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Article

Investigating the functionality of an Eco-Cooler made of plastic bottles

Anni Tong[1], Angi Tong[1], Victor Migenes[2]
[1] Stephen F. Austin High School, Sugar Land, Texas
[2] Physics Department, Texas Southern University, Houston, Texas

SUMMARY

In 2015, Ashis Paul from Bangladesh invented the Eco-Cooler, a low-cost, zero-electricity cooler for indoor spaces made of plastic bottles. However, there has been debate on the effectiveness of this Eco-Cooler. Therefore, we conducted a study to assess the effectiveness of this Eco-Cooler and developed a method to improve its performance. In this study, we tested the effectiveness of two Eco-Coolers, one with the original design and another with wet paper towels inside the bottles, referred to as the altered Eco-Cooler. We designed three experimental scenarios: one with a fan alone, one with the original Eco-Cooler, and one with our altered Eco-Cooler. We hypothesized that the altered airflow with an Eco-Cooler would reduce environmental temperature more than a fan alone, and the addition of wet paper towels to the Eco-Cooler would lead to a greater reduction in environmental temperature compared to the Eco-Cooler alone. Our results showed that the original Eco-Cooler was ineffective, causing no temperature reduction and even increasing room temperature by an average of 0.2°C. On the other hand, the altered Eco-Cooler was much more effective and had an average temperature reduction of 1.9°C, with a maximum temperature reduction of 2.7°C. Our project provided a low-cost cooling solution for individuals living in underdeveloped regions without access to air conditioners. In addition, wider implementation of the altered Eco-Cooler can help reduce pollution and global warming by recycling many plastic bottles that would otherwise end up in landfills.

INTRODUCTION

As a result of climate change, global temperatures are expected to rise significantly in the next 25 years (1). Global warming has caused a critical need for cooling, especially during the summer months. By 2050, the total number of days that need cooling will increase by 25% globally, leading to greater greenhouse gas emissions from the refrigerants used in air conditioners (2). Although there has been a global increase in access to air conditioners, many countries like India and Indonesia still have air conditioner ownership rates below 10% (2). Many low-income households in countries with humid climates like Bangladesh do not have access to electricity (3). Since most air conditioners need electricity to function, this makes them an unaffordable cooling method for those in poverty (4). As a result, people are in danger of overheating and are prone to many heat illnesses (5).

To address this problem, Ashis Paul, who worked at Grameen Intel in Bangladesh, invented an Eco-Cooler made of plastic bottles (3,6). This Eco-Cooler has already been used in Bangladesh, where electricity is unavailable for most people (7). A previous study claims that the Eco-Cooler is a viable method for cooling because it does not require electricity and is environmentally friendly (8). The Eco-Cooler is inexpensive and made from recycled plastic water bottles and cardboard (**Figure 1**) (7). The Eco-Cooler works by being mounted in a window, where the necks of the bottles face the inside of the house (7). According to the inventor, the Eco-Cooler is based on the Joule-Thomson effect, where throttling gas causes a pressure reduction and a temperature decrease (3, 9).

Currently, the Eco-Cooler has been adopted and used by people in underdeveloped countries like Bangladesh (7). However, we found that there was a debate on whether this Eco-Cooler works or not (6–9). Several studies on the effectiveness of the Eco-Cooler have stated that it could decrease room temperatures by approximately 3–5°C under optimal conditions with steady airflow and a high-temperature climate (6, 8). In contrast, other sources found that the Eco-Cooler's effect on temperature reduction was negligible (7, 9). For example, in a study looking at the effectiveness of Eco-Coolers with higher inlet air velocity, the temperature reduction was less than 1°C (9). Similarly, another study tested the Eco-Cooler's performance under various temperatures, humidity levels, and wind speed conditions, and concluded that the Eco-Cooler did not significantly decrease room temperature (7). These contradictory studies inspired us to conduct our own experiment to examine whether the Eco-Cooler works or not.

Thus, in this research, we aimed to evaluate whether the altered airflow with an Eco-Cooler can significantly reduce environmental temperature more effectively than a fan alone, specifically by 1–2°C, a range known to have a meaningful impact on human health and comfort (10). In addition, we wanted to explore ways to enhance its performance. Therefore, we proposed a method for improving the temperature reduction abilities of this Eco-Cooler by adding wet paper towels to the sides of each bottle (**Figure 2**). We added water to the Eco-Cooler because water is a phase change material (PCM) that absorbs energy during phase transitions caused by heating (11). In this Eco-Cooler, when hot air blows through the individual bottles, water molecules take away heat energy when the water is converted from liquid into gas. This Eco-Cooler is referred to as the altered Eco-Cooler.

