Environmental Issue: Particulate "Black Carbon" Air Pollution and the Contribution to the Urban Heat Island Effect

Urban areas suffer from increased temperatures compared to rural areas. There are many causes of this phenomenon: non-reflective surfaces absorb heat, energy not used in evapotranspiration, reduced air flow to blow away the heated air, waste heat from building/air conditioners and industry/vehicles releasing greenhouse gases and particulate air pollution (black carbon). *"The urban heat island effect is caused primarily by the nature of the building materials: concrete and bitumen warm up rapidly in the day time in contrast to waterways and parks. Due to the nature of the surface its albedo is lower. Much more heat is absorbed and conducted through the material. This heat is then slowly released during the night, adding warmth to the urban atmosphere."*(1)

As the EPA states "*Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality."* (2) Understanding this issue and finding simple ways every person, city governance and national government can do to reduce this issue is what I wish to investigate.

Particulate air pollution can contribute to urban heating because black carbon or soot can settle on the buildings and surfaces in urban areas and increase the heating effect. *"Black carbon is highly efficient at absorbing sunlight, which can be radiated as heat into the atmosphere."* (3)

CXT: Urban heat islands are a relevant environmental issue. The contribution from black carbon, as opposed to other causes (building materials, reflectivity and greenhouse gases), is identified for study.

This investigation will aim to model and test the effect of black carbon deposits on air temperature, which is a serious environmental issue caused by particulate air pollution, most often produced from biomass burning, cooking with solid fuels and diesel exhaust (together known as black carbon pollution), which is one factor believed to contribute to urban heating. (4) That is, a city with a lot of black carbon pollution should become hotter under sunlight due to the greater attraction of heat by darker colours. Using a painted tin can for the model, if the darkness of the can is increased, then the temperature of the air inside the can will increase because of the albedo of dark colours that absorb heat. *"Darker objects absorb more light, they retain more energy from sunlight. This energy cannot simply disappear, so the darker object releases the extra energy by emitting heat. Thus the more light an object absorbs, the more light energy it must transform to heat, and the warmer it will get in direct sunlight."* (5)

CXT: This is a reasonable explanation of the connection between the issue and the research question.

Research Question:

Does a change in colour of an urban building (a tin can) due to varying black carbon deposits (mixes of black and white paint) change the air temperature (the inside air of the tin can)?

Experimental Variables:

	Named Variables	Units	Equipment or Procedure for Measurement/Control	Justification
Independent	Darkness of can (albedo)	Ratio of paint colours	Different shades from white to black	Used to model the black carbon. White = no pollution; black = heavy pollution.
Dependent	Temperature	Centigrade (^{o}C)	Digital thermometer	To obtain the air temperature quickly.
Controlled	The shape and size of the can. The time of day when the temperature is recorded.			Different shapes and sizes of cans might absorb sunlight and emit heat differently. The surfaces may absorb and emit differently as the sun's intensity varies.

Safety/Ethical Considerations:

The edges of the tin can are likely to be sharp and there is a risk of cutting oneself. Hence the tin cans must be opened/handled while wearing gardening gloves. The edges are made safe by using either a "safe edge" can opener or covering the edges with duct tape.

Paint: Non-toxic, water based.

Disposal of the tins: The tins are deposited in a metal recycling bin.

PLA: A risk assessment is present.

Equipment List:

5 tin cans (height: 14.5 cm; diameter: 8.5 cm); same brand (emptied – see safety consideration); paper on outside removed

PLA: Good description making repeatability more feasible.

1 digital thermometer

White and black paint; same brand and matt finish (so the same degree of light reflection)

2 x 50 ml measuring cylinders, one for black paint, one for white paint

3 x 200 ml beakers for paint mixing

5 glass stirring rods for mixing the paint

1 paintbrush – start with the white paint

1 – ruler

Notes:

Five cans of varying shades of black used to generate sufficient data.

No “silver” unpainted cans – as it is reflective.

No external temperature as it is the comparison between the cans internal air temperatures.

Repeated over five days to generate sufficient data.

PLA: Sampling strategy justified, although it is not made clear what is meant by “sufficient”.

100% black paint **75 : 25 black : white paint** **50 : 50 black : white paint** **25 : 75 black : white paint** **100% white**

(author’s own image)

PLA: Ideally the surfaces on which the different cans were placed should have been the same.

