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TOPIC:

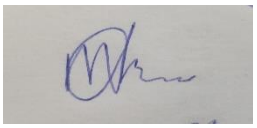
AGRICULTURAL POST-HARVEST SUSTAINABILITY THROUGH THE DEVELOPMENT OF LOW-COST ZERO ENERGY COOLING CHAMBER (ZECC) FOR SMALL HOLDER FARMERS.

SUPERVISOR: Eng. Ever Gongora

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR OF SCIENCE HONOURS DEGREE IN AGRICULTURAL ENGINEERING

DECLARATION

I**, Malvin Nkomo**, declare that this research report is my own work. This project is my original work as a result of my effort except where referenced and indicated. It is being submitted for the degree of Bachelor of Science Honors in Agricultural Engineering at Bindura University of Science Education.

Learner Signature:  **Date:** 22/06/24

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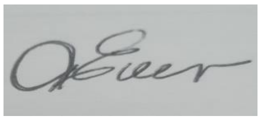
Signature: …

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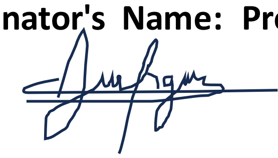
Signature: 

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ABSTRACT

Many low- and middle-income nations, like Zimbabwe, struggle with food security because of substantial post-harvest losses and a lack of sustainable farming techniques. One of the most economic obstacles facing Zimbabwe's marginal farmers, who have very little capital, is post-harvest losses. Highly perishable goods, like tomatoes, are more likely to deteriorate and spoil, particularly while they are in the supply chain. Because of this, they require quick refrigeration following harvest in order to slow down metabolic processes and preserve quality, which will help with supply to the fresh product market.

A primary cause of post-harvest losses during storage, particularly for small-scale and informal sectors, is inadequate storage facilities. In addition, excessive crop exposure to sunshine, inadequate packing, subpar transport containers, insect pest infestation, and microbiological assaults all contribute to these losses. Postharvest losses have an impact on the expansion of the unorganized fruit and vegetable industries as well as income creation.

Finding post-harvest losses to average between 20% and 50% in the time between harvesting and final merchandising is not particularly unexpected. This equates to a massive waste of labor, fertilizer, water, energy, land, seeds, and other planting supplies.

Thus, it becomes necessary to develop a less expensive alternative, known as the Zero Energy Cooling Chamber (ZECC), which makes use of widely accessible and reasonably priced building supplies including water, bricks, straw, sand, and bamboo cement. As the bricks are put flat to create a basis, a raised area will be ready. There will be two brick walls built; the first will be 1.65 meters long by 1.15 meters wide by 0.67 meters high. There will be a gap between the brick walls that is nearly four fingers wide. Sand that is nearly soaked with water will fill the cavity. The chamber will be covered by a 1.65 x 1.15 m bamboo or straw hood that has been matted. Very environmentally friendly, the ZECC is very eco-friendly and it uses the principle of evaporative cooling to increase shelf life.

Perishable goods can be stored using the evaporative cooling method, and fresh agricultural commodities can be temporarily stored on farms using ZECC. Fruits and vegetables can also be pre-cooled using ZECC before being transported. Temperature and relative humidity in the storage chamber have a significant impact on the ripening process of fruits and the quality of the final product, thus they must be maintained at acceptable levels. Under both ambient and regulated circumstances, tomatoes and leaf vegetables were used to assess the cooler's efficacy and performance. Based on the results, the chamber was able to maintain a greater humidity level and reduce the interior temperature, which greatly extended the agricultural produce's shelf life. Small-holder farmers may use this technology to boost profits in the unofficial sector.

Keywords: Post harvest losses, profitability, quality, vegetables, fruits.

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

One of Zimbabwe's most urgent concerns is the storage of perishable horticulture products after harvest. Harvest, storage, grading, transportation, packing, and distribution all take a large toll on Zimbabwe's annual fruit and vegetable crop, which lowers producers' profits. Due to spoiling at different points in the postharvest chain, between 20 and 30 percent of all fruit output is wasted, lowering the amount of fruits and vegetables that are available per capita. Owing to their extreme perishability, over 20–30% of all produce produced—vegetable and fruit—is lost at different points in the post-harvest process. Fruit and vegetable losses are further exacerbated by a lack of adequate cold storage capacity at the farm level and refrigerated storage at the market level (FAO, 2006). Lowering fruit and vegetable postharvest losses in fruit and vegetable operations is a worldwide goal (Clement *et al.,* 2009)

As soon as possible after harvesting, remove the field heat and provide cooling to maximize the fruits' and vegetables' shelf life. Most fruits and vegetables store well at temperatures above their freezing point (FAO, 1995) [17]. Marketing and distribution of horticulture crops depend on proper storage. Additionally, storage maintains a daily equilibrium between supply and demand (Chakraverty et al., 2003) [10]. Using the best post-harvest handling practices throughout storage, transit, and market distribution helps reduce losses. For harvested fruits and vegetables to be stored at the ideal temperature, relative humidity, and atmospheric composition, a variety of methods are available (Chakraverty et al., 2003) [10]. Energy-intensive techniques including air cooling, hydrocooling, vacuum cooling, chilling, ice cooling, freezing, and so on can all be used to manage temperature. Around the world, horticultural crops are stored in refrigerators using a tried-and-true method called chilled storage (Chaudhary, 2004 and Sunmonu et al., 2014) [12, 53].

However, mechanical refrigeration is costly and energy-intensive. It takes a large initial investment, is difficult to build fast, requires a continuous supply of electricity, has high operating costs, cannot be built in isolated areas, and is not environmentally friendly. In many tropical and sub-tropical countries, where refrigeration is most necessary, this approach is not frequently employed for these reasons (Kumar and Nath, 1993; Thakral et al., 2000; Kumar et al., 2003

Adamu et al, 2006 Nitipong and Sukum, 2011) [1, 27, 28, 32, 54]. Small farmers, merchants, and wholesalers cannot afford to use this strategy either (Samira et al., 2013). Furthermore, Basediya et al. (2013) state that it is unsuitable for on-farm storage in rural locations. Furthermore, a number of tropical fruits and vegetables, such as oranges, tomatoes, and bananas, leafy vegetables, etc., lose color and suffer chilling damage when kept in the refrigerator (Adebisi et al., 2009 Liberty et al., 2013). [2, 29]. Global warming and ozone layer depletion are partially caused by the use of hydrochlorofluorocarbon (HCFC) and chlorofluorocarbon (CFC) refrigerants in refrigeration systems (Xuan et al., 2012) [56]. Due to these factors, its usage has been more restricted.

An alternative to a mechanical refrigeration system is an evaporative cooling storage structure (Nitipong and Sukum, 2011) [32]. The process by which a substance's temperature is lowered as a result of water evaporating is known as evaporative cooling. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as water evaporated provide useful cooling. This is the most cost-effective method of raising the air's humidity and lowering the temperature. It is more ecologically friendly than refrigeration systems since it uses less CO_2 and doesn't require refrigerant. Since there isn't a moving portion, it doesn't produce noise. It conserves energy because it doesn't require power. It doesn't need a large upfront investment or ongoing maintenance and design costs. In isolated locations, it may be built using locally accessible materials, and most significantly, since it doesn't require chlorofluorocarbons, it is environmentally beneficial. Vegetables shrink and wilt as their moisture evaporates, which leads to weight loss. Vegetables may be kept fresher for longer by using evaporative cooling, which is an adiabatic heat exchange process wherein ambient air is forced through a saturated surface to produce low temperatures and high humidity.

Using contemporary storage methods is essential to preventing fresh vegetable waste. In underdeveloped nations, fruit and vegetable post-harvest losses are particularly severe. Postharvest losses in handling, storing, and processing are often significant in underdeveloped nations due to inadequate facilities and a general lack of awareness about how to properly care for the fruits and vegetables. Fruit post-harvest loss is dependent on the particular marketing channel being evaluated, which takes into account factors such crop marketing time (delays in marketing) and market distance (Lisa and Adel, 2015).

Therefore, it is imperative to build low-cost, environmentally friendly, and user-friendly storage facilities like the Zero Energy Cooling Chamber (ZECC), which can run power, in order to address the post-harvest losses of fruits and vegetables among small holder farmers. This chamber operates on the basis of evaporative cooling and makes use of readily accessible materials that farmers may harvest for free, such as brick, sand, and bamboo. The ambient temperature is higher than the temperatures within these chambers. At the farmer's field, these cooling chambers can be utilized to store agricultural products temporarily. In order to minimize postharvest losses in extremely perishable horticultural goods, on-farm storage is also necessary. To address this issue, low-cost, low-energy, ecologically friendly cool chambers based on evaporative cooling principles and constructed from locally accessible materials will be created. Depending on the season, this cooling chamber can maintain temperatures between 100°C and 15°C below ambient and a relative humidity of around 85%. Fruits and vegetables can be kept in the chamber in wooden or plastic boxes. Fruits and vegetables stored in the cold chamber will have a 20-day shelf life instead of just three days at room temperature. The length of storage depends on several factors. Variety, maturity stage, rate of chilling, storage temperature, relative humidity, rate of CO_2 buildup, pre-packing, and air dispersion are a few of these.