Our research goal was to assess the effectiveness of Ashis Paul's Eco-Cooler and propose a way to improve its performance. We hypothesized that altered airflow with an

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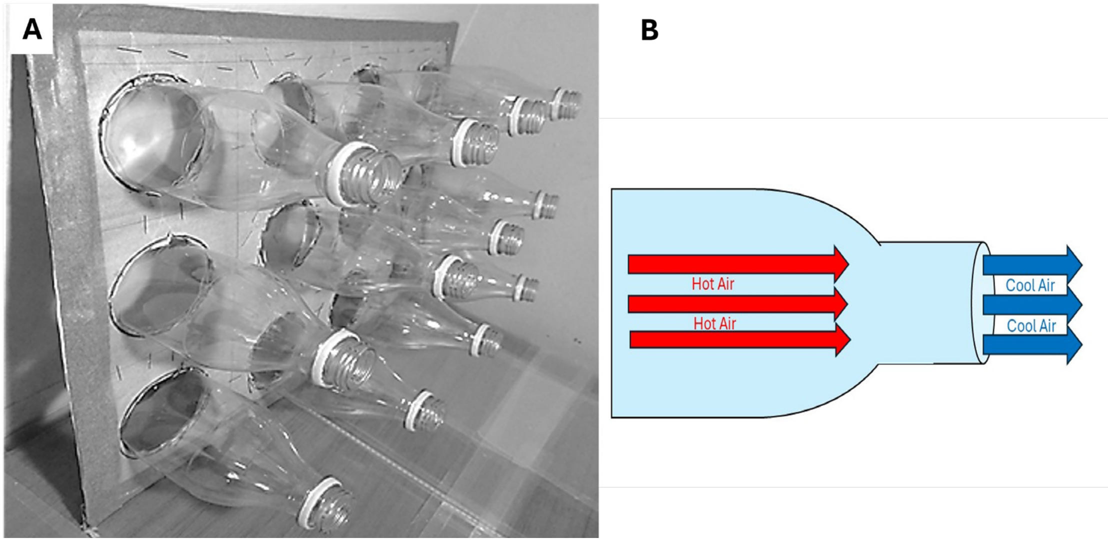

Figure 1. Original Eco-Cooler designed by Ashis Paul (3,6). A) The original Eco-Cooler uses recycled plastic bottles mounted on cardboard. B) The model illustrates the design idea: the air that entered the wider opening of the bottle and passed through the narrower bottle neck is proposed to expand and decrease in temperature according to the Joule-Thomson effect.

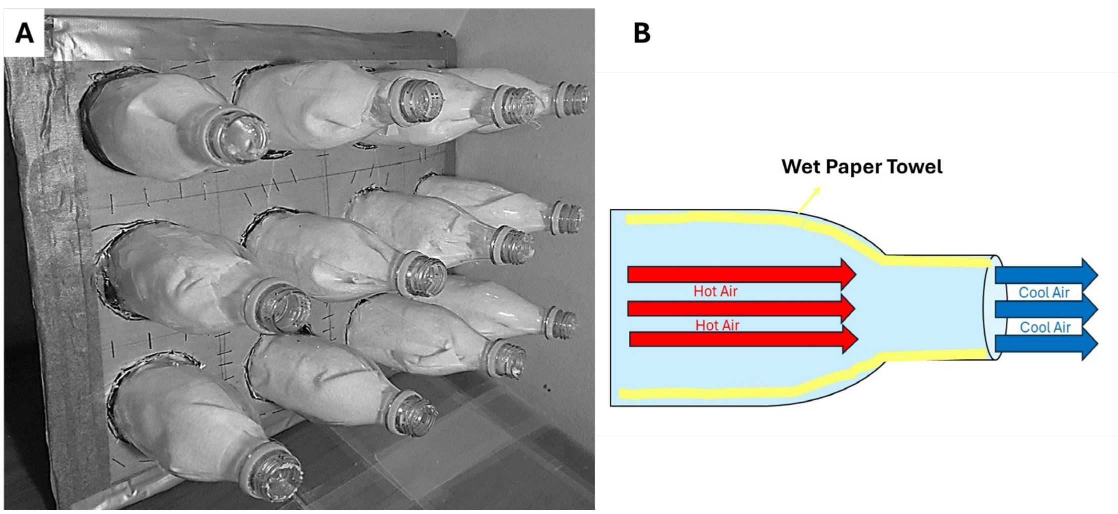

Figure 2. Altered Eco-Cooler design with wet paper towels. A) The altered Eco-Cooler design with wet towels added to the openings of each bottle. B) The model illustrates the concept behind the cooling ability of the altered Eco-Cooler. As air passes through the wet towels, water evaporates, leading to a reduction in temperature.

Eco-Cooler would reduce environmental temperature more than a fan alone, and the addition of a PCM to the Eco-Cooler would lead to a greater reduction in environmental temperature compared to the Eco-Cooler alone. To test these hypotheses, we examined two different designs: one using the original plastic bottle-based design and another using the modified design with the addition of PCM in the form of water-soaked paper towels. Our results showed that the original Eco-Cooler had no effect on temperature reduction and even increased room temperature by an average of 0.2°C. On the other hand, the altered Eco-Cooler was much more effective and was able to decrease the temperature by an average of 1.9°C. These results demonstrate that the original Eco-Cooler is ineffective in reducing temperature, consistent with the results of some previous studies (7, 9). However, we showed that the Eco-Cooler's design can be improved by using PCMs, such as water, to remove the heat from the cooling system. By introducing a more effective Eco-Cooler, our project may increase the use of Eco-Coolers, potentially leading to the recycling of many plastic bottles that would otherwise end up in landfills and reduce reliance on air conditioners.

