Vertical Algae Farming

Written report

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Abstract

The upper secondary classrooms in Hwa Chong Institution have air conditioners operating throughout the day to provide a conducive learning environment. However, these buildings are exposed to direct sunlight as well, incurring higher electricity bills. As such, this project aimed to utilise algae farming techniques to overcome this problem. The proposed solution used multiple bottles of water filled with algae to act as a buffer between the sunlight and the walls of the building. Using the scientific concepts of convection and conduction, and by testing the temperature of the buildings with and without a bottle of algae placed in front of it, it was determined that the bottles of growing algae were able to reduce the temperature of the concrete walls. This indicated that the wall would have reduced thermal absorption should our proposed solution be implemented. As such, the solution allows a lower rate of thermal energy transfer from the sun to the air-conditioned classrooms, reducing the overall energy consumption to cool down the classroom. The proposed solution also functions as an algal photobioreactor, the sunlight blocked by the proposed solution not only cools the building, it is also used in cultivating and growing algae in the solution design. This proposed solution aims to achieve two goals, cooling and reducing energy consumption for air conditioning in buildings, and the growing of algae.

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1.0 Introduction

1.1 Energy usage

Throughout every day of the academic year, air conditioners are utilised by classrooms around the world to provide a comfortable learning environment for the students in them. Large amounts of energy is required to power these air conditioners, contributing to large amounts of greenhouse emissions (Tan, 2019) and leading to climate change. On top of that, the concrete buildings the air conditioners are in readily absorb and release heat (Asadi, Shafigh, Hassan, & Mahyuddin, 2018), which leads to the internal temperature of the buildings being higher , causing even more energy to be used to cool down the classrooms.

In Hwa Chong Institution, Singapore, such classrooms also experience the Urban Heat Island (Bornstein, 1968). Urban areas on an island will tend to have higher temperatures than the rest of the island. Hwa Chong Institution is located in a more urbanised part of Singapore, hence its surroundings will have a higher temperature. A higher surrounding temperature will mean that more energy is required to cool the classrooms down. As such, this adds on to the problem listed above, where energy is being used unnecessarily.

1.2 Vertical Green Walls

In recent years, one method of solving this problem has been through using vertical green walls, which decreases the indoor temperature of buildings significantly (Safikhani, Abdullah, Ossen, & Baharvand, 2014). Use of conventional green walls have been observed in high rise buildings in Hong Kong with the aim of reducing energy consumption for cooling during summer. Green walls have proven to be a good insulation system, significantly limiting heat transfer through the external facade into the interior (Wong & Baldwin, 2016). However, there are many problems associated with a conventional vertical green wall. Namely, irrigation and watering problems are the biggest challenges faced by the maintenance of a vertical green wall (Bustami et al., 2019).

1.3 Algae

Algae is a group of organisms which is extremely adaptive. Algae can grow almost anywhere with sufficient water, nutrients and sunlight (Cao et al., 2015). Algae also has many uses, and can be used in industries ranging from the cosmetics and food industries to the farming and fuel industries. Chlorella Vulgaris, a popular species of algae, has been considered in the realm of oleaginous (meaning high in oil content) microalgae due to its high lipid content, specifically triaclyglycerols (TAGs), which amount to up to 40-60% of their dry weight content (Wells et al., 2016). On top of that, lipid productiveness of Chlorella Vulgaris is much higher than that of other plantations (Pal et al., 2019), making it a viable option for biofuel production. Another species of algae, *Spirulina*, also has applications in the farming industry. It can be used for feed, and has been shown to increase the milk production of cattle (Kulpys et al., 2009)

1.4 Vertical Algae Green Wall

As such, this project aims to apply the concept of a vertical algae farm, which is a vertical green wall with algae grown in vertical containers of substrate, in place of plants, to reduce the internal temperatures of a building. This retains the benefits of a normal green wall, where the algae and water would also block out the sunlight and heat from reaching the building exterior. Resulting in lower heat transfer into the interior. And directly reducing the energy consumption in cooling the interior. Concurrently, the sunlight is not only blocked, but also used in photosynthesis by the algae. With its fast growth rate and wide range of uses, algae can then be harvested for other uses as well. A vertical algae green wall is able to combine the advantages of green walls and algae, offering a multi-beneficial solution.

