Reducing the A/C use in a classroom by replacing it with Passive Cooling Devices

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Abstract

As society becomes more aware of our carbon footprint and negative environmental impact, we need to start adapting our habits to be more environmentally friendly. One way to start lessening our impact is by cutting down unnecessary energy usage. This project will test different passive cooling devices in order to minimize the usage of an air conditioner in a high school classroom. Each device is installed and classroom temperature and light data is acquired. Analysis of the data will show that an external canvas awning is the most effective passive cooling device for the subject classroom. Suggestions for additional research are also provided.

1.0 Introduction

After taking a rigorous AP Environmental Science course, I was heavily influenced by the negative impact people have on the environment and how we can work to fix it. One of the ways that a person can start helping the environment is by reducing their energy consumption. Simple actions like turning off the light when you are not using it, turning off a faucet, or opening a window instead of turning on the air conditioner, have an impact. With these conservation methods in mind, I sought out information about the household. I choose this topic because it is something that I can have control over. After further research, I learned that heating and cooling systems consume the most energy in a household (Reduce Your Impact, 2019). In addition, air conditioning systems release a harmful pollutant called CFCs (Friedland & Courard-Hauri, 2012). These pollutants disrupt the natural cycle of ozone in the stratosphere, causing there to be holes in the ozone layer. Because of these holes, harmful UV radiation passes through the ozone layer and disrupts photosynthesis and increases the risk of skin cancers and cataracts.

At school, there is one particular classroom that constantly uses the air conditioner. During the day, the classroom gets uncomfortably hot. After further inspection and interviews with teachers, it was learned that the classroom's wall of south-facing windows could allow large amounts of sunlight to directly penetrate through the windows. The solar radiation causes the classroom to quickly heat up. For years, this classroom has compensated by operating the air conditioner continuously throughout the day. The blinds attached to the south-facing window are always down to block out the sunlight from hitting the classroom. The horizontal slats allow some bright light to enter the room which can be distracting to students if the patterns fall on desks, the board, or faces. The air conditioner poorly distributes the cool air among the classroom, therefore it is not effectively cooling down the room. Lastly, the air conditioner generates a loud, distracting sound that makes it very hard to teach or concentrate in the classroom. In addition to the air conditioner, teachers turn on the ceiling fan as well as open the windows in order to help cool the room. With these factors in mind, I want to develop an ideal set of passive cooling devices that maximize the room's cooling efficiency.

1.1 Passive Cooling Overview

Within the field of energy conservation, there are techniques such as passive cooling, that combat the issue of cooling a room effectively, cost-efficiently, and is harmless towards the environment (McGee, 2013). Passive cooling is a technique that uses a room's insulation, windows, shading, thermal mass, and ventilation to efficiently cool a room without energy usage.

1.1.1 Insulation

Insulation is a key component in keeping a room cool because it helps to maintain the room's temperature. Without good insulation, the hot or cold energy in a room escapes. More specifically, insulation acts as a barricade for energy so that it does not escape through the walls, ceiling, cracks, or windows (REenergizeCO, 2017). This is important because insulation could prevent an A/C or a heater from having to turn on frequently because the temperature would stay constant. With good insulation, the room better maintains the desired temperature and the less work that the heater or A/C has to do.

1.1.2 Windows

Windows greatly impact a room's temperature because they can allow a lot of solar energy to penetrate through them (warming objects which radiate heat) or allow a lot of energy to escape. The energy loss from windows can total up to 25% of the room's energy (McGee, 2013). This is why insulating products for windows are beneficial. In this classroom, the windows are predicted to be the biggest reason as to why the room gets uncomfortably hot. With the sun hitting the windows for the majority of the school day, a lot of solar radiation is transferred into the classroom, causing the temperature to rise. In order to combat this exposure, products such as films, coatings, tints, blinds, paned windows, awnings, and other devices work to filter out and reduce the solar radiation from penetrating through the window.