RESULTS

We conducted experiments to test the effectiveness of the Eco-Cooler with the original design and the altered Eco-Cooler design. We placed both Eco-Coolers over the opening of a cardboard box (**Figure 3**). In addition, a control scenario using a fan only was added for comparison purposes. Therefore, three different experimental scenarios were designed in total. In Scenario 1, only a fan blew air directly into the cardboard box (**Figure 3A**). In Scenario

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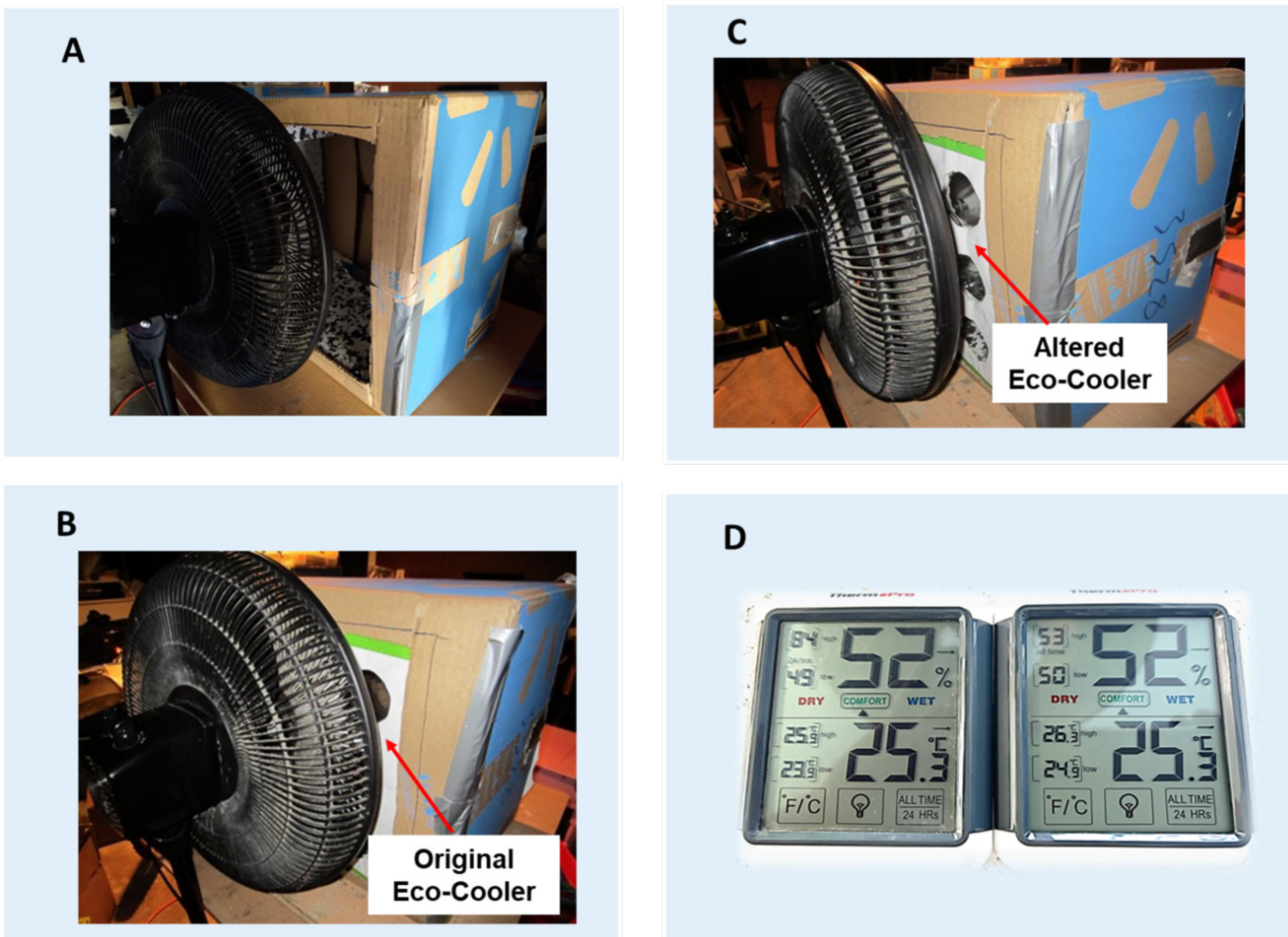

Figure 3. Experimental scenarios and equipment. Three cooling apparatus scenarios were created for testing. A) In Scenario 1, only a fan blew air directly into the cardboard box. B) In Scenario 2, a fan blew air through the original Eco-Cooler into the cardboard box. C) In Scenario 3, the fan blew air through the altered Eco-Cooler into the cardboard box. D) Two digital thermometers were used to collect data. Temperatures were measured under control conditions and with the original or altered Eco-Cooler. Each scenario was tested under similar conditions.

