CERTIFICATION

This is to certify that **AROWOSAYE,** Mayowa Joel, an undergraduate student in the Department of Agricultural and Bioresources Engineering, Federal Universiy Oye-Ekiti with Matriculation Number ABE/13/1038, has successfully carried out and completed this project work in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering in Agricultural and Bioresources Engineering. The work embodied in this report is original and has not been submitted in part or full for any other Diploma or Degree in this University or any other University.

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DEDICATION

This project is dedicated to my father and mother Elder J.O. Arowosaye and Deaconess Arowosaye who believed in me and always encouraged me to stay focused and never give up on any challenge and my backbone.

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Firstly my acknowledgment goes to my Creator who is the source of my life and without Him I'm just a pack of dust. I am also highly appreciative of the effort of my supervisor Engr. Prof. A. M. Olaniyan for his patience and fatherly commitment shown towards me during the completion of this project. I also want to use this medium to appreciate the best mummy in the world Deaconess Mrs. Arowosaye Romoke. I also want to appreciate my Head of Department Dr. O.E. Omofunmi and all the members of staff of the Department of Agricultural and Bioresources Engineering including the technical staff like Engr. J.O. Falodun, Mr. O.V. Akinyeye and the others. I want to say thanks for always been there at any time.

ABSTRACT

An evaporative cooling system was designed, fabricated and tested for the storage of fresh fruits and vegetables. The system's working principles is based on the principle of evaporation which causes a cooling effect to its surrounding. The system is an enclosed system and air is allowed to pass only through the pad, also a suction fan centrally located which draws in air through the pad. Water drips into the foam at a constant rate through a water distribution system. As the water drips into the foam the suction fan draws warm air through the wetted pad. During this process the warm air which is the sensible heat passes through the wetted pad which is now changed to latent heat due to the evaporation that has occurred as a result of the water being evaporated which causes the cooling within the enclosure with the achievement of a temperature difference of about 14.1°C.The excess water drops down to the trough or water collector. As the excess water is stored at the water collector, the circulating pump is used for circulating the water back to the water reservoir. The materials for construction were selected based on the type of produce to be stored, availability, nearest to market, durability and economic consideration. Some of the materials included are; suction fan, pad end, water reservoir, pipe, water pump, water collector/trough. The system was tested for storing some fresh tomatoes for seven (7) days. Test result showed that the Evaporative Cooling System (ECS) is more efficient and sustainable means of storing fresh fruits and vegetables. From the result of the test, it can be deduced that the cooling efficiency was found to be 81.9% and the average temperature of the Evaporative Cooling System (ECS) was 14.1°C while the average ambient temperature was found to be 25.6°C. With the production cost of seventy-four thousand three hundred naira (₦74,300), the system can easily be afforded by small holder's farmer who are the intended users.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Vegetables are vital agricultural products for human consumption worldwide. They are of a herbaceous plants, with soft stem and with a high degree of moisture content. They can be grouped according to the edible parts of different plants which are leaves (lettuce), stalks (celery), root (carrot), tubers (potatoes) and bulbs (onions). Fruits like tomatoes are considered as vegetables.

Plant foods are a rich source of nutrients (Steinmetz and Potter, 1996).Vegetables enhances the nutritional quality of diet because of their richness in vitamins and minerals such as carotene (provitamin A), ascorbic acid, riboflavin, iron, iodine, calcium etc (Ihekoronye and Ngoddy, 1985). Deficiency of these nutrients can lead to widespread of diseases and on the long run, lead to death. Vegetables are also rich in fibres which are essential for good digestion. Results from the Global Burden of Disease project for year 2000 show that up to 2.7 million deaths worldwide and 1.8 percent of the total global disease burden may be attributed to inadequate consumption of food and vegetables (Lock et al., 2004). There is proper need to address the production, preservation and storage of vegetables to reduce the death rate caused by the defect of the needed nutrients.

Vegetables should be consumed in the fresh state because they are usually perishable. (Olosunde, 2006) .In Nigeria, the bulk of these items such as tomatoes, bananas, plantains, mangoes and leafy vegetables, are produced and marketed by peasant farmers and these people have an inadequate means of proper handling ,transportation and storage (Dzivama, 2000). In their fresh form most fruits and vegetables contain 80 percent water with some varieties such as cucumber, lettuce and melons containing about 95 percent (Sanni, 1999).When vegetables are harvested the moisture in them reduces partly due to respiration that occurs and since there is no replenishment and loss to the atmosphere . If equilibrium moisture content is not achieved vegetables begin to die gradually. Fruits, vegetables and cut flowers are living, respiring tissues separated from their parent plant (Sushmita et al., 2008).
Post-harvest respiration is a deterioration process. It results in the depletion of reserve carbohydrate by oxidizing them to carbon (IV) oxide, water and energy (Dzivama, 2000) represented in the equation below:

$$C_6H_{12} + 3O_6 = 6CO_2 + 6H_2O + 67Kcal\ (energy) \quad (1.1)$$

The environment for safe and prolonged storage of perishable commodities must therefore be one of high humidity and low temperature (Olosunde, 2006). Uniform air circulation is major requirement in storage room and it is important to remove product head entering through door opening and building surfaces (Ajibola, 1991) .Therefore, the essence of storage of vegetable is of uttermost importance since it adds a considerable amount of nutrients to the diet of humans. Sushmita *et al.* (2008) disclosed that keeping products at their lowest safe temperature (0°C for temperate crops or 10-15°C for chilling sensitive crops) will increase storage life by lowering respiration rate, decreasing sensitivity to ethylene gas and reducing water loss .He further said that the most common method followed by the vegetable traders in local famers is to add moisture to the air around the commodity as mists, sprays, or at last resort, by wetting the store room floor.

Dzivama (2000) noted that during evaporation, there is a simultaneous heat and mass transfer. He further disclosed that the heat in the air is utilized to evaporate the water which changes the water liquid form to vapour form which results in a drop in the temperature and increase in the relative humidity of the air .This principle was then used in the storage of food and agricultural materials. Evaporative cooling has enormous applications, ranging from comfort cooling in residential, commercial, agricultural, and institutional buildings to industrial applications such as spot cooling in power plants, foundries etc. ASHRAE (2003).This principle is also majorly used in the greenhouses.

Refrigeration is considered as one method of food preservation, but it requires a high input, it is expensive and is not suitable for the storage of perishable crops due to chilling injury (Ndirika and Asota 1994; Gross *et al.* 2002; Olosunde *et al.* 2009). Many fruits and vegetables are sensitive to low temperature. These crops are injured after a period of exposure to chilling temperatures below 10–15°C but above freezing point (Gross *et al.* 2002). The injurious effect this has on stored produce is often severe; hence, this is one of the major reasons for the low efficiency of this system in extending the shelf life of fresh fruits and vegetables. The environment for safe and prolonged storage of perishable commodities must therefore be one of high humidity and low temperature. This will retard moisture loss, reduce the respiratory process and lessen the activity of microorganisms (pathogens) which is the most destructive activity during storage of vegetable crops (Barre *et al.*, 1992). Minimizing the deteriorative reactions in fruits and vegetables enhances their shelf life, implying that the produce will be available for longer periods. This would reduce fluctuation in market supply and prices. These are favorable indices for food companies that rely on a steady supply for processing. There is also every possibility that the availability of fruits and vegetables in all seasons at affordable prices would encourage the consumption of fruits and vegetables at the end-user's level with a concomitant improvement in the nutritive status of the populace. Evaporative cooling has been reported for achieving a favorable environment in greenhouses (Jain and Tiwari, 2002), adiabatic systems and storage structures for fruits and vegetables (Helsen and Willmot 1991; Umbarker *et al.*1991). Evaporative cooling system storage, which is believed to be the best method for storing fruit and vegetables in fresh form, is not available in rural or remote locations where a network for distributing electricity is almost nonexistent. Therefore, for the benefit of small-scale producers in developing countries, it is necessary to devise a storage system that can be powered using solar energy. This is so that the average farmer, trader or householder can afford and easily acquire such a system in order to store products with a minimum energy input. An inexpensive system whereby partially ripe crop would be kept for 1 or 2 weeks with little further ripening or loss of quality could be of some value to the horticultural industry, as well as to small scale growers. Not only would the quality of market products be considerably improved, but also the products would attract higher prices, resulting in higher earnings and an improved living standard.

The choice of mangoes, tomatoes, bananas and carrots in this project is based on their economic importance and the fact that they are more perishable among the most important fruits and vegetables produced and consumed in Nigeria. The ideal storage conditions of these fruits and vegetables ranges from 10 to 20°C and from 85 to 95% temperature and relative humidity (RH), respectively (Hall 1981; Wills *et al.* 1989; FAO/SIDA 1986; Dzivama 2000). Most of the other important fruits and vegetables also fall into this range of storage conditions.

1.2 Statement of Problem

Many farmers producing fruits and vegetables live in areas where there is no electricity supply, making it difficult to store excess produce due to in adequate storage facilities. The farmers do not get enough value for their products due to weak infrastructure, poor transportation and the perishable nature of the crops.

The consumption of vegetables is important because the nutrients contained in them can be used in the treatment of CDR (Cardio Vascular diseases) and cancer. In Nigeria research showed that at the national level, 24.8% of children lower than 5 suffered from subclinical vitamin A deficiency while 4.7% were vitamin A deficient, making a total of 29.5% who suffered from clinically deficiency (IITA, 2004).