1.1.3 Shading

Shading is important because it can lower a room's exposure to sunlight, which lowers the overall temperature in a room. Shading can reduce 90% of the heat coming into a room, making this an essential factor for cooling a room (Mc Gee, 2013). In addition, shading can cool the potential air that might ventilate through the room. Different shading mechanisms such as shades, awnings, blinds, and drapes block out the sun. The most effective devices are the ones that block the sun from outside. This helps divert the sunlight before it has the chance to enter the room. The shading device that was looked at was an awning because it should best block the sun from entering the classroom. Additionally, the ventilation that passes through shade dramatically cools down as it travels into the room. These shading methods do not have to be devices but it also includes nature. Trees and shrubs can do a very good job of shading buildings and cooling the air that can go through windows.

1.1.4 Thermal Mass

Another factor of passive cooling is thermal mass. It works similarly to insulation because it is the ability of building materials to retain heat or absorb it (Thermal Mass Design, 2018). A few examples of this material are concrete, bricks, and tiles (McGee, 2013). These materials work best for passive heating but they can also perform well for passive cooling. However, incorporating thermal mass into the project isn't feasible but impacts the room's ability to retain the cold and heat. For example, noting that the floor is made of concrete, a material with high thermal mass, helps to assess why the room's temperature fluctuates and it provides an idea of how to fix it. Also, depending on the season, the angle of the sun adjusts. By knowing this, shades can be added to prevent sunlight from entering in the summer. When it is winter, the angle of the sun is lower, therefore, sunlight can be allowed to penetrate through the window and hit the concrete floor, which would radiate heat, making the room warmer. Thermal mass has its advantages but they are not particularly essential to this project, however, it may impact my results.

1.1.5 Ventilation

The most important factor when it comes to passive cooling is ventilation. The most effective way to cool people off is through evaporation of moisture on one's skin (Passive Cooling, 2019). Ventilation causes air movement that cools the skin on the body, which cools the person off entirely. In order to use this method, rooms need to maintain air circulation and movement. A room's orientation can help a breeze enter through a window and make its way out through another window, door, or vent on the other side of the room. The air needs a way to enter, distribute throughout the room, and exit without the air getting stuck inside the room (McGee, 2013). Alternatively, air pressure differentials can be used in order to get a breeze to enter a room. Air moves to areas with low pressure. If rising warm air is allowed to leave a room through a ceiling vent or window, a low-pressure area is created in the room which can pull cool air in through a floor vent or low window (Image 1). This is the key to proper ventilation.

1.2 Problem Statement

Because air conditioners consume so much energy and release harmful pollutants, this experiment was created to test the effectiveness of different passive cooling devices so that they can be combined to make a cooling system that minimizes A/C usage.

More specifically, occupants in room 32 need a device that better distributes cool air and reduces the amount of heat and light that the room is exposed to. This experiment was composed to test the effectiveness of different cooling devices in a room to see what combination of devices best cools the room with minimal to no A/C usage.

2.0 Methods

The subject room for this project is Room 32 (See image 2). Room 32 has a full bank of windows along the SouthEast wall. The windows are single pane, with a single layer of partially reflective film on the exterior surface. A window A/C unit is installed in the center of the windows along with horizontal blinds. Two 5-blade, 3-speed fans are ceiling mounted and two heating vents along the north wall connect to the building central heating system. The heating vents have no individual control. An evaluation of contributing energy factors resulted in the decision to measure temperature and room brightness. Additional data on incident sun angle and an A/C use log could be beneficial but were not included in this study.

Determining where to locate the temperature and light sensors required evaluating both project goals (wanting to have data related to student comfort) and feasibility (the number of sensors available is limited). Ultimately, two sensors were assembled for placement near the window and near the center of the room.

The assembled sensors consisted of an Arduino controlled device with the ability to record temperature and light data and store the data on an SD card. The device is powered by a wall charger so there are no problems with battery failure for long data runs. After recording, the data was exported to an excel spreadsheet for analysis.

