SASTA OLIPHANT SCIENCE AWARDS

Prize Winner

Scientific Inquiry

Year 11-12

Yu (Amy) Shi

Glenunga International High School

Government of South Australia
Department for Education

SASTA South Australian Science Teachers Association

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Particulate "Black Carbon" air pollution and its contribution to the Urban Heat Island Effect

RESEARCH QUESTION

To what extent does a change in the amount of black carbon deposits (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) on urban roofing materials influence the air temperature (°C) inside a house?

BACKGROUND INFORMATION

The urban heat island (UHI) effect refers to the phenomenon of a built-up urban area which is significantly warmer than its surrounding rural areas. Circumstantially, this prominent global environmental issue raises the average urban daytime air temperatures of 5.6°C higher than the rural areas (Akbari, Menon & Rosenfeld, 2009). UHI is primarily caused by heat energy received from the sunlight by heavyweight mass elements that constitute the foundation of roofs and buildings of urban areas (Melbourne.vic.gov.au. 2019). Due to the nature of building surfaces, the reflection rate of heat (albedo) decreases as heat is trapped within the impermeable roofing materials in the daytime. The heat is then gradually released during the night time, enhancing the air temperature of urban areas.

In the United States, heat is considered the No.1 weather-related killer (Climatecentral.org. 2019). The urban heating process raises air temperature and urges people to use air conditioners for cooling down. This not only raises energy costs, but also results in the increase of greenhouse gas emissions. The release of greenhouse gas emissions will further exacerbate human health and cause respiratory problems. The Centres for Disease Control and Prevention estimates that from 1979 to 2003, increasing heat exposure in urban areas leads to more than 8,000 premature deaths in the US (US EPA. 2014). Understanding this environmental concern and brainstorming ways that every citizen and government can do to lessen the effect of urban heating is what I hope to explore.

This investigation aims to explore the effect of varying amounts of black carbon deposits on roofing materials within the air temperature inside model houses. Particulate air pollution enhances the UHI effect since black carbon can settle on rooftops to absorb sunlight, which is radiated as heat back into the atmosphere. It is a devastating environmental issue since black carbon is commonly produced from biomass burning and diesel exhaust (Yoon, Fairley, Barrett, and Sheesley, 2018). Furthermore, roofs are considered primary depository areas of carbon deposits since they take over approximately twenty percent of exposed urban areas (Epa.gov. 2019).

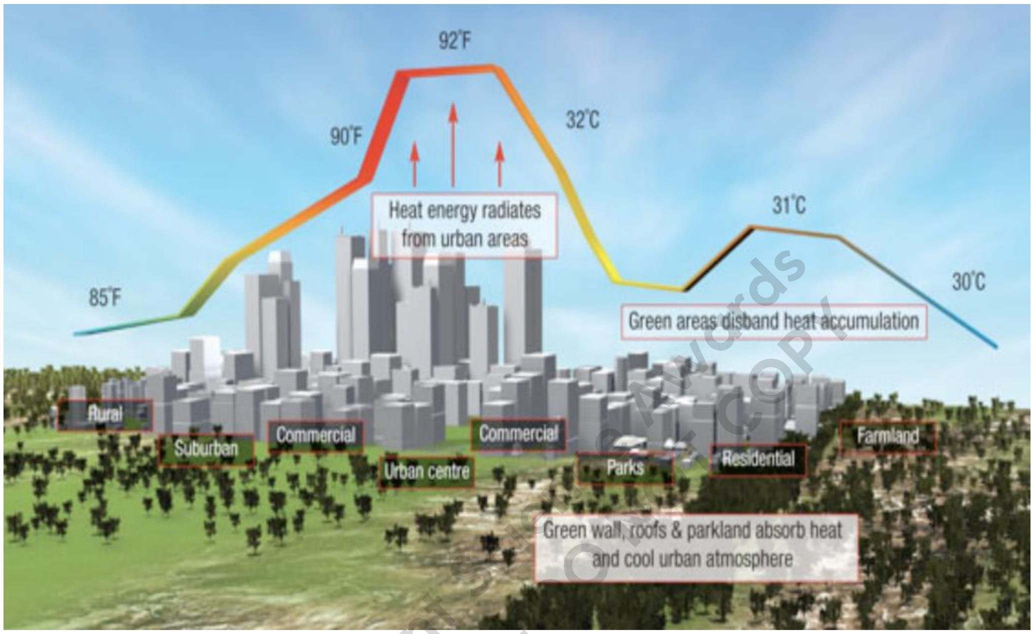


Figure 1 The comparison of the amount of the heat energy between urban areas and green areas (OUPblog, 2015).