The effect of lack of adequate storage facilities for vegetables after being harvested leads to the reduction in the quantity of vegetable that get to the market which also has a direct effect on the distribution and consumption of the needed quantity for healthy living.

1.3 General Objectives

The main objective of this project is to develop an evaporative cooling system as a medium or to prolong the shelf lives of fresh fruits and vegetables.

The specific objectives of these project are:

(i) to design an evaporative cooling system for the storage of fresh fruits and vegetables;

(ii) to construct the evaporative cooling system based in the design specifications; and

(iii) to test the performance of the system for the storage of fresh fruits and vegetables.

1.4 Justification of the Study

The essence of storage is of great importance because not all the harvested vegetables or crops in general will be used immediately after harvest so, measures of preserving the vegetables before it exceeds its shelf life is of great importance. Some methods of preservation of raw and processed fruits and vegetables include: storage in ventilated shed, storage at low temperatures, use of evaporative coolant system, waxing and chemical treatment (Olosunde, 2006). Most of the peasant farmers are not able to afford the cost of purchasing high tech storage equipment for their harvested crops. Evaporative cooling has been found to be an efficient and economical means of reducing temperatures and increasing humidity in an enclosure where the humidity is comparatively low and to retain its original freshness (Sushmita et al., 2008). Minimizing deteriorative reactions in fruit and vegetables enhances their shelf lives, implying that the produce will be available for longer periods; this would reduce fluctuation in market supply and prices and to supply to them. (Dzivama, 2000).

1.5 Scope of the Work

This project will involve doing analysis or calculation to achieve a good construction. Carrying out the construction of the evaporative cooling system and its chamber for the storing of fruits and vegetables. Testing of all components done and constructed to achieve a better result for the project.

CHAPTER TWO
LITERATURE REVIEW

2.1 History of Evaporative Coolers

Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface; the faster the rate of evaporation the greater the cooling.

There have been various designs over the years. In early Ancient Egyptian times, paintings depicting slaves fanning large, porous clay jars filled with water which is essentially is a very, very early form of evaporative cooling. The first man made coolers consisted of towers that trapped wind and funneled it past water at the base and into a building. This in turn kept the building cool at the time. (dualheating.com). In 1800 B.C the New England textiles factory began to use the evaporative cooling systems to cool their mills (www.evaprocool.com). In the 1930's the Beardmore tornado airship engine used to reduce and completely remove the effect of using a radiator which reduces the effect of lag.(coco.cooler.com) Bamboo coolers were constructed with bricks with hessian cloth which were used to wrap the bricks. Also, charcoal coolers were also produced together with the Almirah coolers.

Rusten, (1985) described some types of evaporative cooling that was been used in New Delhi, India in high a wetted mat with fan was used to cool a local restaurant. The concept of water-cooling a roof has a long history but it is estimated that less than 60 million square feet of roof have ever been water cooled Tiwari *et al.*, (2002). It was also reported that if only a small amount of water is placed on the roof, the evaporation is highly accelerated as compared to what would be if the roof surface was flooded. Carrasco, (1987)

2.2 Evaporative Cooling Equipment Design Challenges

Cooling for commercial applications requires large airflow rates. Early attempts incorporated larger pads and replaced the water drip application systems with slinger wheels, spray systems, or rotary pads. This step was necessary since drip systems distributed water poorly.

This condition existed in small coolers limiting their performance and was amplified in larger pads. In the slinger wheel configuration, a partially submerged, rotating wheel produces a sheet of water in the plane of the wheel. Evaporation takes place as air moves through this sheet of water and in the pads where the un-evaporated water is caught.

It was quickly found that slingers were not the answer. The problem with slingers is that the density of the airborne water created by the slinger varies inversely with the square of the distance from the center of the slinger plate. This variation is further disturbed as the air stream collides with the water dependent on slinger rotation speed, direction, and the air velocity profile. Similarly, spray systems suffer from variation in physical nozzle coverage and alignment, water pressure over time, nozzle erosion, nozzle clogging, and non-uniform air stream air velocity profile.

Each of these systems failed to achieve desired air and water distribution to effectively wet the pads uniformly. Areas of the pad that are not wetted effectively allow air to pass through without being cooled and at the edges between wetted and un-wetted surface establish sites for scale formation.

2.3 Advances in Evaporative Cooling Technology

Vakis, (1981) developed a cheap cool store in Kenya, with the help of local grass for storage of vegetables. He kept the roof and walls wet by dripping water from the top of the roof. Evaporative coolers, which rely on wind pressures to force air through wet pads, have also been designed and constructed, especially in some developing countries like India, China and Nigeria (FAO, 1986). Construction of various evaporative systems was done by Roy, (1986) using available materials as absorbent (pads). Materials used include canvas, jute curtains and hourdis clay blocks. Also a mechanical fan was introduced to some of the coolers constructed.