A list of possible passive cooling devices was created and evaluated for possible prototyping with Rm 32 (See image 10). The testing process included installing a device and collecting multiple days worth of temperature and light data. Methods tested include Existing Blinds Down, Existing Blinds Up, White paper window covering, and External Awning. For each data trial, daily high temperatures were retrieved from AccuWeather and recorded.

2.1 Initial Data Collection - Blinds Down

The first set of collected data is from February 22 - 23, 2020. On the 22nd, the sensors recorded data from 6 am to 6 pm in an empty classroom with the blinds down. This set of data recorded the classroom without people and with the blinds down.

2.2 White Paper Testing

White Butcher Paper used to cover the outside of the classroom windows was used as a prototype simulation of honeycomb blinds (Image 11). Data was acquired over the course of two weeks with the room in both a Blinds Up configuration and a Blinds Down configuration.

2.3 Awning and Vents Testing

A temporary external canvas awning was constructed and installed (See image 12 and 13 for design details and image 14 for final installation). Over the course of two weeks data was recorded in the empty classroom. During this timeframe, the internal central heating vents were blocked off with cardboard and tape to prevent any hot air from “leaking in”. This vent blockage was unique to the awning data trials.

3.0 Results

3.1 Blinds down

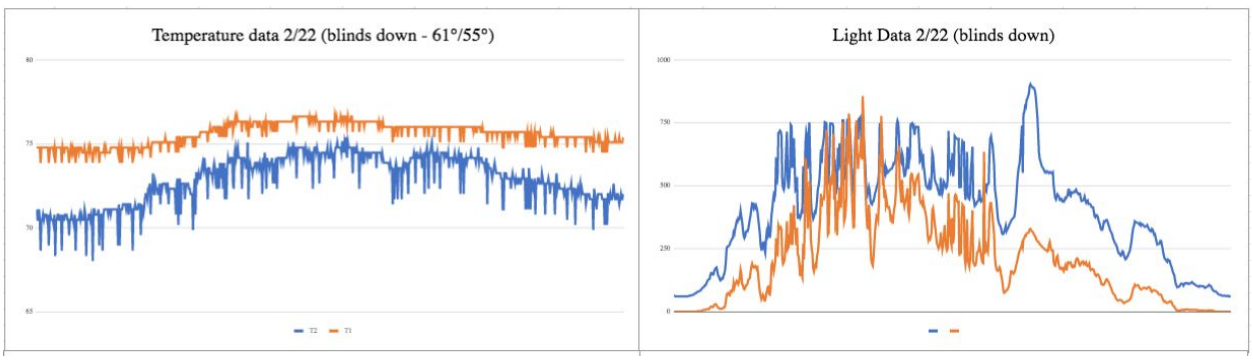

Figure 1: Temperature and Light Data for Blinds Down trial (Orange: Window, Blue: Student Desk)

The graphs provide temperature and light data from 6 am to 6 pm with the temperature ranging from 61° to 55°. For this set of data, the blinds in the room were rolled down.

The temperature in the beginning and end of the day is the lowest but as the day approaches noon, the temperature reaches its peak. It is shown that both sensors by the window and desk are following the same trend but the values by the window is continuously greater.

Additionally, the temperature by the desk rises faster as noon approaches, but the values never surpass that of the window.

In the light graph, the overall trend loosely follows that of the temperature. The beginning and end of the day have the lowest values because of the sun's lack of solar radiation. In the middle of the day, the values increase dramatically. It is likely that the noise in the light values were from the blinds unevenly distributing the light as the sun moves across the sky. These frequent changes can affect the light values displayed in the graph. In all, the graphs show how the temperature and light graphs are correlated throughout the day.

