0.016
$temp_{270\ min}$ - $temp_{240\ min}$	0.001
$temp_{300\ min}$ - $temp_{270\ min}$	0.326
$temp_{330\ min}$ - $temp_{300\ min}$	0.085
$temp_{360\ min}$ - $temp_{330\ min}$	0.484

For the percentage of light reflected or the albedo, the one-way ANOVA test was conducted to determine if there is a significant difference between the samples (see Table 3). The results show that the albedo of the samples is not significantly different, with only a p-value of 0.386.

This indicates that the amount of solar radiation reflected by the roofing without HDPE is not significantly different from the amount of radiation reflected by the HDPE-sprinkled roof sheets. Thus, HDPE cannot act as a retroreflector.

Table 3. The average albedo of each setup.

Set-up	Average Percentage of Light Reflected (Albedo)
White acrylic-painted roof sheets without HDPE plastics	0.48
White acrylic-painted roof sheets with 0.25 kg/m^2 density of HDPE roof sheets	0.46

White acrylic-painted roof sheets with 0.30 kg/m^2 density of HDPE roof sheets	0.41
White acrylic-painted roof sheets with 0.35 kg/m^2 density of HDPE roof sheets	0.50

Error Analysis. Gross errors may arise from taking the temperature through the thermogun and the albedo data through the application “Albedo: A Reflectance App”. To prevent these errors, the researchers cross-examined the data collected by each other during the data gathering.

Measurement errors can also stem from the equipment used, particularly the smartphone, thermogun, and digital weighing scale. To minimize the errors, the equipment was calibrated with help of equipment professionals from Philippine Science High School - Western Visayas Campus.

Furthermore, basking the HDPE plastics under the sun is prone to environmental errors as the area of experimentation is open and factors such as wind, cloud cover, and humidity cannot be controlled.

Conclusion. - HDPE plastics do not possess retroreflective properties capable of lowering surface temperature and reflecting solar radiation. In contrast, HDPE acts as an absorber of solar radiation, which increases the temperature of a roof sheet. Thus, applying HDPE microplastics on roofing is not a feasible alternative to cooling technologies.

Nonetheless, the results of the study may further be cross-examined by the scientific community by applying the suggestions listed on the Recommendations section, to produce more accurate results regarding the retroreflectivity of HDPE.

Future studies may also consider using HDPE as alternatives to heating technologies, instead of cooling systems, as both technologies deposit GHGs in the atmosphere and contribute to global warming and climate change. Although the effect of the HDPE to the temperature of a roofing was opposite to what we expected, the HDPE plastics may still be utilized in countries with winter climates. The HDPE can act as absorbers of solar radiation or as heat sinks, which will warm the building without the need of polluting artificial heaters.

Recommendations. - The experiment may be conducted in a controlled setup to minimize the risk of external factors that could affect the data, such as uneven cloud cover and weather conditions. Additionally, to reduce human errors, a mechanical sieve shaker and automated paint sprayer may be utilized, instead of manual sprinkling the HDPE plastics.

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Appendix A. **Badge Selection**

I am a Data Scientist	The researchers synthesized data from existing literature to find knowledge gaps related to their field of study. For example, the researchers analyzed data regarding the quantitative effect of retroreflectors to the temperature of roofing/housing. The researchers also collected their own data, in the form of thermogun temperature values, albedo data, and GLOBE cloud data. Then, the researchers evaluated these data to create inferences about the retroreflective potential of HDPE microplastics.
I am an Engineer	The researchers described an engineering problem (non-environment-friendly approach of cooling technologies and air conditioning systems). They considered several engineering-based solutions to address this climate change problem; one of which is the use of retroreflectors as alternatives to air conditioning and cooling technologies. Then, they optimized a design or prototype for their proposed solution (HDPE-applied roof sheets), and used student-generated data and evidence (surface temperature and albedo measurements) to describe the impact of this engineering-based solution on the environment.
I am a STEM Professional	Three professionals were consulted throughout this research: • **David Bryan Lao**, a math teacher in Philippine Science High School - Western Visayas Campus. Researchers collaborated with Mr. Lao for the statistical syntheses and analyses of the gathered surface temperature and albedo data. Researchers also consulted with him regarding the use of SPSS and R software for the ANOVA and Tukey Tupost hoc test.

	• **Dr. Aris Larroder, Ph.D.**, a Research teacher and GLOBE coordinator of Philippine Science High School - Western Visayas Campus. The researchers consulted with Dr. Larroder, as he has been an advisor of a prior retroreflector study entitled *Determination of reflectivity of concrete slabs applied with paint added with powdered Placuna placenta shell as additive*. • **Cherry Rose Haro**, Science Research Assistant for Biology of Philippine Science High School - Western Visayas Campus. Researchers consulted with Mrs. Haro for the use of equipment during the sprinkling of HDPE microplastics, such as the size 10 sieve.

Appendix B. **Thumbnail Image**