2.0 (Proposed) Solution Design

The proposed solution consists of a specialised rack which holds multiple layers of bottles containing algae and the growth substrate. Multiple racks would be placed in front of the walls of the classroom, providing a buffer zone between the sun and the wall. After taking measurements of plastic bottles from various drink companies, it was found that the heights of the bottles ranged from 20.5 cm - 21.7 cm, and the diameters ranged from 6.3 cm - 6.6 cm. To allow for a margin of error, it was decided that the model would be designed with 22.0 cm for the height and 7.0 cm for the width of each section of the rack. The model of the algae rack was developed using 3D modelling software Tinkercad. Each layer had dimensions of 22 cm x 7 cm x 22 cm, which would allow for ease of accommodation of 3 plastic bottles of any brand.

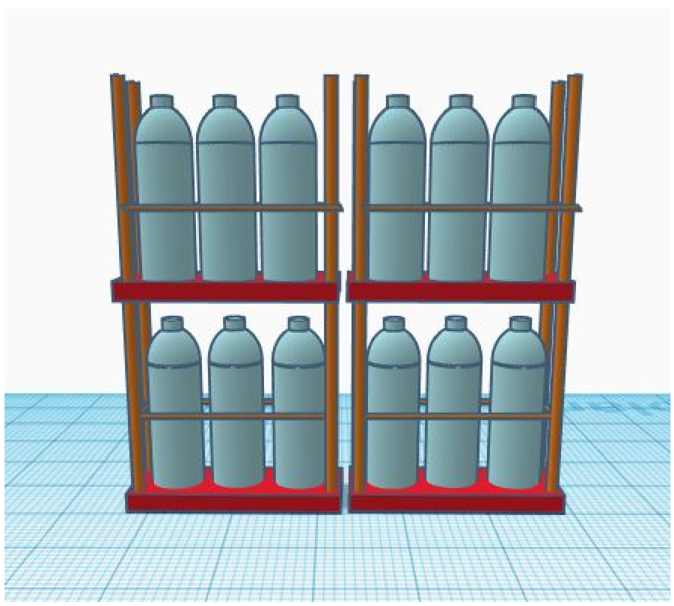

Figure 1.0: 3D model of rack with bottles

The proposed solution will be able to utilise the sunlight to cultivate algae inside the bottle, while also reducing the amount of heat gained by the buildings. Due to the high specific heat capacity of water (Angell, Sichina & Oguni, 1982), the bottles were able to absorb large amounts of thermal energy from the sun. A lower building temperature is achieved through the water slowing down the transfer of heat by conduction and radiation. The bottles blocked the building from direct sunlight, absorbing the heat that would otherwise have heated up the building. This has functionality in cooling the interior temperature of the building, which would reduce the energy used Thus, the proposed solution will be able to increase the functionality of an ordinary algae bioreactor, not only using it to grow algae, but also applying it to cool down buildings as well. This would not only provide a more pleasant environment for learning, it would also reduce the electricity usage for air-conditioned buildings.

2.1 Modular Design

For scaling up of the solution design at the preliminary stage, the frame of the solution design was designed to be modular, where each layer is independent of each other. It was estimated that the design could be scaled up to around a 1-2 m height. Any singular module can also be taken out and replaced at any time. This will be especially useful in situations where the frame is damaged, or certain groups of algae grow faster than the rest of the system.