3.2 Blinds up

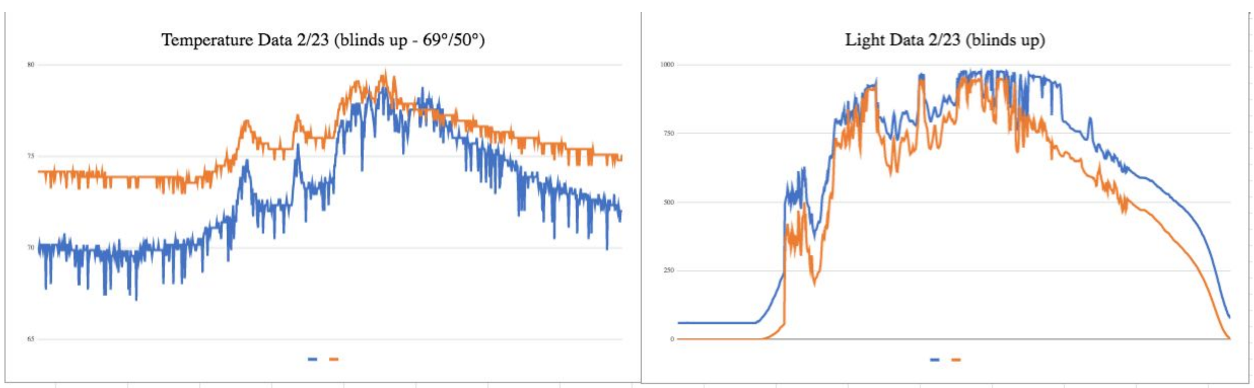

Figure 2: Temperature and Light Data for Blinds Up trial (Orange: Window, Blue: Student Desk)

The data provides a view of the temperature and light data with the room's blinds up. The data was recorded from 6 am to 6 pm with the outside temperature ranging from 69° to 50°. The different trends shown by this data and Figure 1 provide an idea of control data to compare the room's behavior with the different cooling devices. This helps to see whether the cooling devices help the room's temperature or not.

Similar to Figure 1, the trends on these graphs are very similar. With the blinds up, the light patterns are expected to be greater. The light values are much higher in value and the various amount of noise is expected to be clouds passing by. With the increase in light, the temperature also increased as a result. The graphs show that without sun blockage, the temperature rises; therefore the light directly relates to the temperature. The more light exposure, the more the temperature rises. The temperature of the classroom significantly spiked in the middle of the day due to extreme solar radiation.

Compared to Figure 1, this graph begins with a lower temperature but it later spikes around noontime and for a short period, the desk temperature surpasses the window.

3.3 White paper

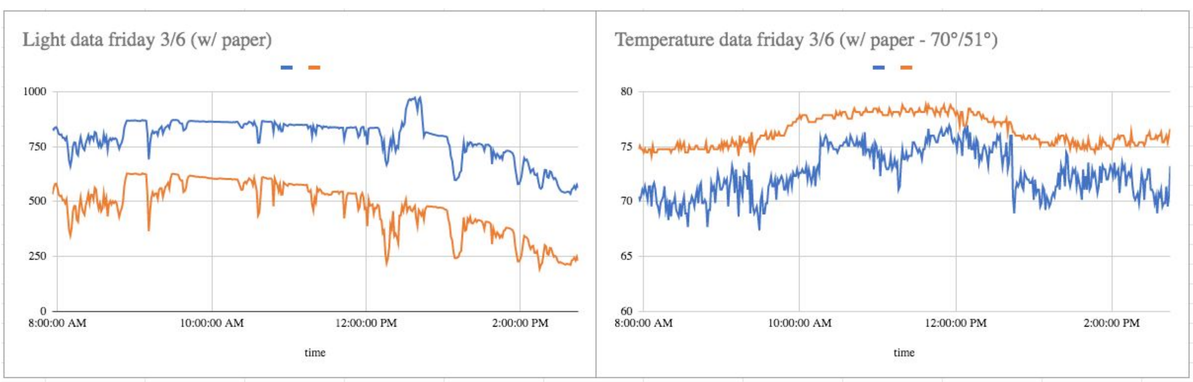

Figure 3: Temperature and Light Data for White Paper trial (Orange: Window, Blue: Student Desk)

Similar to the graphs above, this data represents the results of the classroom's temperature and light data but with the white paper covering the windows. The purpose of this trial was to see how the room would react to a quick and easy alternative to insulating shades.