2, a fan blew air through the original Eco-Cooler into the cardboard box (**Figure 3B**). In Scenario 3, the fan blew air through the altered Eco-Cooler into the cardboard box (**Figure 3C**). To test whether the temperature reductions or increases for different experimental scenarios were statistically significant, we conducted two-sample paired *t*-tests to compare the temperatures inside and outside in each scenario.

For each scenario, temperatures inside and outside of the cardboard box were recorded every 30 minutes from 2:00 pm to 7:30 pm using digital thermometers (**Figure 1**). By subtracting the temperature inside the box from the temperature outside the box, we obtained the reduction in temperature. This allowed us to determine whether the temperature inside the box could be reduced by using these Eco-Coolers and compare the effectiveness of different cooling methods (**Figure 4A**).

In Scenario 1, the use of a fan caused an average temperature reduction of 0.1°C, and a maximum temperature reduction of 0.4°C (two-sample paired *t*-test, *p*-value = 0.031) (**Figure 4B)**. This reduction is significant; however, it is only a slight decrease in temperature, likely due to air movement and circulation caused by the fan. While the fan did provide some cooling effect, the overall reduction was minimal.

In Scenario 2, the original Eco-Cooler also had a negligible effect on temperature reduction, with a maximum temperature reduction of only 0.2°C. On average, the temperature increased by 0.2°C (two-sample paired *t*-test, *p*-value = 0.015), indicating the temperature inside the box was actually greater than the temperature outside (**Figure 4B**). This means that the original Eco-Cooler was not effective in decreasing the temperature. Noticeable temperature changes inside the box were observed at around 4:00 pm, two hours after the experiment began (**Figure 4A**). Temperatures inside the box were slightly warmer than outside temperatures from 4:00 to 7:30 pm by 0.2°C–0.4°C (when outside temperatures dropped below 30°C) (**Figure 4B**). This suggests that the design of the original Eco-Cooler was not only unable to decrease temperatures but also prevented the temperature inside the box from dropping as much as the outside temperature.

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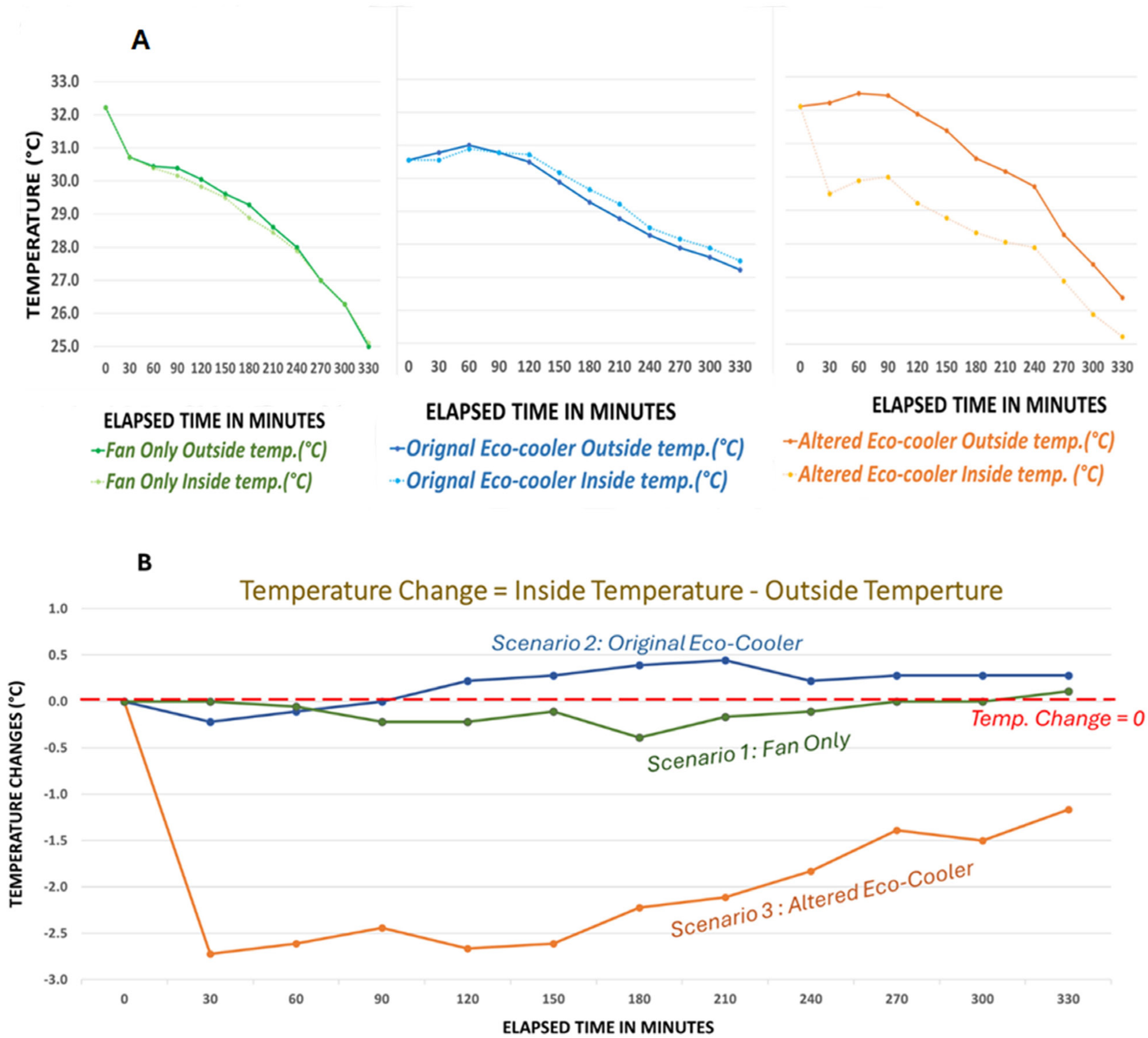