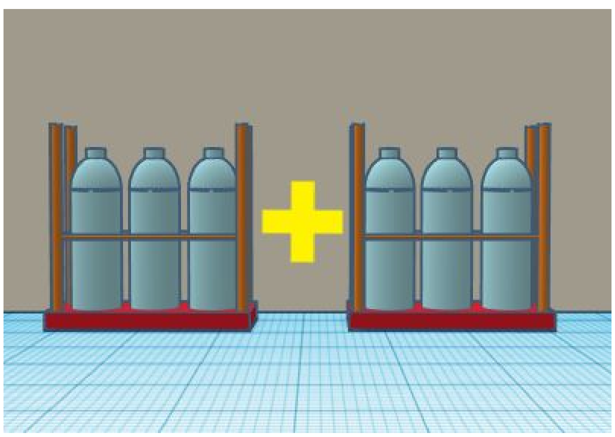

Figure 2.1: Individual modules

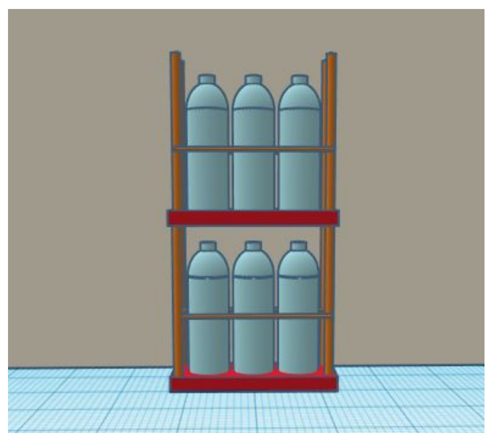

Figure 2.2: Modules stacked together

Due to the limited land space that Singapore, and more specifically Hwa Chong Institution faces, the proposed solution was designed to accommodate vertical upscaling. This allowed for more bottles to be grown per unit of land, thereby increasing the productivity of the system.

2.2 Use of plastic bottles

Incorporation of plastic bottles allowed for maximal utilisation of space and resources. Reusing plastic bottles is environmentally friendly, and a second purpose is a used object that would otherwise be thrown away. With the ever increasing problem of plastic pollution, it would be favourable to avoid contributing to the pollution by using new or specially designed containers. On top of that, plastic bottles also allow for efficient growth of algae due to its relatively small diameter, which allows for light penetration. Its transparent design, relatively high durability and capacity made it a suitable choice. The bottles were able to allow high intensity of sunlight to pass through, maximising the rate of photosynthesis by the algae, and thus ensuring high growth rates and in the case of oleaginous (high in oil content) algae, allowing for prominent levels of lipid production.

2.3 Harvesting methods

A proposed method of knowing when to collect the algae is using a Logistic Function. The Logistic Function is used in ecology to estimate and analyse the population growth of an organism (Pareja, 1984). From the function, the growth rate of algae can be represented by the equation:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$$

$$\lim_{t \to \infty} P(t) = K.$$

Where P is the population at a point in time, K is the carrying capacity (i.e. the maximum population of algae the bottle can contain), and r is the growth rate of the algae at low algal cell concentration. As the Logistic Function is similar to a standard exponential growth graph at the start, the value of r can be derived from the following equation based on experimental data (Taylor, Fletcher & Raven, 2001):

$$r = \frac{\ln(c_1/c_2)}{t_2 - t_1}$$

Where c is the algae cell count, and t_2-t_1 is a time period at the start of the experiment. K can be derived using experimental data, when there is little to no change in the algal cell concentration (i.e. at the maximum concentration). The values r and K can then be inserted back into the equation, which can then be solved to find the growth rate of the algae. Before the growth rate approaches 0, the bottles can be collected and the algae can be harvested. The equation above can be graphically represented as:

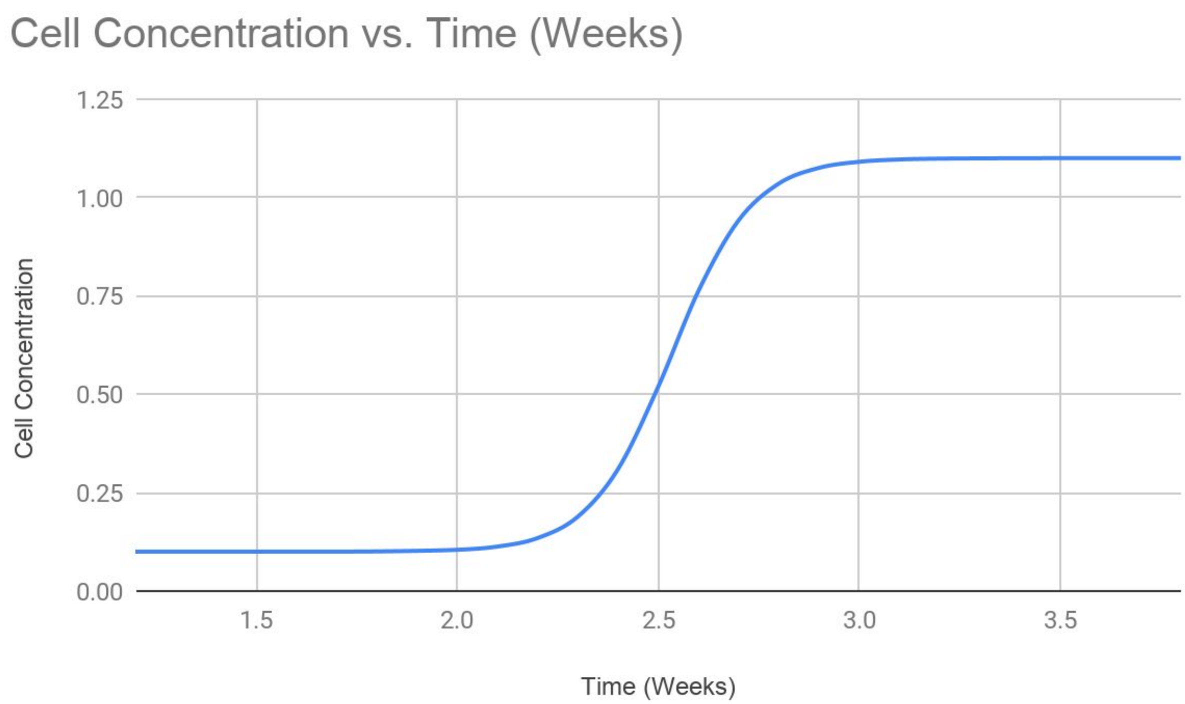

Figure 2.3: Graphical representation of Logistic Function

However, even with mathematical estimation of when to collect the algae, growth rates of algae also varies greatly with many different factors, like sunlight intensity and nutrients composition of the medium in which the algae is grown (Bouterfas, Belkoura & Dauta, 2002). Further empirical studies will have to be conducted in order to derive an equation between cell concentration and time to obtain a more accurate estimation of when to collect the algae. After algae collection, the algae can be sent to professional companies which deal with algae to filter, clean and obtain a usable form of algae.

3.0 COVID-19 Pandemic

Due to the ongoing COVID-19 pandemic, a physical prototype of the vertical algae farm could not be made. Instead, some preliminary experimentation was done to test for the effectiveness of algae in reducing the temperature of a building when placed in front of it. 2 Massive Online Open Courses (MOOCs) were taken in order to gain further knowledge about this project.

3.1 Mechanics of Materials

The structure is to be built to a moderate height, under the heavy loads, each layer held around 1000ml of water, amounting to stress of $649N/m^2$ per layer. The online course covered topics regarding how materials react to axial stress and loads. Regarding the topic of stresses, the topics discussed included Stress-Strain Diagrams, Stress on Inclined Planes, Shear Stress and Strain and Measuring Strains. Coupled with the topics of Material Properties and Factor of Safety, the new information was implemented to improve the structural stability of our proposed solution, with the aim of minimising stress faced by the holding rack.

3.2 Introduction to Algae

In this MOOC, experts in the field of growing algae thought classes regarding the basic principles of growing algae. The history, organelles of a typical algal cell, the Endosymbiotic theory, and the classification of algae was first introduced, before moving on to the actual growing of the algae itself. Industry experts were invited to talk about the different farming models currently used, along with their strengths and weaknesses. The industry experts also introduced methods of maximising algae growth, by introducing essential nutrients, using carbon dioxide pumps or even the arrangement of the algae containers to maximise sunlight exposure. Afterwards, the MOOC also introduced methods of harvesting algae, along with reasons to support them, and comparison between the methods. This information can be applied in our current solution design, or used to improve it in the future. On top of that, the MOOC also brought up the uses and applications of algae, like in manufacturing biofuels. This additional knowledge could be useful in the future of this project, in deciding how to fully utilise the harvested algae.

4.0 Experimental Design

The experiment was conducted to find out about the effectiveness of algae in reducing the temperature of a building. As such, the temperature of the surface of a wall was measured. Four sets of data were measured, the temperature of the wall with a bottle of algae, the temperature of the wall with a bottle of clear water, and the temperature of the wall directly exposed to sunlight. The bottles were placed 2cm away from the wall. SPARK science learning systems, coupled with temperature sensors, were used to record the temperature of the wall in relation to the time. Due to the COVID-19 pandemic, the experiment was conducted at home.