1.2 Problem Statement

Postharvest losses are a serious challenge for the agricultural industry, especially the small-scale sector in the rural areas. Lack of reliable and efficient storage systems leads to accelerated spoilage and deterioration of agricultural commodities, resulting in substantial economic losses hence less profit for the farmers. Some of the challenges lack of knowledge in food handling, poor harvesting techniques, poor transportation system, distances to the markets and improper storage during marketing. Currently there is a rise in use of solar cooling systems as a renewable energy solution to the problem but these systems did not get much popularity among small scale farmers because they require high initials costs to set up and they can be stolen easily in rural area. Conventional cooling systems are usually very expensive to run and maintain and are not the best option for these farmers. Traditional cooling systems rely heavily on electricity which is not available in most rural areas and they significantly strain the grid. The traditional cooling systems significantly contribute to carbon emissions which are an environmental hazard.

1.3 Research question

What is the most cost-effective solution that does not require energy, which minimize post-harvest-losses, improve shelf life and quality of agricultural produce?

1.4 General Objectives

Construct a zero-energy cooling chamber focused on mitigating postharvest losses of fresh agricultural commodities and increasing profits for small scale farmers in rural areas. This project focuses on developing a cost-effective and energy-efficient cooling chamber that minimizes postharvest losses, improves the shelf life and quality of fresh agricultural commodities, and ultimately enables small-scale farmers to increase their profitability and contribute to sustainable agricultural practices.

1.5 Specific Objectives

- To design a zero-energy cooling chamber
- To construct a cost-effective cooling system for small holder farmers
- To enhance profitability of small holder farmers by increasing shelf life and quality of their agricultural commodities
- Performance evaluation of the evaporative cooling system in maintaining quality of produce

1.6 Hypothesis

- The designed cooling chamber will create a controlled environment with optimal temperature, humidity, which are crucial for maintaining quality and extending shelf life of produce
- The cooler will prioritize energy efficient techniques, minimizing or eliminating external energy sources
- The cooling chamber will be affordable and easy to construct by small scale farmers, taking into account their limited financial resources and capabilities.

- The cooler can be easily replicated, scaled up and adapted to many climates and geographical regions, making it feasible for a wide range of small-scale farming contexts.

1.7 Limitations

- The cooler may not be as effective in extreme climates or areas with high humidity, limiting their applicability and effectiveness.
- There may be limitations in scaling up thee the cooling chamber across various sizes of farms or adapting it to different crops and produce types.
- Depends on the willingness and acceptance of local farmers to adopt new technologies and practices. Resistance to change or lack of awareness could limit its widespread adoption.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

For emerging nations to experience reduced poverty and ensure food security, small-scale farmers' sustainability is essential. The largest issue that farmers deal with is the post-harvest losses of perishable crops as a result of inadequate refrigeration and storage facilities. Many technologies, such as cold rooms and refrigerators, are available on the market to effectively cool, decrease post-harvest losses, and extend the shelf life of fresh agricultural products. However, the majority of these techniques require high-energy sources, such as refrigeration, which are not readily available or reasonably priced for local farmers. However, as local farmers cannot store the extremely perishable food for an extended amount of time, it suggests that farmers would constantly have to sell at a lower price. This is because these facilities are not available to them. The development of an economical zero-energy cooling chamber is necessary to provide small-scale farmers a sustainable and cost-effective alternative, as this has serious consequences for their revenue and might lead to a quick drop in their welfare.

2.2 Background and context

Losses incurred after harvest up until the point at which the produce is consumed are referred to as post-harvest losses. Both quantitative and qualitative losses may occur. Losses after harvest are more excruciating and expensive in terms of labor and money than losses before harvest. Vegetables have about 80–90% moisture content, making them extremely perishable. Since they are living commodities, they will continue to breathe and transpire even after harvest. Water and photosynthates are given to the fruit when it is affixed to the parent plant. However, losses are not made up for during the post-harvest phase, thus the fruit perishes quickly since it is dependent on its own food supply and moisture content. Transpiration causes the product to lose water, while respiration depletes the food store. Vegetable quality is greatly impacted by transpiration, or water loss. Loss of water can impact quality in a variety of ways, such as wilting, shrivelling, flaccidity, soft texture, and loss of nutritional content, in addition to lowering saleable weight (Nath A.et al, 2018).

Each product will have a different rate of water loss and a different effect from it. Cooling items, keeping the storage environment's relative humidity high, managing air flow, and, when allowed, using plastic film or surface coatings can all help to minimize water loss (Chris and Jacqueline, 2012). Common storage refers to the techniques utilized to preserve the majority of the product produced by our predecessors. This entails keeping harvested vegetables cold and dark. This may be accomplished in a number of methods, such as burying the produce in trenches in the ground, leaving it in the ground, keeping it in cellars or basements, or storing it in wooden boxes or barrels kept in cold places like a garage. Pits, earthen pots, and underground storage are a few examples of conventional fruit and vegetable storage methods. Because soil temperatures are constant and remain lower than air temperatures, burial under the earth permits the creation of a controlled atmosphere. Pits, however, need to be kept free of vermin and properly drained. (2020, William).

According to Saraswathy et al. (2010), post-harvest technologies aim to preserve the fresh quality of produce by enhancing its look, texture, flavor, and nutritional content. They also safeguard product, uphold food safety, and minimize average losses that occur between harvest and consumption. A horticultural produce's quality will often decline in direct proportion to the length of time it is exposed to any unfavorable conditions (Leblanc and Vigneault, 2008). Research on the physiological changes in produce, storage structures, varieties with longer shelf lives, appropriate cultivation techniques, ideal harvest indices, storage environment recommendations, pre-cooling, refrigeration, transportation strategies, and enhanced handling techniques have all contributed to minimizing post-harvest losses. Harvest is a crucial stage in every commercial fruit and vegetable operation as it marks the beginning of the post-harvest management procedure. The post-harvest food chain has so many different reasons for losses that it is helpful to divide them into a variety of subgroups. These include microbiological, physiological, mechanical, physical, and biochemical. In Adekalu (2014).

According to Atanda S.A. et al. (2011), secondary causes of loss are those that contribute to circumstances that support a primary cause of loss. Usually, insufficient or ineffective capital expenditures, technology, and quality control are the cause of them. Inadequate harvesting, packaging, and handling abilities; a lack of suitable containers for the handling and transportation of perishables; inadequate refrigeration facilities; inadequate transportation to get food to markets before it spoils; inadequate drying equipment or an unfavorable drying season; conventional processing and marketing systems; and bumper crops, which can overwhelm the post-harvest handling system or exceed the need for consumption and result in excessive waste.

2.3 Postharvest factors

Produce that has been harvested has live tissues, therefore changes can occur even after harvest. While such changes are unavoidable, they can be managed within specified bounds by employing a variety of postharvest techniques. The following post-harvest variables might impact the quality of harvested produce:

2.3.1 Temperature:

The most crucial factor in preserving the quality and extending the shelf life of harvested vegetables is temperature. Intervals between harvesting and chilling or processing can cause indirect losses like off-flavor and degradation in nutritional content, as well as direct losses like water loss and decomposition. For example, the variety of citrus fruit affected the temperature range and the amount of vitamin C lost. Ascorbic acid (AA) levels often decreased more in veggies than in acidic fruits like citrus when exposed to higher temperatures. In acidic environments, ascorbic acid is more stable. Every 10oC increase in temperature causes the rate of spoiling to increase by two or three times. After harvest, temperature management is crucial to keep unwanted bacteria from growing and preserve the freshness of the goods. Insufficient temperature can hasten the ripening and deterioration of fruits and vegetables, diminishing their nutritional worth and shelf life. Furthermore, keeping perishable goods at the right temperature is essential to halting the growth of harmful microorganisms.

2.3.2 Ethylene management*:*

The two-carbon, odorless, and colorless natural plant hormone ethylene (C_2H_4) is released when climacteric fruits reach maturity. It is also referred to as the "natural ageing, death, or ripening hormone." It accumulates over time and can cause fruit deterioration and waste when harvested product is in the postharvest stage. It is active in trace amounts. Numerous physiological processes related to plant growth, germination, development, ripening, maturity, and senescence are governed by it. Additionally, it is crucial for the abscission of plant organs. A number of crop management techniques, pre-harvest and postharvest factor coordination, and plant breeding techniques have been studied in order to better understand the physiological and biochemical processes involved in ethylene regulation, increase the shelf life of harvested produce, and enhance the quality of the harvested product after harvest. Certain fruits may either create or absorb ethylene. Broccoli, cabbage, and cauliflower are ethylene sensitive, whereas fruits like apples, bananas, melons, pears, and peaches generate ethylene.

Within non-climacteric crops, ethylene has little effect on respiration rate. Watermelon, strawberries, grapes, and green vegetables are a few examples of non-climacteric produce. Crops that are not climacteric will not release ethylene gas during ripening. Ethylene exposure will hasten the commencement of an irreversible increase in respiration rate and quick ripening of climacteric fruits. Fruits can have a longer shelf life and avoid climacteric by using appropriate packaging, which lowers ethylene production and sensitivity. Produce type affects ethylene production rates, which rise with harvest maturity, physical damage, disease incidence, temperatures up to 30°C, and water stress.

2.3.3 Chemical Treatments:

Apples and cherries can be kept firm and physiological abnormalities reduced by using calcium dips. Increased vitamin C retention and less color change after storage were seen in dehydrated pineapples and guava that had been pre-treated with cysteine hydrochloride.