Roy, (1986) did an extensive research in the construction of different evaporative cooling systems using locally available absorbent materials such as canvas, jute curtains, etc. Mechanical fans were used in some of the designs which drew air through a continuously wetted pad. The continuous wetting of the pad was achieved by placing elevated water basins on the fabric material, which absorbed the water gradually and eventually got saturated. He described the functionality of a hourdis clay block coolers which was constructed by two researchers.

Ajibola, (1991) worked on the development of hexagonal wooden evaporative cooling systems and the system could be sub-divided into three parts head tank and pipe lines work, the through and the frame work made of woods and its adjoints. The pipe line works at the top of the hexagonal frame supplied water constantly to wet the pad which is made of jute fibre. Wind pressure forced the air through the wetted jute pad. Limitation of this design is that the sufficiency of the evaporative cooler depends on wind velocity FAO/SIDA (1986).

Roy and Khurdiya, (1986) constructed an evaporative cooled structure for storage of fruits and vegetables with a double wall made of baked bricks and the top of the storage space covered with khaskhas/gunny cloth in a bamboo framed structure.

Abdalla and Abdalla, (1995) worked on the development of a fan driven evaporative cooler. The research was study the suitability of using palm leaves as a wetted medium. This research was made possible due to the availability of palm leaves in Saudi Arabia. According to the research it was claimed that palm leaves could be used as the wetted media which is locally available to the masses. Sanni, (1999) did a research on the development of evaporative cooling system on the storage of vegetable crops .The major development was implemented by adding a regulated fan speed, water flow rate and wetted-thickness .This was possible as a result of varying temperature and relative humidity within the facility.

Dzivama, (2000) did a research on the performance evaluation of an active cooling system using the principles of evaporative cooling for the storage of fruits and vegetables. He developed mathematical models for the evaporative process at the pad-end and the storage chamber and a stem variety of sponge was considered to be the best pad material from the local materials tested as pad material.

Mordi and Olorunda, (2003) in their study on storage of tomatoes in Evaporative cooler environment reported a drop of 8.2°c from ambient condition of 33°c while the relative humidity increased by 36.6% over an ambient 60.4%. They further reported storage life of unpacked fresh tomatoes in evaporative cooler environment as 11 days from the 4 days. Storage life under ambient conditions while in combination with sealed but perforated polyethylene bags; it was 18 days and 13 days respectively.

Olosunde, (2006) also did a research on the performance evaluation of absorbent, materials in evaporative cooling system for the storage of fruits and vegetables. Three materials were selected to be used as pad materials: jute, Hessian and cotton waste. The design implemented a centrifugal fan, high density polystyrene plastic, Plywood used as covering for the walls and basement and the top and the main body frame was made of thick wood. The performance criteria included the cooling efficiency, amount of heat load removed and the quality assessments of stored products. The result showed that the jute material had the overall advantage over the other materials. The cooling efficiency could be increased if two sides were padded.

Sushmita et al., (2008) did a research on Comparative Study on Storage of Fruits and Vegetables in Evaporative Cool Chamber and in Ambient. An evaporative cool chamber was constructed with the help of baked bricks and riverbed sand. It was recorded that weight loss of fruits and vegetables kept inside the chamber was lower than those stored outside the chamber. The fruits and vegetables were fresh up to 3 to 5 days more inside the chamber than outside.

2.4 Factors Affecting the Shelf Life of Fruits and Vegetables

There are various factors that do affect the shelf life of fruits and vegetables which would lead to their spoilage. The various factors include:

i) Ambient Condition

ii) Temperature

iii) Relative Humidity

iv) Variety and stage of ripening

2.4.1 Ambient Condition

The environmental condition has a great influence on the shelf life of fruits and vegetables and the factors can be sub-divided into temperature and relative humidity.

2.4.2 Temperature

Temperature is defined as the degree of hotness or coldness of a material. Temperature has a great influence on the shelf life on agricultural products. FAO, (1986) found that all produce are subject to damage when exposed to extreme temperatures which will lead to increase in their level of respiration. Also, it was further disclosed that agricultural products vary in their temperature tolerance. Wilson et al., (1999) suggested that deterioration of fresh commodities can result from physiological breakdown due to natural ripening processes, water loss, temperature injury, physical damage, or invasion by microorganisms. All of these factors can interact, and all are influenced by temperature. He further said that exposure to alternating cold and warm temperatures may result in moisture accumulation on the surface of commodities (sweating), which may enhance decay development. Wilson et al., (1999) observed that for every 18°F (-7.7°C) rise in temperature within the moderate temperature range (50°F-100°F)/(10°C-37.8°C) where most food is handled, the rate of chemical reactions is approximately doubled. As a result, excessive temperatures will increase the rate of natural food enzyme reactions and the reactions of other food constituents.