HYPOTHESIS

An increase in the amount of black carbon deposits on roofing materials (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) will increase the internal air temperature (°C) of houses.

VARIABLES

Variables	Units, range, uncertainty	Measured with	Justification
Independent variable	Different amounts of black carbon deposits (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) Uncertainty: +-0.005grams	An electronic scale	Used to model the urban heating process by using real black carbon
Dependent variable	Internal air temperatures of five houses (°C)	Temperature logger from Stelr sustainable housing kits	To obtain an accurate temperature quickly

Controlled Variable	How will it be controlled	How would this variable affect the data (Justification)
The size and shape of roofs and houses	The model houses all come from the Stelr sustainable housing kit and all measurements remain consistent for roofs (10cm x 10cm square).	A larger surface area (SA) of the roof enables more carbon deposits to be scattered onto the roof, which improves the capability of heat absorption. In contrast, a smaller SA contains less carbon deposits, the efficiency of heat absorption significantly reduces. Moreover, different house sizes affect the SA to volume ratio, greater SA to volume ratio increases the rate of heat loss. A smaller SA to volume ratio has resulted in a lower rate of heat loss (GRÜN ECO DESIGN, 2017).
Distance from the house to the light	All model houses and roofs will be placed 10.00 cm away from the lamp.	If the lamp is placed closer to the house, heat will reach the roof faster, contributing to a higher rate of the increase in the house temperature. If the lamp is placed further away from the house, heat will reach its roof slower, causing a slower increase in the internal air temperature.
The overall time of the experiment	The stopwatch will be used for twenty minutes.	Houses with longer heat exposure will have a higher internal air temperature than others, since it has longer time for heat absorption. Conversely, less light exposure will obtain a lower internal air temperature compared to others as it has a shorter time for heat absorption.
The angle at which lamps are directed towards houses	A protractor is used to ensure the angle to be 60°C.	Since the samples are experimented simultaneously, the difference in angle of lighting from one lamp would affect carbon deposits on another roof. They absorb heat from two sources rather than the intended one, increasing the overall internal air temperature.

MATERIALS AND DIAGRAM

- **10.00g black carbon deposits**
- **4 x Stelr Sustainable Housing Kits**
- **1 x electronic scale**
- **1 x scissors**
- **5 x salt shakers**
- **2 x A4 thin cardboards**
- **1 x bottle glue and brush**
- **10 x filter papers**
- **1 x box of plastic wrap**
- **1 x 30cm ruler**
- **1 x facial mask**
- **1 x protractor**

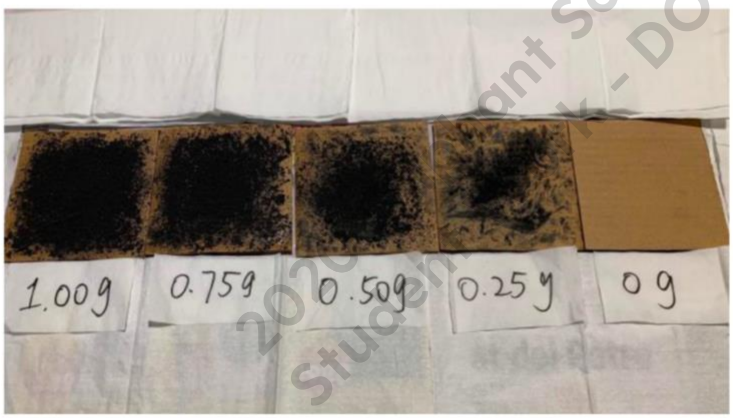


Figure 2: Different concentrations of black carbon deposits on roofing materials (cardboards), ready for temperature testing

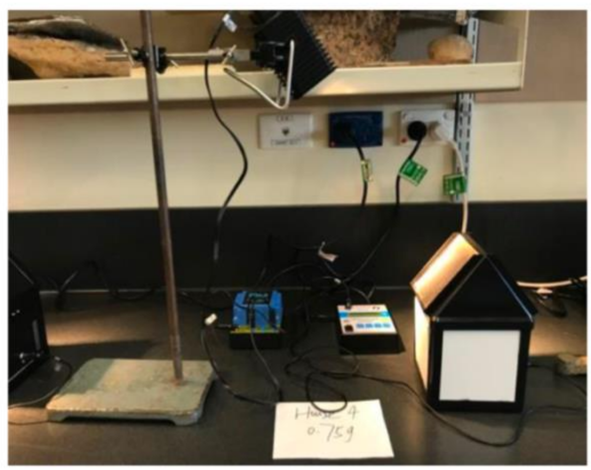


Figure 3: The proper setup of one house (house 4) with 0.75 grams of black carbon deposits placed on the cardboard (roofs) under testing condition