2.3.4 Irradiation:

Ionizing radiation can be applied to prevent sprouting, manage insects, or postpone the maturity of specific fruits and vegetables. Regardless of storage temperature, horticultural crops exposed to very modest doses of 75–100 krad of radiation permanently impeded the sprouting of potatoes. When potatoes were irradiated for sprout control and then kept at 15°C, there was less vitamin C loss than when non-irradiated tubers were stored at 2-4°C.

2.3.5 Respiration:

Harvested produce's respiration rate affects its metabolic processes. create that has been harvested may create CO_2 and respire at a faster rate under high temperatures. Depending on other variables like O_2 or CO_2 levels, exposure duration, and ripening stage, CO_2 generation in stored climacteric items like tomatoes might initiate ethylene synthesis. An adequate amount of air is necessary for respiration. About 20% of the oxygen needed for a plant's regular respiration—which turns carbohydrates and starches into carbon dioxide and water vapor—is found in the air. When supplies of starch or sugar are depleted, respiration stops, causing the product to age and eventually rot. Fermentation takes place in place of respiration when the air supply is constrained and the environment's oxygen content drops to 2% or less. Sugars undergo fermentation to produce carbon dioxide and alcohol, and the alcohol that is created taints product and accelerates the aging process

2.3.6 Relative Humidity:

Relative humidity, a measure of how much moisture is in the air, is what mostly causes moisture loss from harvested vegetables. At extremely high relative humidity, harvested fruits and vegetables retain their nutritional value, aesthetic appeal, weight, and flavor. Fruits that have been harvested shrivel with minimal moisture loss. Relative humidity levels between 85 and 95% (v/v) for mature green tomatoes and 90 to 95% (v/v) for firmer ripe fruits are ideal for preserving the quality of these crops. Overly damp conditions might encourage the growth of mold and fungus. Maintaining the freshness and aesthetic appeal of fresh food requires maintaining the proper humidity levels in the storage and transportation environments. Produce retains its marketable weight, look, nutritional value, and flavor at high relative humidity levels, however wilting, softening, and juiciness are reduced. Only a tiny percentage of the entire amount of water vapor that the air can contain is held when the relative humidity is low, even if the air can still absorb more moisture. Transpiration rates are increased by low relative humidity. On the other hand, poor water evaporation rates result in low cooling when relative humidity is high (Odesola & Onyebuchi 2009). Reducing water loss in harvested food by maintaining high humidity levels minimizes the risk of poor quality (shrivelling, wilting), as well as loss of marketable weight. Because humidity and warmth, or high temperate conditions, together promote the growth of fungus and bacteria, high humidity should be employed in conjunction with low temperature storage.

2.3.7 Physical Handling:

product handling from the point of separation from the parent plant, packaging from the farm gate to the market, and finally eating the product are all closely linked to mechanical injuries such cuts, scuffs, bruises, and punctures. negligent handling, the use of improper harvesting containers, unsuitable trucks, negligent loading and unloading, and poor packing materials can all contribute to some of these mechanical injuries. Miller claims that these mechanical injuries have cumulative effects that result in a complete disintegration of the cell structure and undesired metabolic processes like accelerated respiration rates, ripening, and increased ethylene production, which either shorten the shelf life or degrade the quality of the product. Therefore, it's critical to treat harvested product carefully both during and after harvest. It is, therefore, important to handle harvested produce with care during harvest and postharvest activities to minimise mechanical injuries to avoid losses.

2.3.8 Gases:

To increase the shelf life of harvested product, the composition of gases in a storage environment is crucial. A very low oxygen supply is the ideal environmental condition needed to prevent senescence in mature harvested product. Since carbon monoxide (CO) has been studied as a gas to accelerate ripening, low oxygen levels must be balanced with carbon monoxide to prevent senescence in harvested food. Carbon dioxide and oxygen may be managed with the use of technologies such as MAP modified atmosphere packaging and CAP controlled atmosphere packaging.

2.4 Traditional storage methods

These are methods that have been around for a long time ago and are passed down from generation to generation. They make use of natural materials and simple techniques.

2.4.1 Natural ventilation storage

This is the simplest of the many different types of storage systems. It uses the ambient airflow to its advantage to eliminate moisture and heat produced by breathing. Structures with holes for ventilation and some sort of external environment protection can be employed. Produce can be arranged on pallets, bins, bags, boxes, and other containers. Say, shallot and onion.

Figure 1: (Kale et al., 2016) below shows onions being dried using natural ventilation

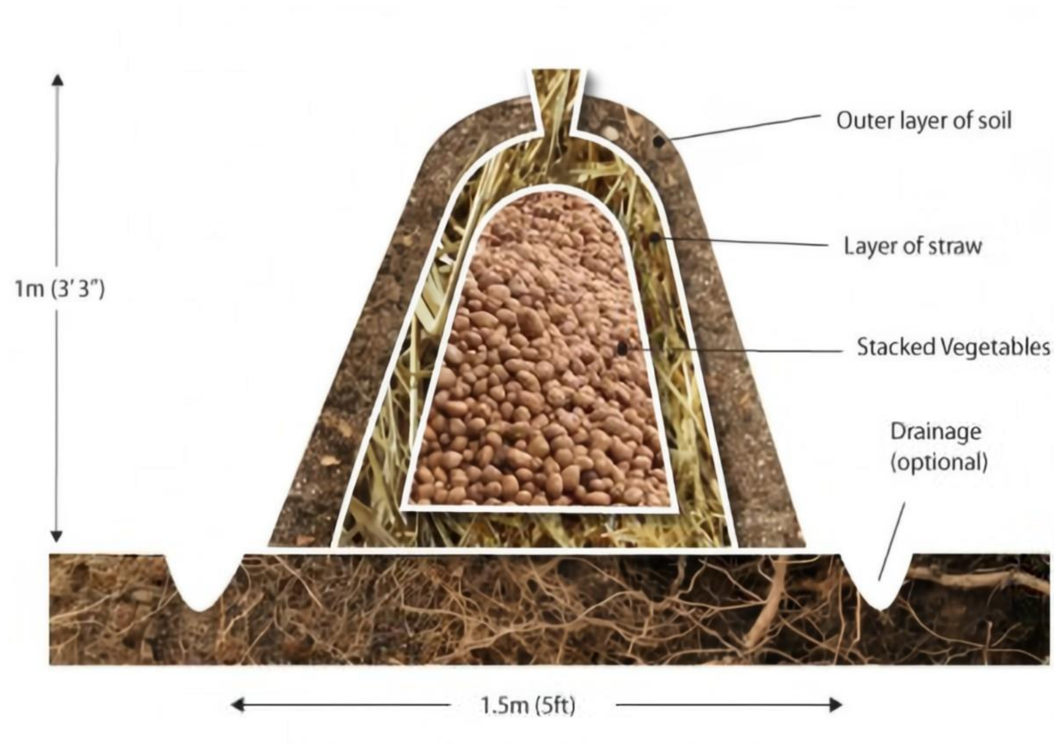
2.4.2 Field storage

This is great for root, tuber (onions), and rhizome crops including carrots, potatoes, cassava, and ginger. It entails keeping the produce in the soil until it is needed for consumption or marketing.

2.4.3 Clamps storage

This entails piling the vegetables over a layer of leaves or straw, covering it again with leaves or straw, and then filling the entire pit with dirt. Produce doesn't dry out because of the insulated, wet atmosphere this produces.

Figure 2: (adapted from Kale et al, 2016) below shows carrots and beets under clamp storage



2.4.4 Sand storage

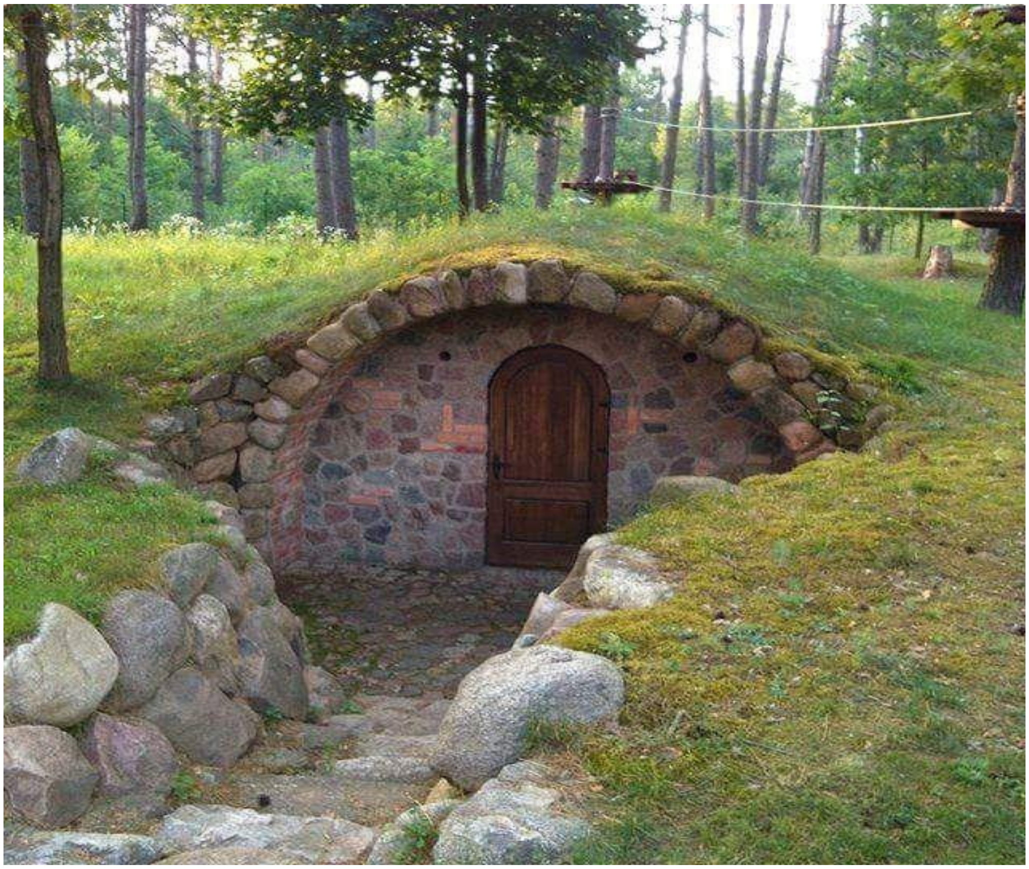
This entails packing fruit inside crates, barrels, or buckets filled with damp sand layers. In order to keep the product from shrivelling or decomposing, the sand offers moisture and insulation. This works well with root crops including parsnips, turnips, beets, and carrots.