Figure 4. Comparison of temperature reductions of three different scenarios. A) Comparison of the recorded temperatures both inside and outside the box from 2:00 to 7:30 pm for all three scenarios. B) Temperature changes for different scenarios. These are defined as the inside temperatures subtracted from the outside temperatures. Negative temperature changes indicate that the temperature was reduced inside the box. In Scenario 1, the use of a fan caused an average temperature reduction of 0.1°C, and a maximum temperature reduction of 0.4°C; In Scenario 2, the original Eco-Cooler also had a negligible effect on temperature reduction, with a maximum temperature reduction of only 0.2°C. On average, the temperature slightly increased by 0.2°C; In Scenario 3, the altered Eco-Cooler reached a maximum temperature reduction of 2.7°C and an average temperature reduction of 1.9°C.

In Scenario 1, the fan-only control scenario achieved a small average temperature reduction of 0.1°C; however, the increase in average temperatures inside the box in Scenario 2 shows that the original Eco-Cooler reduced the effectiveness of passive cooling (**Figure 4B**).

In Scenario 3, the altered Eco-Cooler reached a maximum temperature reduction of 2.7°C and an average temperature reduction of 1.9°C (two-sample paired *t*-test, *p*-value < 0.001) (**Figure 4B**). Only 30 minutes into the experiment, the altered Eco-Cooler had already decreased temperatures by 2.7°C, showing a significant temperature reduction as early as 2:30 pm (**Figure 4B**). Although the temperature reduction did not reach 5°C, as claimed by the inventor of the Eco-Cooler, the altered Eco-Cooler consistently maintained a temperature reduction of more than 1°C throughout the entire experiment (**Figure 4B**) (3). Even when temperatures dropped below 30°C, a temperature reduction of at least 1.2°C was still observed, demonstrating that the design of the altered Eco-Cooler could effectively reduce temperatures (**Figure 4A**). To further compare the performance of the altered Eco-Cooler, the original Eco-Cooler, and the fan, we conducted a one-way ANOVA (Analysis of Variance) test to compare the temperature reductions during the three different scenarios. The ANOVA test is used to determine if there are statistically significant differences between the means of three or more

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independent groups. The *p*-value of the ANOVA test was less than 0.001, indicating that the difference in average temperature reductions between the three scenarios is highly statistically significant. Since the average temperature reductions for scenario 1 (fan only), scenario 2 (original Eco-Cooler), and scenario 3 (altered Eco-Cooler) are 0.1, -0.2, and 1.9, respectively, the altered Eco-Cooler is significantly more effective than the original Eco-Cooler and the fan (**Figure 4B**) (ANOVA test, *p*-value < 0.001).

DISCUSSION

In this study, we focused on evaluating the effectiveness of a cooling device called the Eco-Cooler, made of plastic bottles and developed by Ashis Paul from Bangladesh (6). We hypothesized that the Eco-Coolers would be more effective in reducing environmental temperature than a fan alone, and that the addition of wet paper towels to the original Eco-Cooler would lead to an even greater reduction in environmental temperature. The results from our study didn't support our hypothesis because the original Eco-Cooler was ineffective in decreasing temperatures inside our cardboard box setup. In fact, we found that the Eco-Cooler increased temperatures by an average of 0.2°C. However, we found that adding PCM to the original Eco-Cooler significantly improved its performance and reduced temperatures up to 2.7°C.