Figure 4: The internal temperature testing of all five houses with different amounts of black carbon deposits (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) on roofing materials (cardboards)

METHOD

1. Measure five "10cm x 10cm" of cardboards and cut them by using a pair of scissors (30cm ruler was used for accuracy).
2. Place filter papers on an electronic scale to measure 0.00g, 0.25g, 0.50g, 0.75g and 1.00g of carbon deposits separately
3. Pour carbon deposits from filter papers into salt shakers and seal them with plastic wrap
4. Assemble the Stelr sustainable housing kit parts and plug in the temperature logger. (Adjust each lamp to 60° with a protractor and ensure that they are pointed towards roofs)
5. Spread the glue on five cardboards (surfaces of roofs) by using the glue brush.
6. Sprinkle black carbon deposits evenly on cardboards with salt shakers (0.00g - house 1, 0.25g - house 2, 0.50g - house 3, 0.75g - house 4, 1.00g - house 5), and place cardboards on the top of allocated houses as roofs.
7. Start the stopwatch simultaneously when the temperature logger begins to record
8. Record every two minutes of the temperature shown in the temperature logger and stop the stopwatch after twenty minutes.

RISK ASSESSMENT& ETHICAL CONSIDERATION

- Black carbon deposits are carefully disposed of into recycling bins.
- The facial mask is used to prevent the inhaling of toxic materials – black carbon deposits.
- Because the temperature logger requires electricity in order to record sufficient data, hence it must be kept dry .
- The lamps used will be hot after the experiment, hence, make sure to wait for them to cool down

DATA COLLECTION

Observation:

a. Cutting carboards leads to the loss of roofing materials, which presents in the form of dust.

b. When pouring the black carbon deposits from salt shakers to carboards, carbon residues resided in salt shakers and failed to be fully spread onto cardboards.

c. The temperatures of each house measured by temperature loggers over twenty minutes were noted to be consistently increasing.

Table 1: Raw results for internal air temperatures of five houses with different amounts of black carbon deposits (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) on roofs

Black carbon deposits (g) Time (min)	House 1 0.00g Temperature °C	House 2 0.25g Temperature °C	House 3 0.50g Temperature °C	House 4 0.75g Temperature °C	House 5 1.00g Temperature °C
1	18.40	18.40	18.40	18.40	18.40
2	18.40	18.40	18.50	18.60	18.60
3	18.40	18.50	18.50	18.70	18.70
4	18.50	18.50	18.60	18.80	18.80
5	18.50	18.60	18.70	18.80	19.00
6	18.60	18.60	18.70	18.90	19.10
7	18.60	18.70	18.80	18.90	19.20
8	18.70	18.70	18.90	19.00	19.30
9	18.70	18.80	18.90	19.10	19.40
10	18.70	18.80	19.00	19.10	19.50
11	18.80	18.90	19.10	19.20	19.60
12	18.80	19.00	19.20	19.30	19.70
13	18.90	19.00	19.20	19.40	19.90
14	18.90	19.10	19.30	19.60	20.10
15	19.00	19.10	19.30	19.70	20.20
16	19.00	19.20	19.40	19.80	20.20
17	19.10	19.20	19.50	19.80	20.30
18	19.10	19.30	19.50	19.90	20.40
19	19.20	19.30	19.60	20.00	20.50
20	19.20	19.40	19.60	20.10	20.60

DATA PROCESSING

Table 2: Rate of temperature change inside five houses with different amounts of black carbon deposits (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) on roofs

Black carbon deposits (g) Categories	0.00g House 1	0.25g House 2	0.50g House 3	0.75g House 4	1.00g House 5
Change in temperature °C	0.800	1.000	1.200	1.700	2.200
Rate of change in temperature °C/M	0.040	0.050	0.060	0.085	0.110

The change in temperature is increasing when more carbon deposits are presented. The rate of change in temperature is higher when more carbon contents are added, for example, 0.00g grams of carbon has a rate of temperature change of 0.040 whilst 0.25 grams has a rate of temperature change of 0.050.