Figure 3: (by Jaspreet Kaur, 2016) below shows carrots under sand storage

2.4.5 Root cellars

These buildings, which can be made of stone, wood, concrete, or metal, offer a cool, dark place to store fruits and vegetables. They can even be partially or fully underground. They can also be altered from pre-existing constructions like caves, wells, and basements.

Figure 4: (from Afthab Saeed., 2021) is an example of a cave turned into a root cellar.



2.5 Modern storage methods and techniques to increase shelf life

2.5.1 Cold storage

Cold storage is widely acknowledged as the most effective strategy for maintaining freshness in fruits and vegetables and can be seen as the primary physical means of preventing or delaying biotic and abiotic disorders. While low temperature storage is obviously not an antifungal therapy, its effects can lessen cause weakness, which affects the infection and the host at the same time. In fact, there are two ways that low temperature works:

(a) Indirectly by slowing the host's metabolism, which delays senescence and helps to maintain fruit resistance to fungal infection

(b) Directly by preventing or postponing the pathogens' growth and enzymatic activity.

Furthermore, compared to fruit stored in low moisture environments, low temperature minimizes moisture loss from the host tissues and the ensuing shrivelling, allowing tissues to retain a high level of resistance to infections.

The only commonly used technique for managing perishables in large quantities between manufacturing and marketing processing is cold storage. It is one way to preserve perishable goods in their freshest, unaltered states for an extended amount of time by managing the humidity and temperature inside the storage system. It is important to maintain a sufficiently low temperature to prevent chilling harm to product. Additionally, the majority of perishables should be maintained in the storeroom at a relative humidity of 80–90%; anything lower or higher would negatively impact the produce's ability to preserve its quality. If stored at typical harvesting conditions, the majority of fruits and vegetables have a very short shelf life after harvest. Field heat is quickly removed by postharvest chilling, extending storage times. Market the produce right away after harvesting is not essential if refrigeration and storage facilities are available. Farmers who supply grocery shops and restaurants, as well as small farmers who wish to put together truckload quantities for shipping, may find this advantageous. In order to provide consumers with product of the best quality possible, postharvest chilling is necessary.

2.5.2 Controlled atmosphere storage

Fruit and vegetable quality and freshness are preserved in Controlled Atmosphere (CA) environments without the use of chemicals. Many items can be preserved for two to four times longer than normal under CA conditions. A technique called CA storage is used to store product in an environment with CO2 and O2 concentrations significantly different from that of regular air. The term "controlled atmosphere storage" describes the ongoing monitoring and regulating of the O2 and CO2 concentrations in gas-tight containers or depots.

Due to gas leakage via doors and walls and the metabolic activity of the respiring fruits and vegetables in the store, the gas composition will continually vary. As a result, the gases are monitored on a regular basis and adjusted to the target level by adding nitrogen or fresh air, or by treating the store environment with a chemical to eliminate CO_2. Several forms of controlled atmosphere storage exist, mostly based on how much or how little the gases are regulated.

2.5.3 Hypobaric and hyperbaric

A brief hypobaric therapy is administered, with an absolute pressure range of 0 to 100 kPa. In fact, its function is different from that of hypobaric storage at low pressure, which is used to kill quarantine insects in transhipped loads of imported and exported commodities, delay the ripening of fruits and vegetables, and lessen the fading of cut flowers over the entirety of the storage time. Short treatments with pressures marginally higher than atmospheric are also used, similar to hypobaric therapy, to manage postharvest illnesses in fresh produce.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

It is very important to concentrate on the design and analysis of the zero-energy cooling chamber for small holder farmers for various reasons. To make sure the system is successful, efficient, it is crucial to design and analyse it. This chapter describes the design and fabrication of the zero-energy cooling chamber (ZECC) for storage of fresh agricultural produce. It also outlines the materials used in construction and the objective and subjective methods used or tests. The objective of this study is to evaluate the non-electric cooling and storage technology for suitability to improve the postharvest storage of fruits and vegetables in Zimbabwe using a combination of electronic sensors to monitor the performance of the evaporative cooling devices and measurements of fruit and vegetable shelf life stored in evaporative cooling devices compared to storage in ambient conditions

3.2 Site selection

The cooling chamber must be installed where there is proper shading do prevent it from direct sunlight during the day which affect efficiency. The site also needs to have free air circulation. The site needs to be close to a water source which is needed by the cooling chamber.

3.3 Material Selection

Some of the factors that need to be considered when selecting material for the zero-energy cooling chamber are:

- Availability: the materials have to be easily accessible and locally available
- Cost: The materials should be affordable to the small scale farmers which have limited resources
- Permeability: The materials selected has to be permeable to water for the cooler to be effective

3.4 Design considerations

In order to increase the efficiency of the cooling chamber we must use clay bricks which have moderate water absorption (5-15 %), good compressive strength (10-15 MPa) and low thermal conductivity of 0.5 to 1.0 W (m/k) making those good thermal insulators. They are also durable, fire-resistant, and have good thermal mass. Face bricks and ceramic bricks may be stronger but are not suitable as they do not allow water to evaporate through the walls. The cover of the chamber must not be solid wood. Solid wood can be good for security reasons but it does not absorb water, therefore it is not an effective material for evaporative cooling. There is need for shading to protect the chamber from sunlight and farmers can make use of natural shading like under trees.

3.5 Construction of evaporative cooling storage structure

An upland area having a nearby source of water supply is ideal for the construction of the cooling chamber measuring 60cm x 60cm. The double-wall was erected to a height of 60 cm leaving a cavity of 6 cm. The chamber was drenched with water and soaked the fine riverbed sand with water. The 6 cm cavity between the double walls was filled with this wet sand and with a mixture of clay. A frame of the top cover was made with bamboo (60cm × 60 cm) frame and straw or dry grass etc. Make attached/ shed over the chamber to protect it from direct sun or rain. The cavity, brick walls, and top cover of the chamber were kept wet with water. Watering was done twice daily to achieve the desired temperature and relative humidity. The fruits were stored in this chamber by keeping in perforated plastic crates and these crates were covered with a thin polyethylene sheet.

Figure 5: below shows drawings of the ZECC, (plan and side view).

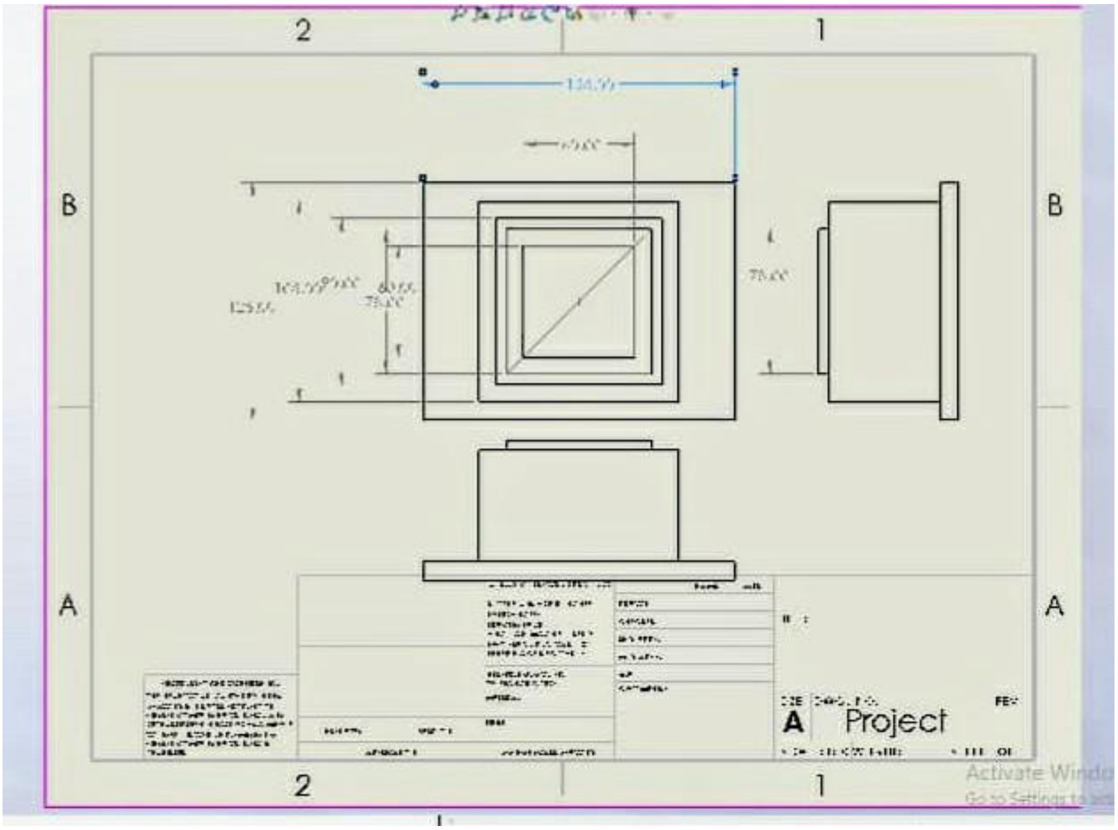


Figure 6: shows a top view of the 3D representation of the ZECC.