We suggest a possible reason why the original Eco-Cooler does not work. The inventor has stated that this innovative cooler works on the Joule-Thomson effect, which describes the temperature change of a gas when it is expanded through a throttling process. Due to the Joule-Thomson effect, at room temperature, all real gases except hydrogen, helium, and neon become cooler upon expansion when being throttled (12). In the proposed Eco-Cooler, when air passes through the bottleneck, it is throttled and then expanded after leaving the mouth of the bottle (**Figure 5A**). However, the Joule-Thomson effect may not directly explain the working principle of an Eco-Cooler. This is because the Joule-Thomson effect is applicable when there is a very high-pressure difference, but the pressure difference across the Eco-Cooler is much lower (3, 9). According to a previous study, the basic work principle of the original Eco-Cooler is that air passing through the bottleneck of the bottle becomes compressed (8). As a result, this compression causes the velocity of the air to increase and the pressure to decrease. After leaving the mouth of the bottle, the compressed air then expands rapidly. As the air expands rapidly, its temperature decreases, creating a low-pressure area that pulls in the surrounding air (8). This explanation is in line with the Venturi effect theory (**Figure 5B**) (13). According to the Venturi effect, air pressure decreases as it passes through the bottleneck. The decrease in pressure will then result in a decrease in temperature, as indicated by the ideal gas law. The ideal gas law equation is $PV=nRT$, where P is the pressure, V is the volume, T is the temperature, n is the amount of gas in moles, and R is the gas constant. According to this law, pressure and temperature are directly proportional to each other when the volume and the amount of gas are constant (14). Thus, when air moves through the neck of the plastic bottles, the decrease in pressure will cause a temperature decrease. However, the ideal gas is a theoretical concept — a simplification used to model the behavior of real gases under certain temperature and pressure conditions. Since the air flowing through the Eco-Cooler may deviate from an ideal gas, the Venturi effect alone may not be able to fully explain its cooling mechanism.

Our results showed that the original Eco-Cooler did not work, and this may be because the decrease in temperature is temporary. While it is true that gases cool as they expand and warm as they are compressed, there still needs to be an effective mechanism to remove heat from the gas to create a lasting cooling effect. In the original Eco-Cooler, air flowing into the bottles is compressed as it goes into the neck and then expands as it leaves the neck. Without some way to cool the higher-pressure air over a short distance, the outlet stream will eventually return to the same temperature as the inlet air. Furthermore, the friction created by the air and the plastic bottle walls may cause the temperature of the outlet air to be slightly warmer than the inlet air, as seen in our results.

The altered Eco-Cooler did work because it addressed the possible issue described in the paragraph above. One way to cool the inlet air is to first cool the compressed air by using a PCM to absorb the heat and then allow the air to expand. This process can be seen in most refrigerators and air conditioners today. For example, air conditioners use a refrigerant (such as Freon) as a PCM to absorb heat from the compressed air in the compressor, a process that takes place outside the house (11). Then, expansion takes place in the coils inside the house, producing cool air, which is blown by a fan to circulate throughout the home. In our altered Eco-Cooler, the water in the wet towel inside each bottle served as the PCM that absorbed some of the heat from the compressed air and caused the temperature reduction in the outlet air. Our results showed that we can inexpensively alter the design of the original Eco-Cooler by adding phase-changing material, such as water, to make it functional and achieve its purpose of reducing room temperature while being environmentally sustainable.

In Scenario 3, we also observed that the temperature reduction of the altered Eco-Cooler dropped from 2.7°C at 2:30 pm to only 1.2°C by 7:30 pm. One possible explanation for the weakening of the altered Eco-Cooler's ability to reduce temperature is the rise in humidity during the evening. Because the design of the altered Eco-Cooler is based on the idea of evaporative cooling, as the air becomes more saturated with moisture, less space is available for water molecules to transition from liquid to gas, slowing down the process of evaporation. As a result, the altered Eco-Cooler's ability to absorb heat is reduced due to the increase in humidity in the evening. The decrease in the outside temperature throughout the day could have also caused a decrease in the temperature difference between the inside and outside temperatures, reducing the effectiveness of the altered Eco-Cooler over time.

In conclusion, the original Eco-Cooler does not work, perhaps because it does not have a mechanism to cool down the compressed air before it is expanded again. As a result, the temperature first increases because of compression and then returns to normal outdoor temperature again after the expansion. Therefore, it does not decrease the overall temperature inside the box. On the other hand, our altered Eco-Cooler likely works because the wet towel inside each bottle absorbs some of the heat in the compressed air.