Temperature change: $The\ final\ temperature\ -\ the\ initial\ temperature\ =\ \Delta\, Temperature$

- Example in 0.00g: $19.20°C - 18.40°C = 0.80°C$

Rate of temperature change: $\frac{\Delta\, Temperature}{Time} = Rate\ of\ \Delta Temperature$

- Example in 0.00g: $\frac{0.80°C}{20\ min} = 0.04°C/M$

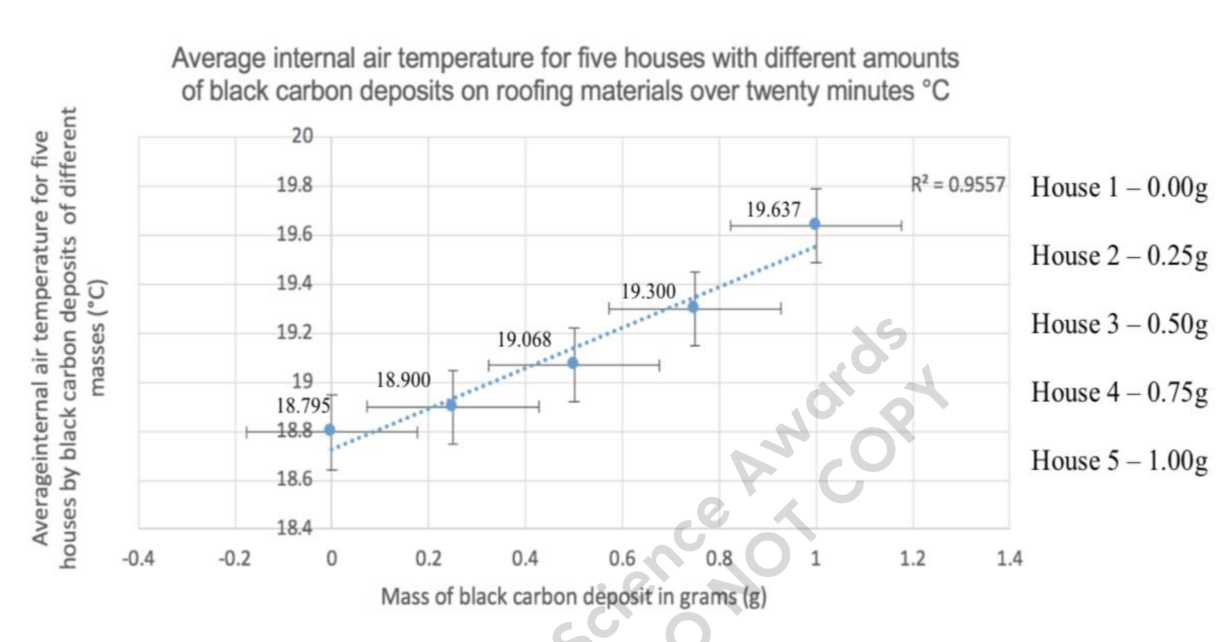
Table 3: One-way analysis of variance (ANOVA) for five houses with different amounts of black carbon deposits (0.00g, 0.25g, 0.50g, 0.75g, 1.00g) on roofs

Groups	Count	Sum	Average	Variance
0.00g carbon (House 1)	19.000	357.100	18.795	0.067
0.25g carbon (House 2)	19.000	359.100	18.900	0.094
0.50g carbon (House 3)	19.000	362.300	19.068	0.137
0.75g carbon (House 4)	19.000	366.700	19.300	0.228
1.00g carbon (House 5)	19.000	373.100	19.637	0.408

Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	8.633263158	4	2.158315789	11.55227244	1.30×10^{-7}	2.472927039
Within Groups	16.81473684	90	0.186830409			
Total	25.448	94				

The F value is greater than F critical, (15.196 > 3.443) and the analysis is performed at a significant level of 0.05, and the P value is 1.30×10^{-7} , which is much smaller than 0.05. Therefore, it is evident that carbon contents influence temperature levels to a great extent.

Graph 1: Average internal air temperature obtained for five houses with different amounts of black carbon deposits on roofing materials over twenty minutes



The five means of internal air temperatures indicate an upward trend with carbon masses. Either systematic or random errors have occurred which are shown by error bars and the regression number (R^2 = 0.9557).

CONCLUSION

In conclusion, there is a positive correlation between carbon contents and internal air temperatures. In particular, an increase in the amount of black carbon deposits on roofing materials will cause an air temperature rise inside houses.

The hypothesis is supported by the raw data in table 1 as it demonstrates a temperature increase when more carbon contents is presented. Moreover, the rate of temperature change will be higher if more carbon deposits are added. According to table 2, 0.50 grams of carbon has a rate of temperature change as 0.060°C, whilst 0.75 grams has a rate of temperature change as 0.085°C. Refer to graph 1, it accepts the hypothesis by portraying an increasing trend between carbon masses and five mean internal temperatures of houses. Although errors have occurred during the experiment, however, it is highly accurate, since the regression number is close to 1.00 (R^2 = 0.9557). Furthermore, there is a statistically significant difference between each set of result in the ANOVA. Accordingly, carbon contents are shown to have influence on air temperature levels.