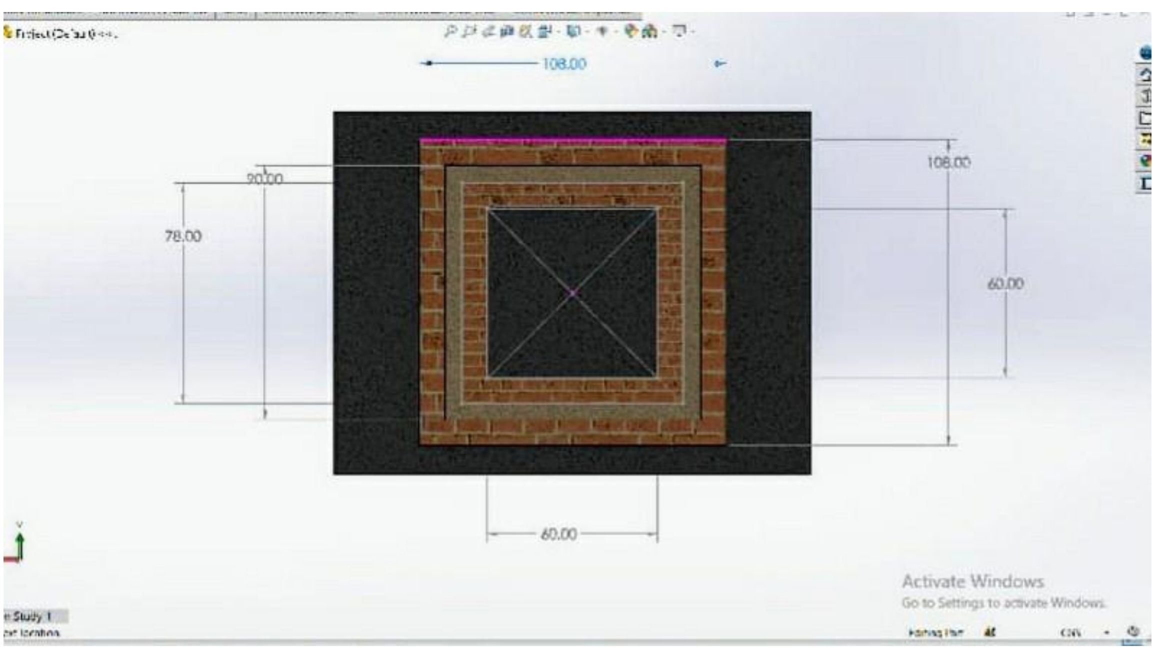


Figure 7: shows a side view of the 3D representation of the ZECC.

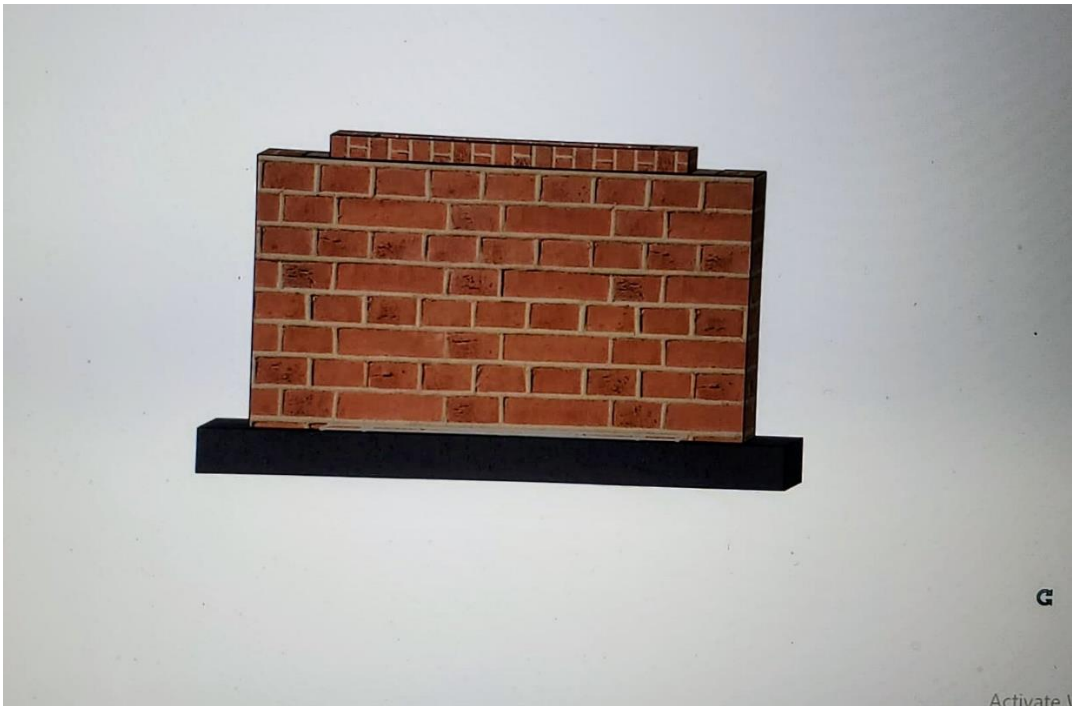
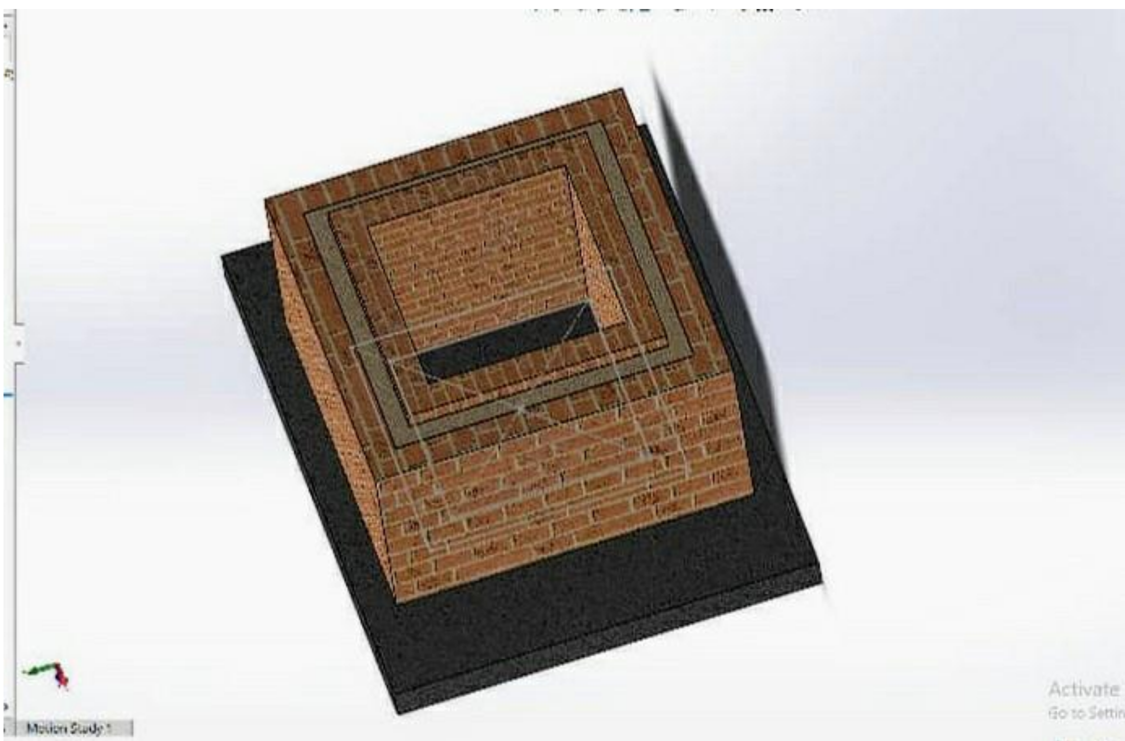


Figure 8: shows an isometric projection of the 3D representation of the ZECC.



3.4. Materials used in construction

Figure 9: showing a table of bill of quantities

Table 1 Bill of quantities

Bricks	250
clay	1 wheel burrow
Sensors	2
Sand	7 wheel burrows
Straw	5kg
Labour	

3.4.1 The chamber walls

The double walls of the cooling chamber were made of brick without mortar for maximum permeability of water. A mixture of clay and river sand was used as mortar. The cavity between the bricks was filled with river bed sand which was later soaked with water. The inside walls are measuring (60cm x 60cm x 60cm). The cavity between the walls is 6cm wide which is filled with wet sand.