Method:

1. Prepare the cans safely.
2. The five metal tin cans were first painted: the ratios were made out of 100 ml. For example, 75 ml of black and 25 ml of white mixed for the 75 : 25 black : white paint can.
3. Position the cans in an open outdoor area, no shade, at 8:00 am.
4. Place a tape on the probe to indicate when the probe is 2 cm from base of each can.
5. Record temperature of each can at 10:00 am, 1:00 pm, 6:00 pm. Place probe to tape level. Angle the probe to be in the centre of the can. Secure with tape. Leave for 30 seconds then record the temperature.
6. Repeat steps 2–5 over five days using the same painted tin cans.

PLA: Three times during the day over five days is sufficient. In practice, only three were actually done. The justification of why five days (to generate enough data for standard deviations to be calculated, for example) is not stated.

Data Collection:

Table 1: Inside Can Air Temperature Variations of Five Different Coloured Tin Cans During Three Different Times of the Day, on Three Days (+/− 0.05 °C)

RAC: The data table is fine, clear, easy to interpret and all conventions are followed.

	Inside Can Air Temperature at 10:00 am (°C)			Inside Can Air Temperature at 1:00 pm (°C)			Inside Can Air Temperature at 6:00 pm (°C)		
Colour of Tin Can	**Day 1**	**Day 2**	**Day 3**	**Day 1**	**Day 2**	**Day 3**	**Day 1**	**Day 2**	**Day 3**
100% black paint	29.80	20.70	22.40	33.50	23.40	27.90	22.20	20.20	23.80
***75 : 25 black : white paint**	28.60	20.60	22.30	33.10	23.10	27.70	22.10	20.10	23.70
***50 : 50 black : white paint**	28.10	20.50	22.20	32.70	23.10	25.90	22.10	20.10	23.40
***25 : 75 black : white paint**	27.90	20.40	22.10	32.40	22.50	25.90	22.00	19.90	23.30
***100% white paint**	27.70	20.30	22.10	32.10	21.90	25.80	22.00	19.70	23.30

*****The paint ratio is an indication of albedo. According to David Adam from *The Guardian*, "*Dark roofs reflect about 10–20% of sunlight, while white surfaces tend to send back at least half. In technical terms, the percentage of light reflected by a surface is called its albedo – so a perfectly reflective surface has an albedo of 1. Coloured paints have an albedo of 0.1–0.3, and white paints an albedo of 0.5–0.9. Asphalt road surfaces have albedos as low as 0.05, so they absorb up to 95% of the sun's energy. Concrete has an albedo of up to 0.3, tar and gravel just 0.1". (6)*

Table 2: Conversion of Paint Ratios to Assumed Albedo

Paint Ratios	**Assumed Albedo**
100% black paint	0.1
75 : 25 Black : white paint	0.3
50 : 50 Black : white paint	0.5
25 : 75 Black : white paint	0.7
100% white	0.9

Averages were calculated for time of day and standard deviation (SD) calculated on a TI 84+.

Average for 10:00 am. 100% black paint.

29.8 + 20.7 + 22.4 ÷ 3 = 24.3 °C

Standard deviation = 4.84

Table 3: Average Inside Can Air Temperature for each Coloured Can at each Time Period over Three Days

RAC: The student had planned to collect data for five days. Even so, SD has been calculated.

Albedo of the Paint	Inside Can Air Temperature at 10:00 am (°C)	SD	Inside Can Air Temperature at 1:00 pm (°C)	SD	Inside Can Air Temperature at 6:00 pm (°C)	SD
0.1	24.30	4.84	28.30	5.06	22.10	1.80
0.3	23.80	4.21	28.00	5.00	22.00	1.80
0.5	23.60	3.99	27.20	4.94	21.90	1.66
0.7	23.50	3.93	26.90	5.03	21.70	1.72
0.9	23.40	3.86	26.60	5.15	21.70	1.82

SD is very high in all cases. However, many more samples would need to be gathered, ideally at the same time and continuously to make this calculation valid.

DEV: The SD here is hard to use to assess the validity of these differences. The SD in this case measures more the variability in ambient temperature, which is of course reflected in the warming data.