2.4.3 Relative Humidity

This is the measurement of the amount of water vapour in the air as a percentage of the maximum quantity that the air is capable of holding at a specific temperature. Mathematically it can be represented by

$$\text{Relative Humidity} = \frac{\text{actual vapour density}}{\text{saturation vapour density}} \text{ X } 100\% \qquad (2.1)$$

Relative humidity can also be mathematically represented by the equation below

$$\emptyset = \frac{E_W}{E_{W^*}} \qquad (2.2)$$

Where, E_W = partial pressure of water vapour

E_W^*= saturated vapour pressure

$Ew^* = (1.0007 + 3.46 \times 10^{-6} P) \times (6.1121)\, e^{(17.502T/240.97 + T)}$

Where,

T = the dry bulb temperature, °C

P = absolute pressure, millibar(mbar)

It has a great effect on the deterioration of fruits and vegetable because it has a direct relationship with the moisture content in the atmosphere which determines whether the shelf life will not be exceeded.

Olosunde, (2006) said that the relative humidity of the storage unit directly influences water loss in produce. Wilson et al., (1995) also said water loss means salable weight loss and reduced profit.

2.4.4 Variety and Stage Ripening

Post-harvest operation does not stop the fruits and vegetables from respiring which if not controlled will lead to the over-ripening of the fruits which will lead to early deterioration. Depending on the stage the fruits are harvested, which in practice varies from mature green to fully ripened, the commodities have different storage conditions Olosunde, (2006).

2.5 Factors Accountable for Deterioration in Fruits and Vegetables

2.5.1 Physiological Activity

During post-harvest operation the fruits and vegetables still continue their normal physiological activities. Olosunde, (2006) disclosed that ripening transforms a physiological mature but inedible plant organ into a visually attractive and edible organ which marks the complete development of a fruit and the commencement of senescence, and it is normally and irreversible event.

Major changes which do make up fruit ripening are: seed maturation, abscission, production of volatile compounds, development of wax on skin and changes in colour, respiration rate, rate of ethylene production, tissue permeability, composition of pectin and carbohydrates, organic acids and protein.

2.5.2 Pathological Infection

Pathogens are one of the major causes of deterioration of fruits and vegetables when they infest any food material they destroy and make it not pleasing to the sight. (Olosunde, 2000) disclosed that crops destined for storage should be as free as possible from skin breaks, bruises, spots, rots, decay, and other deterioration (Olosunde,2006) also said that insects and pests can cause considerable damage of fruits and vegetables through either complete removal of the fruits or feeding on them, thus causing skin breaks which may facilitate entry of decay organism.

2.5.3 Mechanical Injuries

The injuries that are visible on fruits and vegetables are caused by mishandling or other cause which leads to cracks, bruises, cuts or abrasion which makes the produce not attractive and also less marketable.

Ajibola, (1991) disclosed that impact bruising of tomatoes results in higher respiration and ethylene production rates, increased damage and lower levels of titratable and ascorbic acid, which can alter taste and nutritive value.

Olosunde, (2006) also disclosed that mechanical damage can also accelerate the rate of water loss from produce, bruising damages the surface organization of the tissue and allows a much greater flow of gaseous material through the damaged area.

2.5.4 Evaporation of Water

Evaporative loss from the surface of fruits and vegetable has an effect on the quality of the produce. The higher the rate of evaporation, the lower the moisture content and shelf life of the agricultural produce. (Olosunde, 2006) further said that weight loss results from moisture loss via evaporation of water from the tissues when the fruits and vegetables are attempting to be in equilibrium with the environment with the environment which is usually at lower water activity.

2.6 Post- Harvest Changes in Quality of Fruits and Vegetables

Changes do occur during post-harvest operations for fruits and vegetables which lead to decrease in their shelf life which on the long run leads to decrease in the quantity supplied for consumption and for export market. Dzivama, (2000) described the common and notable changes that do occur during post-harvest in the quality of fruits and vegetables which include:

i) Colour Change

ii) Loss of weight

iii) Change in the firmness.

iv) Change in total soluble solids

2.6.1 Colour Change

Fruits ripening process continues even after harvesting which could be an important factor to be noted during post-harvest operations. Wilson et al., (2005) disclosed that immature or over mature produce may not last as long in storage as that picked at proper maturity. Colour is the most obvious change that occurs in many fruits and vegetables and this a major criterion that most consumers uses to determine whether the fruit is ripe , unripe ,overripe or spoiled and the assessment of colour change is done by comparing the colour of produce under investigation against a standard colour chart (Dzivama, 2000).