3.4.2 The lid

The lid is made with bamboo, straw and dry grass which can absorb water at the same time allowing free air circulation.

3.4.3 The storage structure

The fruits were kept in plastic baskets to avoid the absorption of moisture by the container. Fruits weighed and placed in the plastic crates. Some fruits were stored inside the evaporative cooling storage structure and others at ambient storage conditions.

3.4.4 Storage capacity

To determine the quantity of products to store inside the ZECC we need to consider factors like product density, cooling capacity, product cooling requirements and loading factor (e.g., 0.7 to 0.8) to account for empty space, shelving and other product arrangement.

Below is a simplified formula to estimate the cooling load of a product:

For example;

Given values:

m = 1000 kg (weight of tomatoes)

Cp = 3.9 kJ/kg˚C (specific heat capacity of tomatoes)

-

AT = 20°C – 10°C = 10°C (temperature difference)

t = 2 hours x 3600 s/hour = 7200 s (time)

n = 0.8 (cooling efficiency)

Now, let's calculate Q:

Q = (1000 kg x 3.9 kJ/kg˚C × 10°C) / (7200 s x 0.8)

= (39,000 kJ) / (5760 s)

= 6.77 kw

To estimate the transmission load of the cooler we use the formula below:

Q = L x A x (Outside Temperature - Inside Ⓑ Temperature) x 24 % 1000

Where:

· *Q = Transmission load (in kW)*

· *L = Thermal conductivity of the material (in W/mK)*

· *A = Surface area of the wall, floor, or ceiling (in m^2)*

· *Outside Temperature = Temperature outside the chamber (in °C)*

· *Inside Temperature = Temperature inside the chamber (in ˚C)*

***For example, let's say**:*

· *L = 0,5 W/mK (thermal conductivity of the insulation material, in this case bricks)*

· *$A = 100\ m^2$ (Surface area of the wall)*

· *Outside Temperature = 30°C*

· *Inside Temperature = 10°C*

***Then**:*

$Q = 0,05 \times 100 \times (30 - 10) \times 24 \pm 1000$

$= 0,05 \times 100 \times 20 \times 24 / 1000$

$= 2400 / 1000$

$= 2.4\ kW$

3.5 Performance Evaluation of Cooler

3.5.1 Measurements of temperature, relative humidity and watering

The temperatures and relative humidity of both the cooler and ambient were environment were simultaneously measured by using a digital thermometer which doubles as a hygrometer. One was placed inside to measure inside temperature and another was used to measure outside temperature. The temperature readings of the cooler and ambient conditions were measured and compared to see the effectiveness of the cooler. The products inside and outside the cooler were analysed subjectively and objectively to see the performance of the cooler. To further evaluate the performance of the cooler we created different conditions for the cooler, (e.g. testing the cooler without adding water or varying the quantities of water added to it and varying the ventilation levels).

A no-load test of the system was conducted to see the effect of the evaporation that is expected to take place whether the process is effective or not in order to determine its efficiency before being loaded with the vegetables that will be stored. This was achieved by taken temperature difference and the relative humidity of the system relative to the ambient condition. The cooling capacity of the direct evaporative cooler was calculated as presented in equation:

Cooling efficiency; $\eta = (TDBa - TDBc)/(TDBa - TWBa) \times 100$

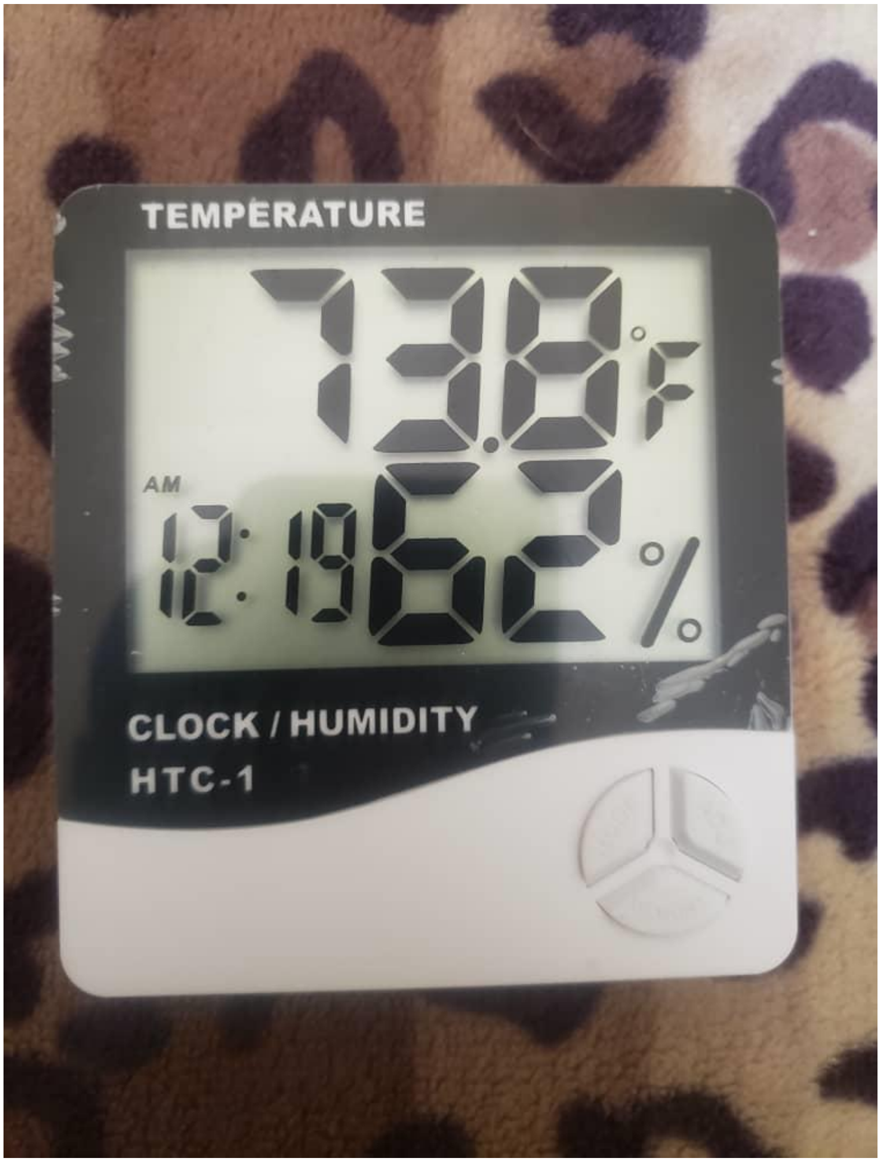


Figure 10: above showing the double acting temperature and humidity sensor.

3.6 Quality tests of vegetables stored in cooling chamber

3.6.1 Color Changes and Firmness

The tomatoes in the cooler were monitored for 2 weeks and the color was assessed using the chart below. The changes in color of the tomatoes were noted both in the cooler and in the ambient condition in conjunction with the physiological weight loss. The color changes observed was based on the physical appearance of the vegetable (Fabiyi, 2010). The physical texture of the tomatoes was examined and noted. The difference in the firmness was also noted after storing the vegetables in the evaporative cooling system and in ambient condition.

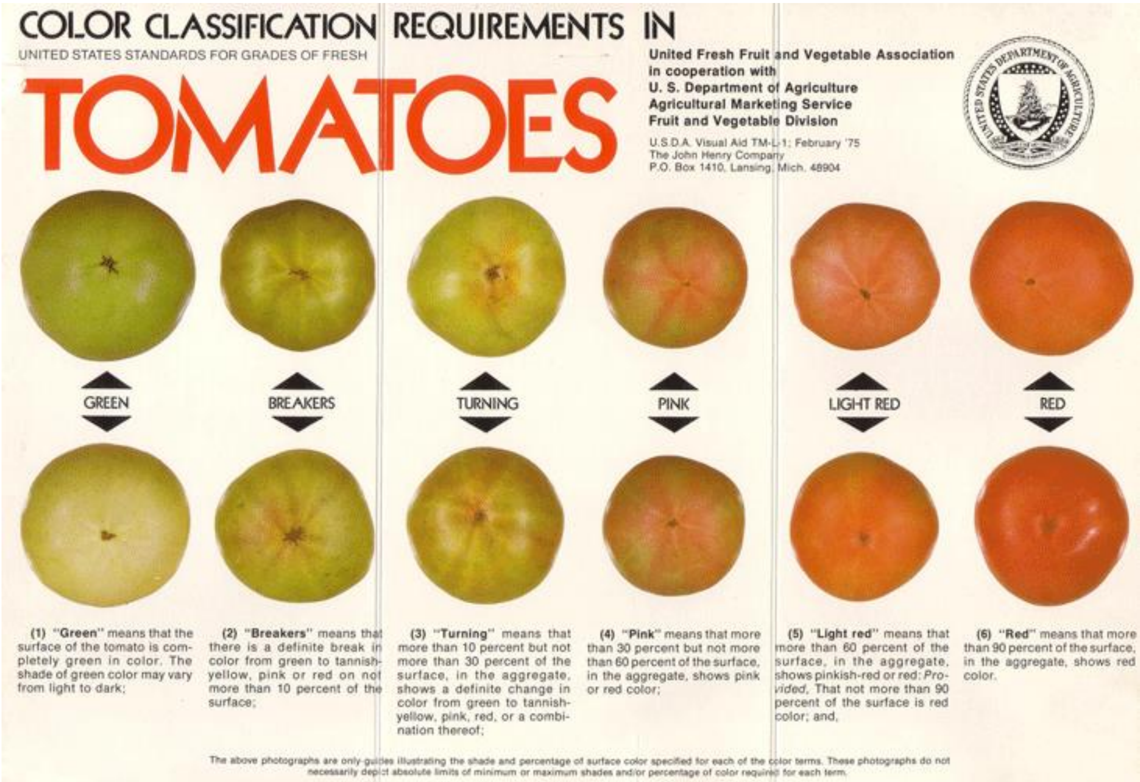


Figure 11: The USDA chart: Source-(Batu, 2004)

3.6.2 Fruit and vegetable shelf life methodology

Measurement of fruit and vegetable shelf life was conducted for a variety of fresh produce in the evaporative cooling device in this study. Fruits and vegetables that were recently harvested before being fully ripe were purchased weighed at the start of the experiment, then placed in the evaporative cooling device and in a container at room conditions. The fresh produce (tomatoes, mangoes, carrots) was weighed and visually inspected for evidence of fungal growth, rot, dehydration, bruising, discoloration, or other signs of deterioration every 2 – 3 days. The fresh produce was left in the chamber until signs of deterioration were observed, or the fruits and vegetables were determined to be fully ripe through visual inspection. The crops chosen are those susceptible to high losses and are grown in the different experiment sites.