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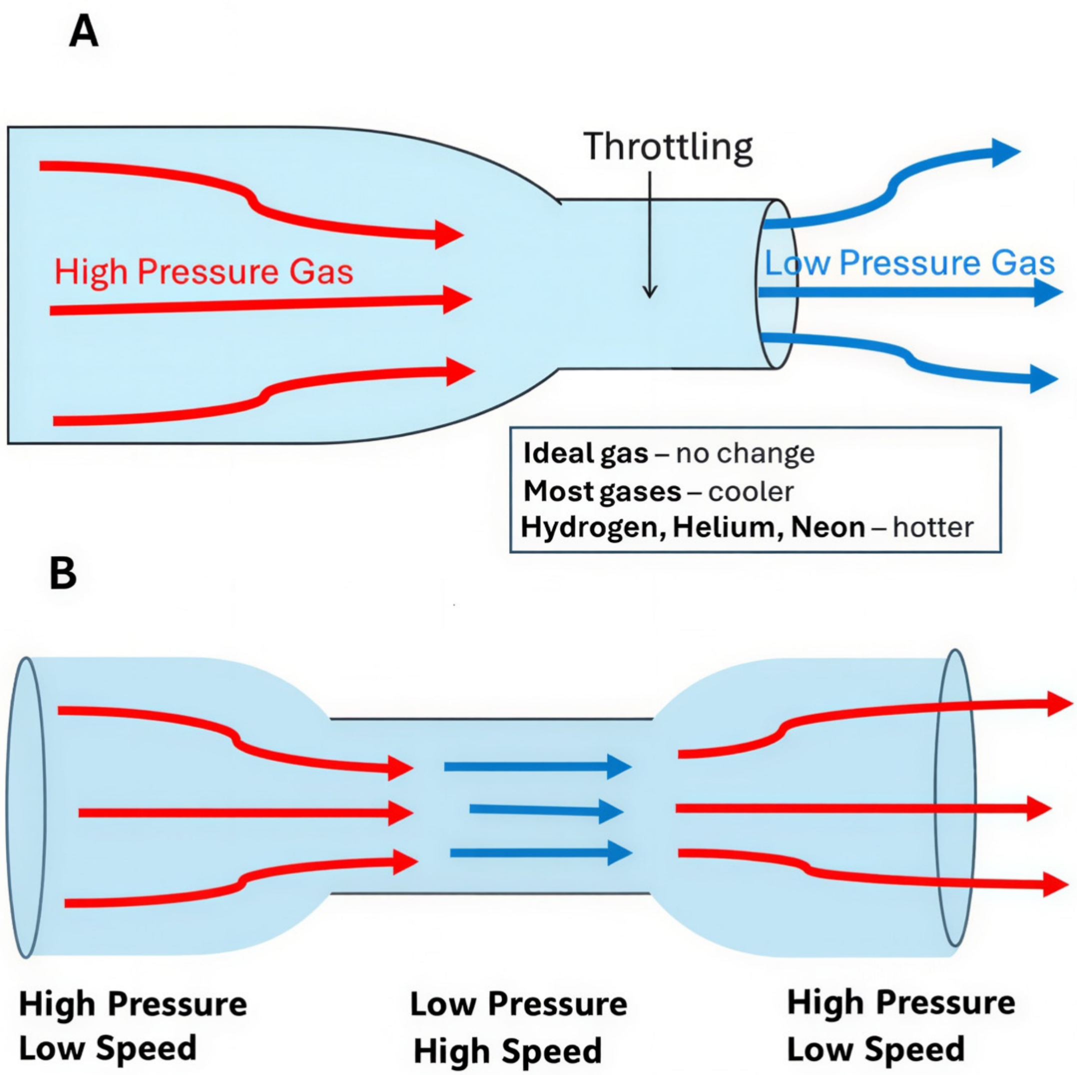

Figure 5. Venturi Effect and Joule-Thomson Effect. These diagrams illustrate the differences between the Joule-Thomson Effect and the Venturi Effect in explaining changes in air pressure, velocity, and temperature as air flows through a constriction, such as a bottleneck. A) The Joule-Thomson effect describes the temperature change of a gas when it is expanded through a throttling process. At room temperature, all real gases except hydrogen, helium, and neon become cooler upon expansion when being throttled. B) The Venturi Effect describes the decrease in air pressure as it passes through the bottleneck. The decrease in air pressure will then result in a corresponding decrease in temperature.

Thus, when the cooled air is expanded into the box, the temperature decreases.

Several limitations could have affected our results. First, although humidity levels were not measured in this study, weather factors, such as humidity and wind, could have impacted our results. For the altered Eco-Cooler, the efficiency of its evaporative cooling can vary depending on the humidity level of the environment. The higher the humidity levels, the lower the rate of evaporation, and consequently, the lower the efficiency of the altered Eco-Cooler. Thus, the altered Eco-Cooler should be tested under different environmental conditions. Another limitation of our results is that we did not measure the variability of wind conditions or how wind could impact the performance of the Eco-Coolers. In our experiments, an electric fan was used to supply a constant rate of airflow and simulate wind blowing through a window. This was done so that the performance of the original Eco-Cooler could be compared to that of the altered Eco-Cooler under controlled circumstances. However, real-world applications of Eco-Coolers attached to windows and other openings in homes can introduce a variable airflow rate that changes in speed or direction. In addition, the shape and size of plastic bottles may also affect the performance of the Eco-Cooler, as indicated by a previous study (6). Thus, more studies are needed to test Eco-Coolers made of different shapes of bottles. Another factor that could have

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affected our temperature measurements was the uneven distribution of heat in the box. As the box cools, warm air tends to rise, leading to varied temperatures in different regions of the box. Further tests should be conducted with multiple thermometers at different heights to get a full account of the temperature distribution inside the box. Furthermore, our tests were done using a box instead of the actual room. This limitation could have affected the accuracy of our results because the amount of space in a box takes less time to cool than in an actual room. Lastly, we did not include some additional control groups in this study, which could limit the strength of our conclusions. For example, we could use a box-only control to test whether the container itself influences temperature by trapping heat or creating a temperature gradient with ambient air. Similarly, using a water-only control, we could isolate the cooling effect of water independent of airflow.