2.6.2 Loss of Weight

Most fresh produce contains from 65 to 95 percent water when harvested (FAO, 1986). Water is an important constituent of most fruits and vegetables and it adds up to the total weight. Losses of water will definite reduce the weight. When the harvested produce loses 5 or 10 % (percent) of its fresh weight, it begins to wilt and soon becomes unusable (FAO, 1986). The loss of weight comprises of both respiratory and evaporative losses. The former, which occurs as a result of respiration, depends mainly on the temperature of the surrounding air. The latter occurs as a result of water vapour deficit of the environment compared with that of the produce (Dvizama, 2000).

FAO, (1986) disclosed that the faster the surrounding air moves over fresh produce the quicker water is lost. Air movement through produce is essential to remove the heat of respiration, but the rate of movement must be kept as low as possible.

2.6.3 Fruit Firmness

Ripening of fruits has a direct relationship with the fruit firmness and since respiration continues even after harvest the fruits have the tendency of become over-ripen. Dzivama,(2000) declared that as a result of continued chemical activity within the fruits tissues even after harvest after which it becomes over-ripe and soft which makes any factor that can slow down the rate of respiration will automatically slow down the fruit firmness change which can be achieved by storing at low temperature.

2.6.4 Change in total Soluble Solid

During ripening, carbohydrate are broken down into simpler unit particularly the conversion of starch to sugar ,giving the fruits its characteristics sweet taste on ripening and the degree of ripening can be measured by measuring the sugar content in an extracted fruit juice (Dzivama,2000).

2.7 Principles of Evaporative Cooling

2.7.1 Evaporative Cooling with Psychrometric Chart

According to Rastavorski, (1981) cooling through the evaporation of water is an ancient and effective way of cooling water. He further disclosed that this was the method been used by plant and animal to reduce their temperature. He gave the conditions at which evaporative cooling would take place which are stated below:

(i) Temperatures are high

(ii) Humidity is Low

(iii) Water can be spared for its use

(iv) Air movement is available (from wind to electric fan)

Also he disclosed that the change of liquid stage to vapour requires the addition of energy or heat. The energy that is added to water to change it to vapour comes from the environment, thus making the environment cooler.

Therefore, the use of the psychrometric chart is of great importance in order to discover whether evaporative cooling has taken place. Air conditions can be quickly characterized by using a special graph called a psychrometric chart. Properties on the chart include dry-bulb and wet-bulb temperatures, relative humidity, humidity ratio, specific volume, dew point temperature, and enthalpy.

When considering water evaporating into air, the wet-bulb temperature, as compared to the air's dry-bulb temperature is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect. When the temperatures are the same, no net evaporation of water in air occurs, thus there is no cooling effect (Wikipedia.com). Therefore for optimum cooling efficiency using the evaporative cooling technique temperature and the relative humidity measurement is needed to be taken and the psychrometric chart defines these variables at various stages.

2.7.2 Factors Affecting the Rate of Evaporation

Evaporative cooling results in reduction of temperature an increase in relative humidity (Olosunde, 2006).It is necessary to understand the factors that can limit the efficiency of the system from producing the intended results. There are four major factors that affect the rate of evaporation which was analyzed by (Rastavorski, 1981).He later added that though they are discussed separately but it is important to keep in mind that they all interact with each other to influence the overall rate of evaporation, and therefore the rate of cooling.

The factors discussed by (Rastavorski, 1981) include:

2.7.2.1 Air Temperatures:

Evaporation occurs when water is absorbs sufficient energy to change from liquid to gas. Air with a relatively high temperature will be able to stimulate the evaporative process and also be capable of holding a great quantity of water vapour. Therefore, areas with high temperatures will have a high rate of evaporation and more cooling will occur. With lower temperature, less water vapour can be held and less evaporation and cooling will take place.

2.7.2.2 Air Movement (Velocity):

Air movement either natural (wind) or artificial (fan) is an important factor that influences the rate of evaporation. As water evaporates from wet surface, it raises the humidity of the air that is closest to the water surface (moist area) .If the humid air remains in place, the rate of evaporation will start to slow down as the humidity rises. On the other hand if the humid air near the water surface is constantly being moved away and replaced with drier air, the rate of evaporation will either increase or remain constant.

2.7.2.3 Surface Area:

The area of the evaporating surface is another important factor that affects the rate of evaporation. The greater the surface area from which the water evaporates, the greater the rate of evaporation.

2.7.2.4 Relative Humidity of the Air:

This is the measurement of the amount of water vapour in the air as a percentage of the maximum quantity that the air is capable of holding at a specific temperature. When the relative humidity of the air is low, this means that only a portion of the total quantity of water which the air is capable of holding is being held. Under this condition, the air is capable oftaking additional moisture, hence with all other conditions favourable, the rate of evaporation will be higher, and thus the efficiency of the evaporative cooling system is expected to be higher.