3.6.3 Physiological Weight Loss (%) Determination

The weight loss of fruits was determined by weighing each sample with an electronic balance with an accuracy of 0.5 g, from the evaporative cooling storage structure and fromambient storage. Any fruits that showed signs of decay were recorded and removed from the sample under study. As deterioration indicators, general cracks, bruise spots, over softening, and mold growth were used. Cumulative percent loss was determined until citrus fruits become pulpy, or their freshness was lost.

3.6.4 Titratable Acidity (TA)

According to OECD guidelines (2003), TA was estimated by titration of tomato juice extracted during TSS with 0.1 M NaOH. A clean and dry 10 ml pipette was used to draw 5 ml of juice and discharge into a 250 ml beaker. 25 ml of distilled water were drawn using another clean pipette and added to juice in the beaker. Three drops of phenolphthalein were added in this juice/water solution with a dropping pipette. A funnel was used to pour 0.1M NaOH into a burette until it reached a zero mark whilst ensuring that the tap was shut. NaOH was slowly titrated into the juice/water solution whilst solution swirling was continuously done. Towards the end of titration, NaOH drops were added a drop at a time. Titration was stopped when colourless solution changed to light pink. The amount of NaOH used was read off on the burette and figure recorded. All results were recorded to one decimal place and percent acidity as citric acid was calculated using Equation 8 and the sugar/acid ratio using Equation 9.

$$\text{Titratable acidity (g/l)} = \frac{ml\ NaOH \times M\ (NaOH) \times acid\ meq.factor}{ml\ Juice\ Titrated} \times 100 \quad \text{.........Equation 8}$$

The acid meq. Factor used was 0.0064.

3.7 Data Analysis

Data collected in the experiments were subjected to Analysis of Variance (ANOVA) using Python. Means were separated using least significant difference (LSD) when treatment effects were significant at $P<0.05$. The means on interaction diagrams were separated using ± standard error of the difference when interaction effects were significant at $P<0.05$.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter outlines the results following the methodology of the study. The section shows results of designing, fabricating and testing of a ZECC and also to what extent was it able to reduce the temperatures and increase relative humidity in order to decrease deterioration of the products inside to extend their shelf life and maintain quality.

4.2 Design and development of a tomato charcoal cooler storage

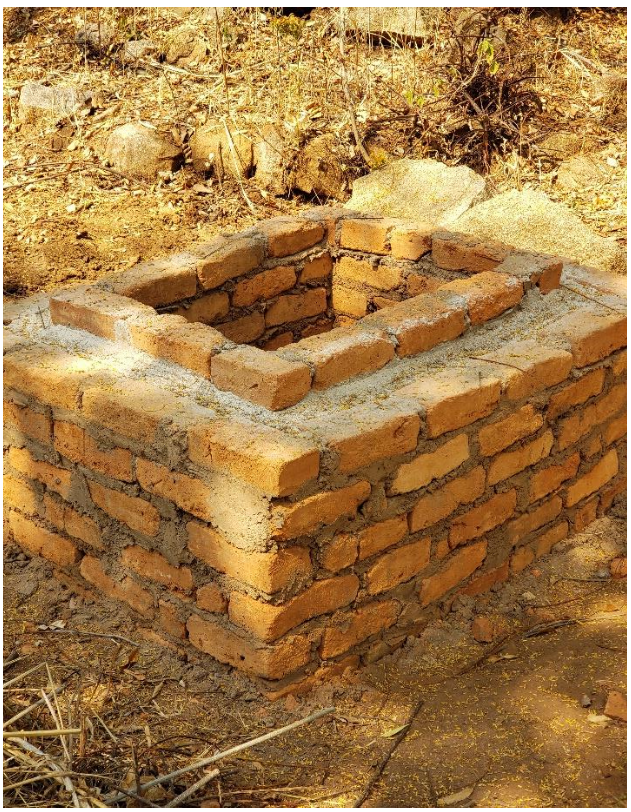


Figure 12 showing the ZECC constructed with farm bricks and clay mixed pit sand as mortar.

4.3 To evaluate the performance/ effectiveness ZECC in reducing storage temperature and increasing humidity

4.3.1 Temperature and humidity values under different water conditions

On day 1, we tested temperature without adding water to the cooler to see if the cooler itself have the ability to reduce temperature and increase humidity. It turned out that the cooling chamber did not reduce the temperature significantly. The perforated roof allowed air to circulate inside and maintain a low temperature.

On day 2, water was applied to the cooling chamber once at 08:00hrs, the readings registered that the cooler significantly reduced the temperature. There was a significant gap between the cooler humidity against the control and ambient.

On day 3, water was applied to the ZECC two times a day at 08:00hrs and 11:00hrs.The application of water had a significant effect on the temperature and humidity readings therefore the temperatures in the cooler were low than those in the control and ambient.

On day 4, water was applied on the sand 3 times and the cooler significantly reduced the temperature than the control and the ambient. The more the water was applied on the sand the more the cooler walls remained moist and the more evaporative cooling occurs. The cooler was able to maintain the temperatures below 19℃ and humidity of above 90%. The cooler was able to reduce the temperature by at least 5℃ as compared to the control.

4.4 Overall readings

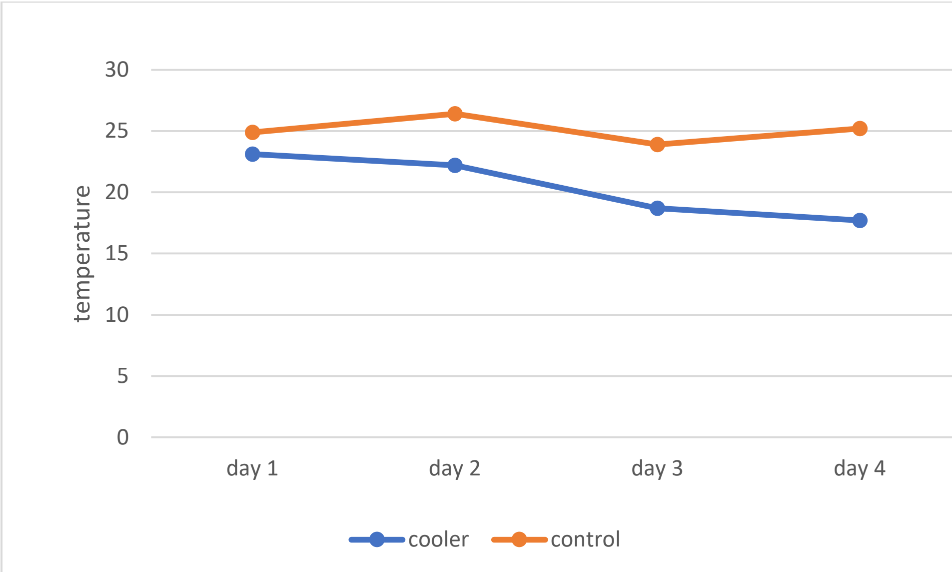


Figure 13 showing temperature readings for 4 experiments.

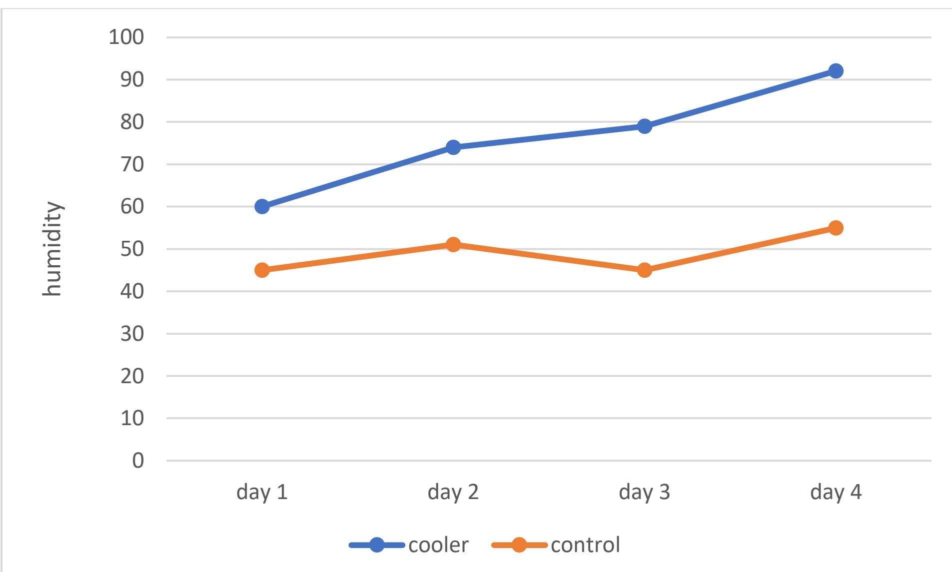


Figure 14 showing humidity for 4 experiments.