The data shows how the light values were consistently higher compared to the data in Figure 2. The light values by the student's desk were higher than the values by the window because the white paper dispersed the light from the sun as it entered the room. This allows for less dependence on artificial light and less consumption of energy. However, this cooling device did not have much of an impact on the room's temperature. Compared to Figure 4, the white paper slightly lowered the temperature by the window and desk but did nothing significant.

At around 12:30pm, it was assumed that a window was opened because the light value spiked, and the temperature by the desk dropped.

3.3.1 White paper (control)

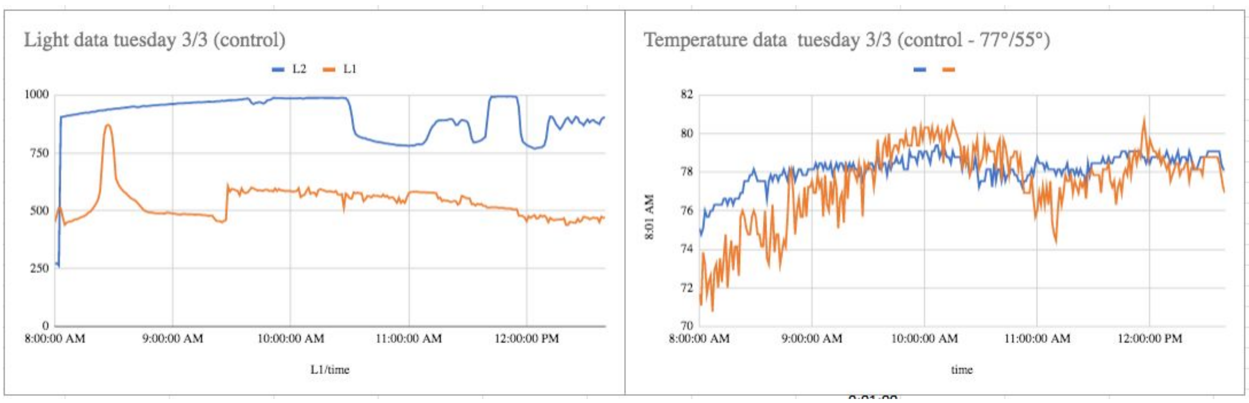

Figure 4: Temperature and Light Data for White Paper control

The purpose of this graph was to provide some comparison of control data for Figure 3. It is not accurate to compare Figure 3 to Figure 1 because the white paper data was taken during a school day, which accounts for many other factors. These factors include students coming in and out of the room, the A/C and fans being turned on and off, and the windows being open and closed. This graph solely represents data from a school day without white paper.

This graph is most useful when looking at the temperature graph. Compared to Figure 1, this graph has more dips and increasingly fluctuates. This is because of the bodies coming in and out of the room as well as the A/C being turned on. Comparing this graph to Figure 3 shows that the white paper actually helped to stabilize the temperatures but increased the overall temperature. This graph of light data is inaccurate due to technical issues.