4.1 Hypothesis

It was hypothesised that the wall behind the bottle with algae will be cooler than the wall behind the bottle with water only, and the wall with no bottles placed in front of it.

4.2 Materials

Materials Used	Quantity/Amount
Plastic Bottles	3
10g of algae	1
Water	1000ml
Data Loggers	2
Temperature Sensors	2

4.3 Experimental Set-Up

Two experiments were conducted a few days apart. In the first experiment, one 250ml plastic bottle fully filled with algae and water was placed in front of a wall. SPARK™ LXi Datalogger and a temperature sensor extension was used to record the temperature of the surface of the wall behind the setup. Another similar setup was put up in the same vicinity, where another SPARK™ LXi Datalogger was used to record the temperature of the wall without any bottles and obstructions. The experiment was conducted at 1100-1145 hours, which was around the time when the sun was shining directly against the wall. At 1100 hours, the data loggers started collecting data and stopped doing so at 1145 hours. This data was then transferred for interpretation.

In the second experiment, one 250ml plastic bottle fully filled with algae and water was placed in front of a wall with a temperature sensor pasted onto it. Another temperature sensor was placed beside the wall, and a 250ml plastic bottle fully filled with water only was placed in front of it (See Figure 2.0. The experiment was conducted from 1600-1645 hours, which was also the time when the sun was shining against the wall. The data loggers were started at 1600 hours and stopped at 1645 hours. Data was then transferred for interpretation.

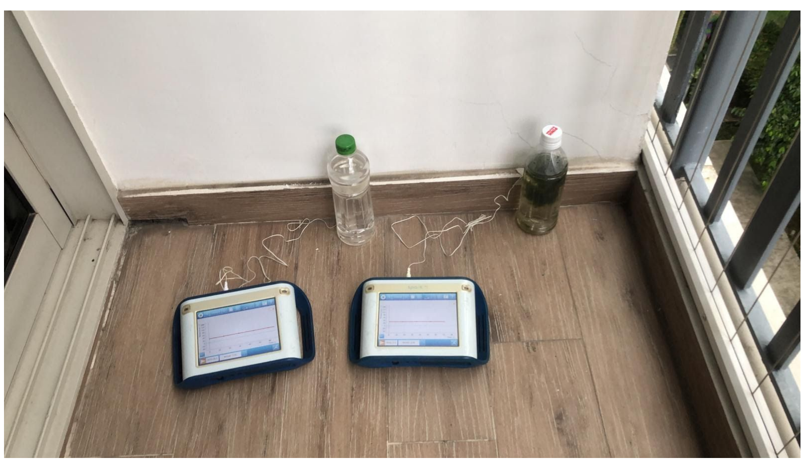

Figure 3.0: Set-up for Experiment 2

<u>5.0 Results</u>

Results were obtained by transferring data out of the data loggers. In experiment 1, it was found that the bottles filled with algae and water were able to reduce the temperature of the wall by a mean of around 2°C for the first 626 seconds. However, after 627 seconds into the experiment, the temperature of the wall without any bottles decreased to below the temperature of the wall behind the bottle with algae and water.