Graph 1: Average Can Air Temperature at Different Albedos and Different Times

RAC: The *x* axis on this graph is not a linear scale.

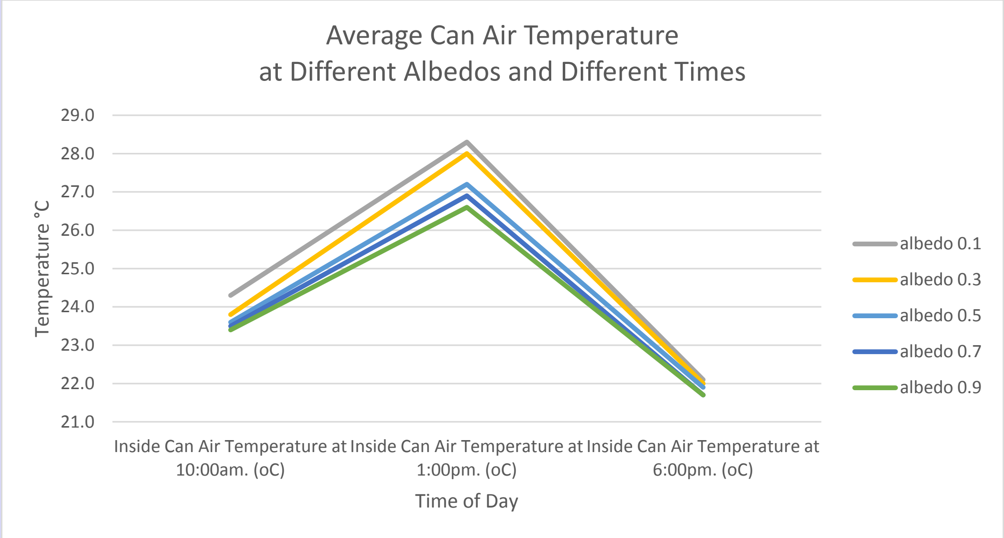


Table 4: Temperature Difference Between the Lowest and Highest Albedos

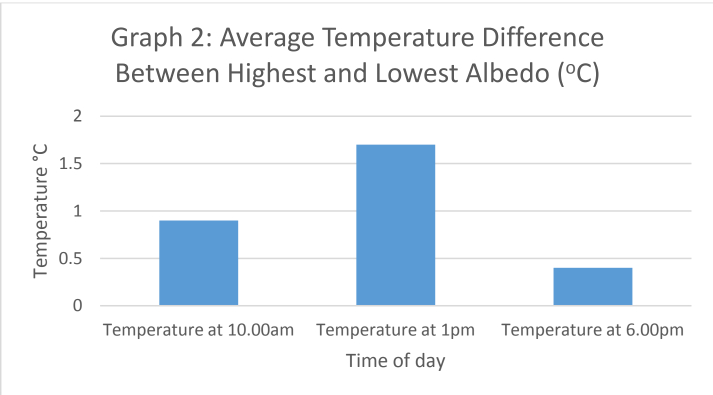
	Time of Day: 10:00 am	Time of Day: 1:00 pm	Time of Day: 6:00 pm
Average temperature Difference Between Lowest and Highest Albedo (°C)	0.90	1.70	0.40

The results presented in table 1 above depict a relationship seen in all of the trials. The darker the colours of the tin cans, the higher the temperature is inside of the tin. This can be observed during all the various time periods of the day examined. Also, there is a change in temperature variation at different times of the day.

DEV: It's a pity that the student didn't draw a scatter plot with albedo against temperature.

In graph 1, the average results for all three trials of temperature variations with the colour of the tin cans can be seen. It is evident that temperature decreases as the albedo increases. Also, one can also easily tell that at 1:00 pm temperature is notably higher than the other time periods where data was recorded. This difference in temperature, as seen in graph 2, can also be seen during the other times of day, but it is not as great: 0.9 °C at 10:00 am and 0.4 °C at 6:00 pm, while at 1:00 pm it is 1.7 °C.

Graph 2: Average Temperature Variations of Albedos of Paint as Shown by Five Different Coloured Tin Cans During Three Different Times of the Day



Conclusion:

A change in colour of an urban building (a tin can) due to varying black carbon deposits (mixes of black and white paint/albedo) does change the air temperature (the inside air of the tin can).