3.4 Awning & vents

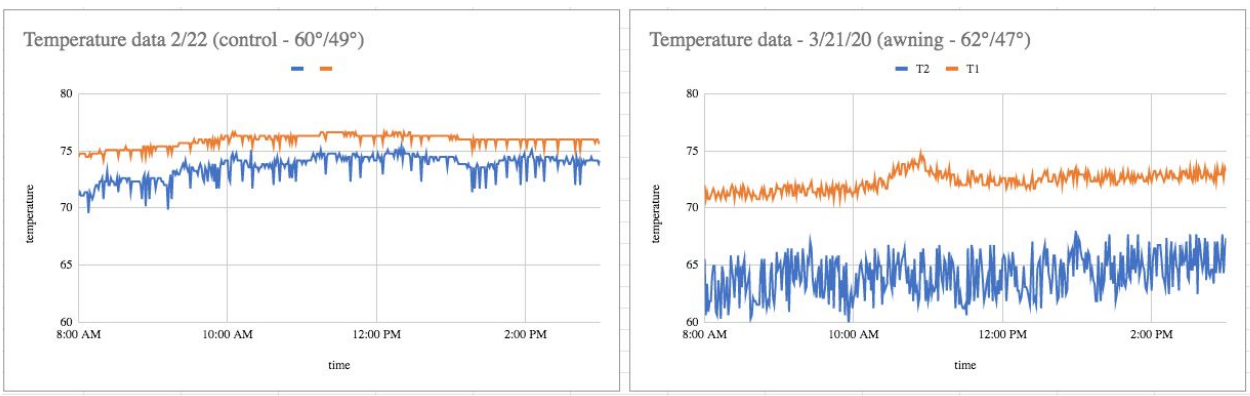

Figure 5: Temperature Data for Blinds Up (left) and Awning (right)

This last trial was recorded with covered vents and an awning placed outside of the windows. The graph to the left is temperature data recorded from Figure 1 and the graph to the right is data from the awning/vents. Light data was not included from this awning trial due to technical difficulties. The orange line represents the sensors located by the window and the blue represents the sensors on the student's desk. The awning data was taken, much like the control data, on the weekends without any students or the use of an A/C.

From the data, it is clearly shown that the awning did everything it was predicted to do. It dramatically lowered the room's temperature, both by the window and the student's desk. The awning helped by shading the room and cooling potential ventilation that may pass through the room.

4.0 Discussion

The following chart summarizes the pros and cons of the two passive cooling prototypes tested on Room 32.

Devices	**Pros**	**Cons**
Awning & vent	• Provided shade → which blocked solar radiation from heating the room • Lowered and stabilized the room's temperature • Cools the ventilation entering the windows	• Covers more light → needs more energy for lights • Partially covers the views of outside
Blinds	• Provides some shade but allows lots of sun to penetrate • Provided better lighting → reducing energy usage for light • Somewhat stabilized the room's temperature	• Doesn't improve room temperature

From the data provided above, it is shown that the best passive cooling devices were the awning and vent covering as well as the blinds. With these products, the graphs showed improvements in the room's overall temperature and light exposure. The white paper dramatically increased the overall light exposure of the room because it dispersed the sunlight but did not help the temperature problem. The goal was to limit the use of an air conditioner and replace it with passive cooling devices but the project did not reach that goal. Instead, different devices were tested to see its effect on the room's temperature. From the experiment, it was found that the two best devices were the blinds and awnings but there is more to be tested. Now that it's proven that blinds are a beneficial cooling device, there is an opportunity to explore more intricate types of blinds. In Image 10, there is a provided list of different devices that are potential candidates for temperature control.

Throughout the experiment, it was found that shading the windows rather than covering them is a better way to moderate the temperature. Additionally, internal heating vents might play a role as well as an important item for additional research. Conversation with a teacher in room 32 (Mrs. Schnieders) suggests that much of the heat from the classroom might be coming from the vents. There is no individual control of the room thermostat since the thermostat controls the heating for the entire freshman wing of the building (Eric Pivavaroff, Director of Facilities). Addressing the central heating may be the key to help to solve the room's temperature problem.

5.0 Conclusion

This project has shown that a room's temperature can be effectively managed using the principles of passive cooling. Awning and blinds were most the effective method of moderating the temperature without negatively affecting light exposure in the room. To continue the experiment, there should be more data trials done with various passive cooling devices to evaluate the effect of how devices could be combined in order to eliminate the usage of an air conditioner.

6.0 References

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7.0 Appendices

The images and files can be found in the 8.ClassroomThermal final documentation folder.