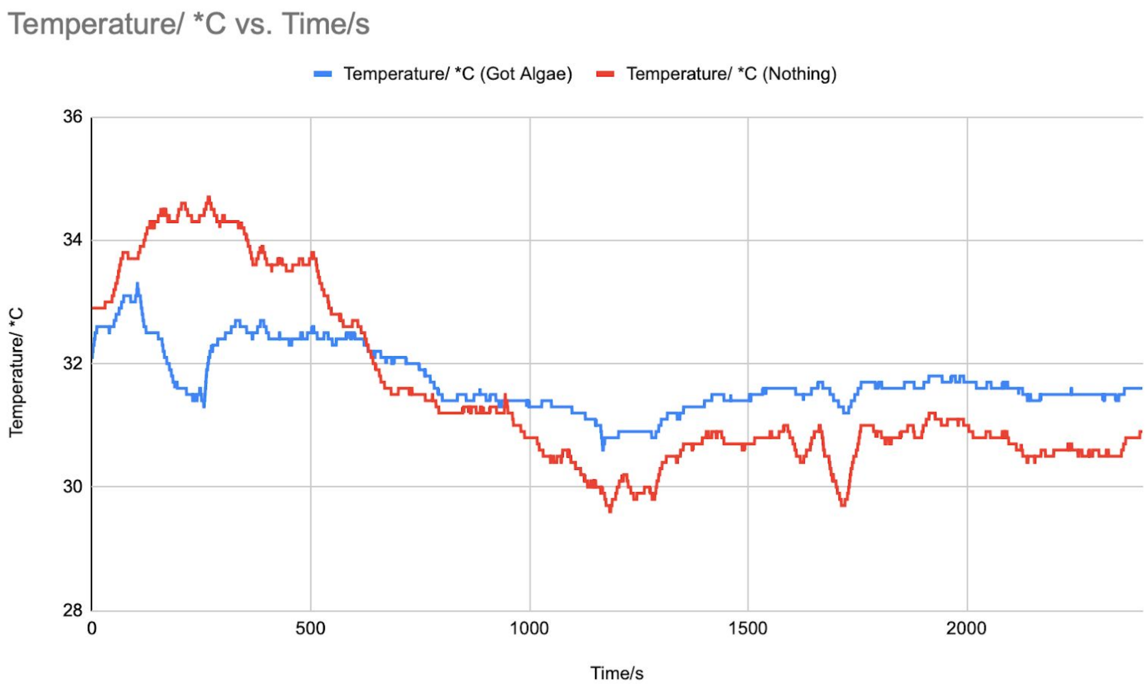

Figure 3.1: Experiment 1 results

In experiment 2, the wall behind the bottle filled with algae and water had a consistently higher temperature than the wall behind the bottle filled with algae only. There was a mean of 0.83°C lower temperature for the wall behind the bottle filled with algae and water as compared to the wall behind the bottle filled with water only. It was assumed that from 289s to 519s, there was an anomaly as the rest of the experimental results were relatively stable as compared to that time period.