2.8 Methods of Evaporative Cooling

(Rusten, 1985) specified that there are two main methods of evaporative cooling namely: direct evaporative cooling and indirect evaporative cooling.

2.8.1 Direct Evaporative Cooling:

This is a method by which air is passed through a media that is flooded with water .The latent heat associated with the vaporizing of the water cools and humidifies the air streams which now allows the moist and cool air to move to its intended direction. (Sellers, 2004) Shiundu, (2002) disclosed that direct evaporative cooling has the following major limitations:

(i) The increase in humidity of air may be undesirable.

(ii) The lowest temperature obtainable is the wet-bulb temperature of the outside air,

(iii) The high concentration and precipitation of salts in water deposit on the pads and the other parts, which causes blockage, and corrosion, and requires frequent cleaning, replacement, and servicing.

2.8.2 Indirect Evaporative cooling:

A heat exchanger is combined with an evaporative cooler and the common approach used is the passes return/exhaust air through an evaporative cooling process and then to an air-to air heat exchanger which in turn cools the air, another approach is the use of a cooling tower to evaporatively cool a water circuit through a coil to a cool air stream (Sellers, 2004).

Shiundu, (2002) also said indirect cooling differs from direct cooling in the sense that in indirect cooling the process air cools by the evaporation of water. But there is no direct contact of water and process air. Instead a secondary airstream is used for evaporation of water. So the moisture content of process air remains the same.

2.9 Forms of Direct Evaporative Cooling

Dzivama, (2000) did a study on the forms of evaporative cooling process and below are his findings; There are two forms of in which the evaporative cooling principle can be applied. The difference is based on the means of providing the air movement across/through the moist materials. These are the passive and non-passive forms. The passive form of evaporative cooling relies on the natural wind velocity, to provide the means of air movement across/through the moist surface to effect evaporation. This form can be constructed on the farm, for short term on farm storage while the non- passive form uses a fan to provide air movement.

2.9.1 Passive-Direct Evaporative Cooling System

Construction and design varies but the general principles are the same. The main components include:

i) The chamber where the produce is stored.

ii) The absorbent material used to expose the water to the moving air

iii) An overhead tank and water collector through which the water seeps down on to and wet the absorbent material.

The absorbent material covering the cabinet absorbs water from the tank on top of the cabinets, the entire cloth that was used as cabinet is soaked in water and the air moves past the wet cloth and evaporation occurs. As long as evaporation takes place, the content s of the cabinet will kept at a temperature lower than that of the environment and the temperature reduction obtained in this type of cooler ranged from 5°C to 10°C.

Different researches have been done by researches names like Rastavorski, (1981), Susanta and Lock, (2004), Olosunde, (2006), Sushmita et al.,(2008) have designed various forms of coolers.

2.9.2 Non- Passive Direct Evaporative Cooling System

This cooling system uses a small fan, a water pump which is powered by electricity. The products are kept in storage cabins inside the coolers, Absorbent material which receives the water and expose it to evaporation with the help of the fan which draws air through the pad and an overhead tank which is constantly supplying water to the absorbent material. Materials used as the absorbent materials are hessian materials, cotton waste and celdek and the body frame is made of wood. The pad and the fan are directly opposite to each other.

2.10 Energy Changes During Evaporative Cooling

2.10.1 Vapour Transmission through Materials

The rate of water vapour transmission is based on Fick's Law which is expressed as:

$$\frac{W}{A} = \frac{-\mu dP}{dx} \qquad (2.3)$$

Where:

W= weight of water vapour transmitted (g)

A= area (m^2)

Θ = time (hrs)

X= distance along path (m)

μ =permeability (g.m/m^2.hr.KPA)

Fick's equation may be integrated from x=0 to L and from P1 to P2 to give

$$W = \mu A \Theta (\frac{\Delta P}{L}) \qquad (2.4)$$

Where,

W = total weight of vapour transmitted (g)

A = area of cross-section of flow path (m^2)

Θ = time of transmission (hr)

ΔP = Partial pressure difference between ends flow path (KPa)

L = length of pad or thickness of material (m)

μ = average permeability of material (g.m/m^2.hr.KPa)

For convenience in evaluating combined materials, permeability can be expressed as a coefficient of transmissions M, as:

$$W = M A \Theta \Delta P \qquad (2.5)$$

Where,

M = permeace in g/hr/m^2 per vapour difference in KPa

Permeance, like conductance relate to any given material or combination of materials. Permeability, like conductivity relates to the property of a substance and is numerically equal to the Permeance for the unit thickness. Resistance to vapour flow provided by sheet or board is the reciprocal of the permeance. The overall vapour resistances of a combination of materials, as in a wall is the sum of the resistance s of the components .The overall Permeance of a wall may be found in away similar to the calculation of the overall coefficient of thermal resistance.