By applying this investigation to represent black carbon over urban areas, it can be perceived that more carbon contents have resulted in greater heat absorption, suggesting a temperature increase in cities as part of the UHI effect. Moreover, when there are no black carbon deposits on house 1's roof, heat is still being trapped and causing a temperature rise. This could potentially cause an overall temperature increase for cities. These temperature escalations give rise to higher energy consumption, which requires more biomass burning and further worsens air pollution. A positive feedback loop is established.

EVALUATION

Strengths:

1. The Stelr housing kit provides the same model house for each carbon sample to be tested under equal light intensity, improving the accuracy of results.
2. The diagram and processed data showed a strong positive linear correlation between carbon contents and internal air temperatures inside houses, making the conclusion more valid.
3. By conducting trial runs beforehand, it carries out possible errors that may occur during the actual experiment. For example, some carbon residues resided in the container when pouring them onto the cardboard.

Weaknesses:

1. Black carbon is not spread evenly across the cardboard; hence clustered carbon areas will create heat spots and lead to unequal distribution of carbon deposits. The unequal carbon distribution fails to maximize black carbon's ability to absorb heat as clusters may cover one another.
2. Urban heating is the combined effect of the increase in both of internal and external temperatures. The experiment fails to fully represent the UHI effect, since only the internal temperature is measured.
3. The cardboard is utilized as its role in insulation of heat is similar to roofing materials. However, the cardboard cannot offer enough heat transfer to showcase the real-life situation.

IMPROVEMENTS

As the data set supports the positive correlation between the amount of black carbon deposits and internal air temperature, the conclusion has some validity. However, the conclusion cannot be fully justified since errors have taken place. With improvements, more comprehensive data could be obtained.

1. Different sized carbons may block the small pores in the salt shaker and make up an unequal carbon distribution. By using a funnel instead of a salt shaker to distribute carbon deposits evenly over houses, it will follow at a constant rate for spreading with a pore in the bottom.

2.By measuring and comparing both of the external and internal temperatures, the results will be more conclusive and relevant to the UHI effect.

3. Asphalt shingles are the most common roofing materials used in the US as they are easy to install and long-lasting (Hgtv, 2019). The cardboard can be replaced by proper roofing materials as asphalt shingles to model the real-life process of UHI effect.

FURTHER INQUIRY

This investigation can be furthered by listing places that are most affected by rising temperatures, and mimicking different light intensities that occur around the world. Thus, it broadens the focus of the experiment from urban areas to hot regions on a world scale. Moreover, another approach to developing the investigation is to identify similar particles to black carbon deposits, such as ultrafine particles. A comparison between carbon and ultrafine particles can be drawn out to determine which type of particle has a more detrimental effect on air pollution.

APPLICATION

One solution for improving the UHI effect is through promoting the use of cool roofs. Cool roofs are innovative techniques in reducing energy consumption in hot regions. For instance, high-reflectance coatings are commonly applied on roofs within hot regions (Pisello and Cotana, 2014). In a Texas retail store, Konopacki and Akbari found that the average daily summertime temperature of the black roof was 75 °C, however, once retrofitted with a white surface, it measured 52 °C (Konopacki and Akbari, 2001). To illustrate this, the use of white reflective roof-painting will increase the albedo, causing light to be reflected away from urban areas.

This solution primarily functions in the presence of new building construction. There are many pre-existing buildings in cities that require white roof-painting; however, funding problems may take place. For centuries, it was common for houses in hot regions to be painted in white as it reflects heat from the sun, which encourages old practices to be re-introduced. Additionally, when the white paint reflects light, the air could be heated up, causing a temperature rise.

The creation of an urban heat island is a convoluted process with many factors, which is hard to predict and evaluate the impact of a single change. The reflection of heat upwards might have further consequences in other ways.

Alongside this should be the reduced use of automobiles, which could be achieved by formulating laws on limiting the type and number of vehicles in cities (Bitre.gov.au. 2019). Laws can effectively promote public transport powered by green fuels instead of biomass burning. If less black carbon pollution is generated, then there is less carbon deposited on roofs, hence lowering the amount of heat absorption. This solution would be cheaper than the first one, and it reduces the amount of greenhouse gas emissions.

Word count approx: 2250

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