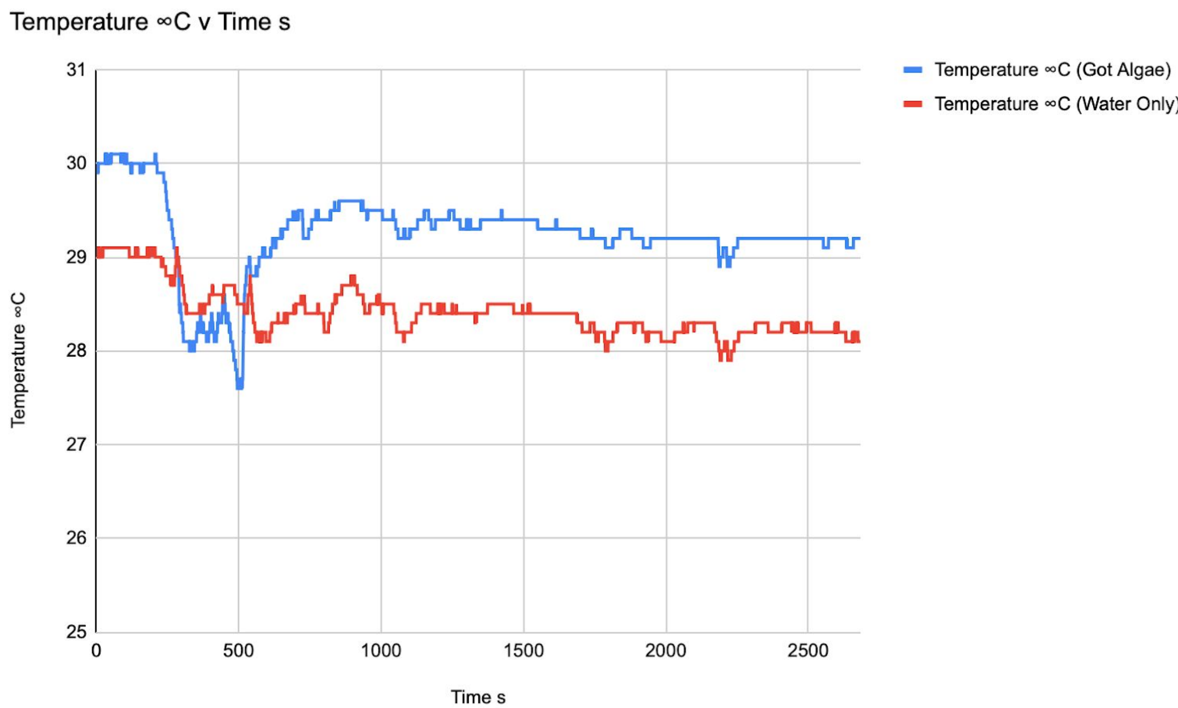

Figure 3.2:Experiment 2 results

5.1 Implications

The results recorded did not match the hypothesis at the start of the experiment. In experiment 1, it was assumed that because the surrounding temperature decreased, the bottle with algae and water lost heat to the wall, causing its temperature to be higher than the wall with no bottles in front. Similarly, in experiment 2, it was assumed that the bottle with the algae and water consistently lost more heat as compared to the bottle with the algae, hence the wall behind the bottle with algae and water consistently had a higher temperature.

5.2 Limitations of the experiment

There are several limitations to this experiment. The temperature recorded was of the wall behind the bottles, instead of the internal temperature of the building with the wall behind the bottles. A rack of bottles, as shown in our solution design, was not constructed and placed in front of the wall. Hence, results will not be very representative of how effective the solution design will be in reducing internal temperatures of buildings. The experiment was also only conducted once, which lacked a large variability of different variables, and failed to account for the myriad of environmental factors that might be caces. So the reliability and accuracy of the experiment will not be very high.

As a result, we look to obtain the bulk of our data from future testings, which would be able to show more comprehensive and conclusive results

6.0 Proposal for Future work

6.1 Solution Design

The solution design can be improved by reducing the amount of resources used when constructing the frame. For example, a solution design which uses wires and strings to hold the bottles in a vertical conveyor belt system can be used instead. However, this proposal also poses challenges of its own as strings and wires also might not have enough tensile strength to carry the bottles of algae and water, hence other changes to the solution can still be proposed and considered.

6.2 Algal Cell Count

Other methods to measure algal cell count can be considered. A Neubauer Hemocytometer can be used to accurately measure the algae cell count in a sample of the mixture of algae and water. The results obtained can be related to the algal cell concentration and which will aid in monitoring the growth of algae. A UV-vis spectrophotometer can also be used to measure the light absorbance of an algae mixture sample. This can also be related to the algal cell concentration and can similarly help in monitoring the growth of algae.

6.3 Testing for Solution Design

The effectiveness of the solution design can be evaluated by conducting experiments and obtaining experimental data. In the proposed experiment, the internal temperature of a building with bottles of algae and water blocking a wall over time can be compared to the internal temperature of a similar building with only bottles of water blocking a wall. If the internal temperature of the building with a wall blocked by the bottles and algae is on average lower than that of the building with only bottles of water blocking a wall, the solution design will be successful. Evaluation of the results can then be related to how effective the solution design is.

During the tests, experimental data like how much algae can be grown in a single bottle can also be collected. This can then be related to how effective algae can be when used as animal feed or as food (i.e. yield vs cost), which will help in future feasibility studies and cost analysis.

6.4 Other solutions

Other forms of our solution design can also be considered. One proposed solution includes having a horizontal green wall design, instead of a vertical one. This horizontal green wall can be placed on relatively flat rooftops, instead of at the walls of buildings. This reduces the problems faced when scaling up, i.e. algae green walls will not have to be scaled up to be very tall. However, a different solution design will have to be implemented in order to maximise the sunlight the algae can receive.

Eventually, the algae growing can be conducted in a monitored environment to try and achieve maximum growth and efficiency. Future research can be done to construct photobioreactors that are more durable and efficient. Less manpower will be needed as algae can be collected at the bottom of the photobioreactors by sedimentation and manpower will only be required to collect the algae that has accumulated at the bottom due to gravity.

7.0 Conclusion

This project has supplied an innovative alternative to both reducing the temperature of buildings and the cultivation of algae. The proposed solution allowed users to harness the benefits of conventional green walls and algal photobioreactors. The proposed solution was made to be easily developed and used for upscaling. The parts used were also relatively inexpensive as recycled materials were used for the construction. As such, the proposed solution aims to be a feasible solution to reducing the temperature of buildings and thus reducing potential energy used by air conditioning. Concurrently, algae can also be cultivated and harvested, and then used for various purposes.

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