In the future, we plan to explore other ways to improve the design of the Eco-Cooler. One way is to use different shapes of bottles to test which nozzles can cause a higher decrease in temperature as air moves through them. Although wet paper towels can contribute to further waste output, they can be replaced by more effective and reusable PCM materials made of plant-based oils (15). Other eco-friendly PCM materials, such as palm oil and coconut oil, which have a higher latent heat capacity, could be tested as alternatives to water to further improve the efficiency of the altered Eco-Cooler (15). Furthermore, PCM performance improves when larger quantities are used, as more heat can be absorbed over time (16). In future studies, different quantities of water should be added to the altered Eco-Cooler to evaluate the amount that maximizes the temperature reduction.

Our evaluation of the Eco-Cooler's effectiveness helps clarify some of the debate surrounding the Eco-Cooler's cooling capabilities. While the original Eco-Cooler has been reported by some as effective, our experiment shows that it does not contribute to significant temperature reduction. Therefore, our research may help correct any false assumptions arising from advertisements or other online reviews regarding this product.

In addition, our altered Eco-Cooler shows potential for improving current cooling systems by using PCM materials, which are more environmentally friendly than traditional refrigerants. Although air conditioners are much more effective than the Eco-Cooler, our study shows the potential for a low-cost, energy-efficient cooling solution, an important measure for protecting the health of those populations without access to advanced cooling systems. Furthermore, the altered Eco-Cooler is environmentally sustainable, as it promotes the reuse of plastic bottles and uses evaporative cooling methods instead of refrigerants, thus providing an eco-friendly option for cooling.

MATERIALS AND METHODS

Experimental setup of the cooling scenarios

A 16 x 21.5 x 12.25 inches cardboard box was used to create a controlled environment to test the Eco-Coolers. One side of the box was left open to attach the Eco-Coolers. Inside the cardboard box, four polystyrene foam boards were attached to each side. The polystyrene foam boards helped provide thermal insulation, which reduced heat exchange between the inside of the box and the external environment. As a result, there was a more stable temperature inside the box, allowing us to accurately measure the cooling effect of the Eco-Cooler. An electric fan was used to create the wind flow and simulate the performance of the Eco-Cooler in a windy environment. Three different scenarios were designed, which involved varied materials and equipment.

In the first scenario, the fan blew air directly into the cardboard box without any Eco-Cooler in between (**Figure 3A**). Scenario 1 acted as the control to show the temperature reduction caused by using just a fan to blow air directly into the cardboard box. By recording these temperatures, we were better able to isolate the cooling effects of the Eco-Coolers from the air movement of the fan.

In scenarios 2 and 3, two Eco-Coolers were each constructed using twelve 16.9 fl. oz. plastic soda bottles (**Figures 3B-C**). One of the Eco-Coolers was made using the original design, and the other Eco-Cooler was an altered design in which wet paper towels were attached to the inside of each plastic bottle (8). Each soda bottle was cut individually, leaving the shoulder and neck of the bottle, and then attached to a cardboard (13 x 17 inches). To prevent interference with airflow from the fan, the wet paper towels were attached securely to the sides of the bottles using super glue. To ensure that the water on the altered Eco-Cooler did not evaporate and affect our results, water was sprayed onto the towels every 30 minutes. To keep the amount of water sprayed consistent, the inside of each bottle was sprayed exactly three times during each interval. The temperature of the water was controlled to be around 25°C before being sprayed onto the towels. Both Eco-Coolers were separately attached to the opening of a cardboard box. This simulated the real-world application of the Eco-Cooler used in homes while also allowing us to compare the cooling ability of each design under controlled conditions.

Measuring cooling for each scenario

To test these three scenarios, three consecutive days when temperatures outside the cardboard box were around 26.67°C were selected. By testing the Eco-Cooler under these conditions, it simulated the real-world application of the Eco-Cooler in hotter locations like Bangladesh. This ensured that the results were relevant and accurately reflected the Eco-Cooler's performance in real-world situations.

Two of the same type of digital thermometer (ThermoPro, Model TP55) were used to record the temperatures (**Figure 3D**). One thermometer was placed inside the center of the cardboard box, elevated by a small wooden platform to avoid heat transfer from the walls and the floor, and another thermometer was also placed outside the cardboard box. The position of the thermometer was also marked with tape to ensure that both the inside and outside thermometers were placed in the same location for all experiments. Temperatures both inside and outside the box were recorded from 2:00–7:30 pm every 30 minutes.

Statistical analysis

To examine whether the temperature reductions or increases were statistically significant for each condition, we conducted two-sample paired *t*-tests to compare the inside and outside temperatures across 12 matched time points (2:00–7:30 pm) for each of the three experimental scenarios: fan only, original Eco-Cooler, and altered Eco-

Cooler. In a paired *t*-test, a low *p*-value indicates that the observed difference is unlikely due to random chance and is considered statistically significant. In this study, we used a significance threshold of $p < 0.05$. We also conducted a one-way ANOVA to determine whether there were significant differences in average temperature reductions across the three scenarios. A *p*-value lower than 0.05 indicates that the average temperature reduction of at least one scenario was significantly different from the others.

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