As the albedo of the tin can is increased, the temperature inside the can stayed lower. For instance, on graph 1, it can be seen that all of the temperature values increase when the colour of the cans become darker/lower albedo. The conclusion is that the dark colour of the cans does play a role in increasing the air temperature inside of the cans. Also, from these results we can see that the temperature changes are greatest at times of the day where there is more sunlight. In graph 2 the greatest temperature difference between the albedos of the cans occurs at 1:00 pm. This suggests the darker cans absorb more energy and re-radiate the heat into the air in the can more, causing a direct temperature increase. However, at the other times of the day, when the sun is not as bright these, temperature changes are still being seen, but are much smaller: 0.4 °C. The data is not considered significant as the SD is greater than the differences between each set of cans. There is a high chance that this is a random occurrence.

RAC: Good point.

In conclusion, using this investigation as a representation of black carbon over a city, we see that as the colour of the cans became darker, they released more heat into the air. This would suggest that the temperature of city areas with black carbon would also increase as part of the urban heat island effect. However, if the area does not face black carbon pollution it would most closely resemble the higher albedo cans in this experiment that had a lower temperature at all times of the day in comparison to the lower albedo cans. Furthermore, from this lab we can see that at times where the sun is no longer bright, heat is still being trapped and the black cans had a higher temperature. For a city, this could potentially mean an overall increase in temperature throughout all times of the day. These escalations in temperature may also bring about economic problems since people may have to spend more on air conditioning and refrigeration. As a result, this leads to a greater consumption of energy, which means more burning of fossil fuels so increasing black carbon pollution creating a positive feedback loop.

RAC: The student has interpreted the data correctly and arrived at an accurate conclusion.

DEV: A connection to the broader issue is discussed here.

Evaluation:

Although the results show trends in air warming, the SD analysis suggests that we cannot be sure of the conclusion. However, the fact that all measurements demonstrated the same trend in the relationship between albedo and air temperature does suggest that there is some validity, and with improvements more conclusive results could be obtained.

It would have been better to have several cans with the same albedo all measured at the same time, and then calculate the average temperature at each time of day, rather than comparing just one can at the same time but on different days. The temperature fluctuation between one day and the other obviously affected this study. Also, there is a possibility that the surroundings of the cans (the tiles) exhibit their own albedo effect and so all cans should be in exactly the same surroundings.

The readings of temperature could also be improved as the digital probe fluctuated as it was moved from can to can. This could be improved by having more probes that could be left in a fixed position in each can. A data logger could then be used to collect more data at regular time intervals from each can.

The paint was mixed manually and the cans were painted by hand. This means that the cans were only an approximate model of real black carbon, and it would be better to somehow spray real soot onto the cans. Not only would this mean that the coating would be more realistic, but also the actual chemical would be the same, as paints might absorb sunlight differently to carbon.

The investigation could also be improved by:

- using real building materials rather than tin cans
- taking readings for longer than five days
- measuring temperature inside and outside the cans
- measuring the light intensity near the cans to show the variation during the day.

DEV: Weaknesses in the method and related improvements are discussed.

Solution:

One solution is to promote green building/green roofing. The use of shiny white paint on buildings and roofs will increase the albedo and so light is reflected away from the urban area rather than absorbed. Also the shiny surface should stop the black carbon sticking so easily and make it easy to wash/blow off.

This solution will only work well where new building is taking place. In most urban areas, buildings already exist and there would be the significant issue of who would pay. Also, where there are historical or culturally significant buildings, people might not want to change the structure and appearance. However, in many hot countries, the use of white “limewash” on buildings has been used for centuries for this reason, and it might be quite easy to encourage the re-introduction of old practices.

Although this solution might help prevent the creation of urban heat islands, the reflection of heat upwards might still have consequences for air heating in other ways. Urban heat islands are complex systems and there might be further consequences of making this one change.

APP: A solution is suggested and evaluated.

Alongside this should be the reduction of fossil fuel use in vehicles, which could be achieved by introducing laws to limit the number and types of vehicles in the cities and to promote public transport powered by green fuels. If less black carbon pollution is generated, then the amount of carbon deposited on buildings will fall. This solution would be less expensive than the first, and would also mean less emissions of greenhouse gases.

Word count approx. 2250

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