CHAPTER 5: DISCUSSION

5.1 Introduction

This section outlines discussion of results in accordance with the objectives and methodology. The research activities include design and development of a zero energy cooling chamber, the evaluation of the performance/ effectiveness of the cooler in reducing storage temperature of tomatoes and the maintenance of the quality of tomatoes stored to increase its shelf life. Tomatoes taken at breaker stage were placed in the ZECC and others at room temperature (control). Fruits ripening parameters tests were conducted on the fruits and the results were recorded in the previous chapter.

5.2 Designing and development of a zero-energy cooler storage

The zero energy cooling chamber with the capacity of 0.216 m^3 was built with a cavity wall for the purpose of storing tomato fruit. The cooler had a double brick wall and a cavity filled with sand between the walls. The roof was made with perforated material to allow air circulation. The cooler facilitates the use of evaporative cooling that operate on the idea of adiabatic cooling caused by the evaporation of water in the wet walls. In the cooler, water evaporates into the air and increases its humidity while simultaneously lowering the air's temperature.(Ronoh, Kanali and Ndirangu, 2020).

5.3 The effect of the zero-energy cooler in reducing temperature inside.

The zero energy cooling chamber registered lower air temperature and relatively high humidity as compared to the control conditions. The cooler had a maximum temperature difference of 8.3°C from the ambient temperature. Low outside air temperatures result in a minor temperature drop since they slightly lower the interiorly cooled temperature. Therefore, it suggests that a better evaporative efficiency could potentially and greatly improve the cooler's capacity to cool(Ronoh, Kanali and Ndirangu, 2020).

Generally, the temperature readings of the cooler were always low as compared to the control and the ambient, this showed that the cooler was effectively able to reduce the temperature of the commodity and also to increase the relative humidity which keeps the products fresh. The cooler was able to maintain temperatures of 19℃ and below. According to (Swetha and Banothu, 2018), most of the physiological, biochemical and microbiological activities contributing to the deterioration of produce quality are largely dependent on temperature. The increase in humidity reduces the vapor pressure deficit and physiological weight loss due to moisture loss through the skin of the product. The lower temperature reduced respiration which in turn suppress ethylene production and sensitivity to ethylene.

5.4 Effects of the quality of tomatoes stored in the cooler

5.4.1 Color and firmness

In the studies, the environments which the tomatoes were stored had a substantial impact on color and firmness, on day 4 there was no significance difference between tomatoes which were ripening in the cooler and the control. The tomatoes were ripening at almost the same rate with those in the cooler. On day 8 there was a significant difference between the ones in cooler and the ones in control. There was accelerated ripening and senescence on the tomatoes outside the cooler compared to the ones inside.

On day 12 there was a large difference between the tomatoes inside and the ones in control. The tomatoes in control were almost at senescence stage. The double wall and wet cavity was able to keep humidity relatively high and maintain a lower temperature, therefore it was able to inhibit the ethylene production in the tomatoes that were in the cooler.

On day 16, the tomatoes in the control were already deteriorating while those in the cooler were still ripening. This is because tomatoes in the control faced higher temperatures, low humidity and they also lost water through evaporation and high respiration leading to completely deterioration of the fruit. The low temperatures that were maintained by the cooler were able to reduce the production of ethylene, rate of respiration of the fruit was also reduced which leads to the long shelf life of the commodity. The tomatoes in the cooler lasted 8 days longer, which is more than enough time for the small scale retailers to sell them before deterioration.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter aimed to summarize the findings of the research study, present the research conclusions from the findings of the study undertaken. The recommendations on the conclusion of the study.

6.2 Conclusions

This study was carried out in order to provide an alternative accessible storage facility for fruits and vegetables. The zero-energy cooling chamber was designed, constructed and tested with tomatoes. The cooler was constructed with a storage capacity of $0.216m^3$. At the end of this study, the cooling chamber was able to maintain an average temperature drop of 5-7℃ from ambient and relative humidity of 85-90 percent therefore making the cooler environment as cool as possible therefore the tomatoes take time to deteriorate. There was significant difference between the tomatoes inside the cooler and the control, the tomatoes in the shade takes time to deteriorate thereby extending the shelf life. Low temperatures inside the cooler reduced the rate of respiration. The relatively higher humidity inside the cooler helped to decrease the vapor pressure deficit which causes products to lose moisture and hence suffer physiological weight loss. The cavity walls absorbs the heat energy that was produced by the tomatoes during the ripening process to evaporate the water in the sand cavity leaving behind a lower temperature. In conclusion the zero-energy cooling chamber was able to reduce the post-harvest losses that were faced by the farmers by increasing the shelf life of the tomatoes by 8 days.

6.3 Recommendations

- Farmers are recommended to have at least one cooling chamber for the storage of tomatoes or fresh vegetables because of the following advantages:

  1) Avoid distress sale of fresh fruits, vegetables and flowers. It requires no special skill to operate and therefore is most suitable for rural application.
  2) It can be made from locally available materials.
  3) Its size can be fitted to the house hold need.
  4) Better marketability of fresh horticultural produce than ambient.
  5) Retain nutritive value.

6) Environment friendly storage system with no pollution.
7) Highly efficient evaporative cooling systems that can reduce energy use by 70%.
8) Evaporation not only lowers the air temperature surrounding the produce, it also increases the moisture content of the air. This helps to prevent the drying out of the produce, and therefore extends its shelf life.
9) Less expensive to install and operate.
10) It can be easily made and maintained.
11) The evaporative cool chamber does not require mechanical or electrical energy input and can be constructed with locally available material with unskilled labour.
12) It is economical and can store the fruits and vegetables for 3 to 5 days without any significant loss

- The tomatoes under investigation must be grown by the researcher so that all the records of fertilizer and chemicals application are recorded so as to avoid compromising results that might be caused by pre-harvest losses that occur during the production.
- To improve the performance of the cooler, researchers can incorporate ethylene scrubbers in the cooler.

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APPENDICES

Appendix 1:

Anova Outputs at day 1, temperature readings when cooler was dry

Analysis of Variance Experiment 1

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	2.48	1.24	NaN	NaN

Grand Mean: 23.10

Tables of Means

	day_3_T_C
0	21.9
1	23.3
2	24.1

Standard Errors of Differences of Means: 0.909

Appendix 2:

Anova Outputs at day 2, temperature readings when water was added once.

Analysis of Variance Experiment 2

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	7.22	3.61	NaN	NaN

Grand Mean: 22.20

Tables of Means

	day_3_T_C
0	20.1

1 22.7

2 23.8

Standard Errors of Differences of Means: 1.551

Appendix 3:

Anova Outputs at day 3, temperature readings when water was added twice.

Analysis of Variance Experiment 3

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	1.46	0.73	NaN	NaN

Grand Mean: 18.70

Tables of Means

	day_3_T_C
0	17.9
1	19.6
2	18.6

Standard Errors of Differences of Means: 0.698

Appendix 4:

Anova Outputs at day 4, temperature readings when water was added 3 times.

Analysis of Variance Experiment 4

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	3.846667	1.923333	NaN	NaN

Grand Mean: 17.73

Tables of Means

	day_3_T_C
0	16.2
1	18.9
2	18.1

Standard Errors of Differences of Means: 1.132

Results for Relative humidity of the cooler:

Appendix 5:

Anova Outputs at day 1, humidity readings when no water was added.

Analysis of Variance Experiment 1 Humidity

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	2.0	1.0	NaN	NaN

Grand Mean: 60.00

Tables of Means

	Humidity
0	59.0
1	61.0
2	60.0

Standard Errors of Differences of Means: 0.816

Appendix 6:

Anova Outputs at day 2, humidity readings when water was added 1 time.

Analysis of Variance Experiment 2 Humidity

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	18.0	9.0	NaN	NaN

Grand Mean: 74.00

Tables of Means

Humidity

0	74.0
1	77.0
2	71.0

Standard Errors of Differences of Means: 2.449

Appendix 7:

Anova Outputs at day 3, humidity readings when water was added 2 times.

Analysis of Variance Experiment 3 Humidity

	df	sum_sq	mean_sq	F	PR(>F)
Residual	2.0	12.666667	6.333333	NaN	NaN

Grand Mean: 79.67

Tables of Means

Humidity

0	77.0
1	80.0
2	82.0

Standard Errors of Differences of Means: 2.055

Appendix 8:

Anova Outputs at day 4, humidity readings when water was added 3 times.

Analysis of Variance Experiment 4 Humidity

df sum_sq mean_sq F PR(>F)

Residual 2.0 14.0 7.0 NaN NaN

Grand Mean: 92.00

Tables of Means

Humidity

0 94.0

1 93.0

2 89.0

Standard Errors of Differences of Means: 2.160