That is $M_{total}=(\frac{1}{M1}+\frac{1}{M2}+\frac{1}{M3}+\cdots\frac{1}{Mn})^{-1}$ (2.6)

2.10.2 Heat and Mass Balance at Pad-end

The heat and mass balance can be derived as follows:

(i) Heat balance for the pad end

The mass of air is passing through the pad of volume P_AP_T at anytime, dt is equal to Equals to:

$$Ma = (\rho aVa + \rho aVaWo)\ PaPp\ dt \qquad (2.7)$$

Where

M_a = Mass of moist air, kg

P_p= Porosity of the pad, in decimal

P_a = Density of air, kg/m3

V_a = Velocity of air, m/s

W_0= Humidity ratio of the air, kg of water/kg of dry air

P_A = Effective pad surface area, m^2, approximated by effective evaporator surface

Area expressed as $P_A = A_T \times P_E$(Earle,1983)

A_T = Total pad surface area, m^2

P_E = Pad material efficiency approximated to fin efficiency as in evaporator and considered as the porosity of the material.

Dt = time, sec, it takes for the air to pass through the pad thickness P_T, express asP_T/V_A

The enthalpy of the air flowing through the pad at any time dt is equal to:

$$ha = (\rho aVa + \rho aVaWoCv)\frac{ToPaPpPt}{Va}$$

(2.8)

Where:

ha= enthalpy of moist air , KJ/Kg

T_O = outside air temperature, °C

C_a= specific heat capacity of the air, KJ/kg°C

C_V = specific heat capacity of water vapour, KJ/kg°C

The change in the enthalpy of the air as it passes through the pad thickness due to thevoid spaces or porosity of the pad in time dt, is equal to

$$hc = (\rho aVa + \rho aVaW0Cv) \times (\frac{dT}{dPT}) \times (\frac{P_A P_P P_T}{V_A}) \quad (2.9)$$

where;

hc= change in enthalpy of the air with the respect to the change in pad thickness , dP_T

d_T/dP_T = change in the temperature of the air after passing through the pad of thickness dP_T

The change in the enthalpy of the air per unit pad thickness is due to the convective heattransfer from the air to the pad, required for the evaporation of the water from the pad .Thiscan be represented by the Newton's law of cooling in time dt, as :

$$q = h^1(To - Tp)\, P_A P_P P_T / T_A \quad (2.10)$$

where:

q = rate of heat transfer from the air to the pad, kJ/s.

h^1= convective eat transfer coefficient, w/m2 °C(KJ/m2°C)

T_P= temperature of the air after passing through the pad , °C

This change in the sensible heat is equal to the change in the enthalpy of the air after passing through the pad through the pad, therefore equating equations

$$\frac{dP}{dP_T} = h^1 \frac{(T_0 - T_P)}{(\rho_a V_a C_a + \rho_a V_a W_0 C_v)} \quad (2.11)$$

ii) Mass balance for the pad- end.

The mass transfer from the pad of a unit thickness, m, to the air, is due to the concentration difference or partial vapour pressure difference between the free air streams and the boundary layer of the pad .The rate of evaporation could be expressed as;

$$M_T = h_D \rho_a V_a (H_p - H_0) \frac{P_A P_P P_T}{V_A}$$

$$= (h_D \rho_a V_a M_w)/(R_0 T_{abs}) \times (P_{vs} - P_{va}) \frac{P_A P_P P_T}{V_A} \quad (2.12)$$

Where:

M_T= mass of water evaporated by the air from the pad, kg/s.

h_D= mass transfer coefficient , m/s.

H_0= concentration of water vapour in the outside free stream, kg/m^3

H_p = concentration of water vapour in the boundary layer of the pad, kg/m^3

P_{vs}= saturation vapour pressure at the wet-bulb temperature, kg/m^2

P_{va}= partial vapour pressure of the water vapour in the unsaturated air stream, kg/m^2

M_w= molecular weight of water

R_0= universal gas constant, 8315kJ/ kg °K mole.

T_{abs}= absolute temperature, calculated as the average temperature between the dry bulb and wet bulb, °K

The heat required to evaporate the water from the pad is dt is equal to;

$$Q = M_T h_{fg} = \frac{(h_{fg} h_D M_w \rho_a V_a)}{(R_o T_{abs})} \times (P_{vs} - P_{va}) \frac{P_A P_P P_T}{V_A} \qquad (2.13)$$

Where;

Q= heat required to evaporate the water from the pad, kJ

h_{fg}= heat of vapourization, Kj/kg, which is expressed as

$h_{fg} = 2.503 \times 106 - 2.38 \times 103(T_{abs} - 273.16)$, for temperature equals to 273.16<338.723 (Bartok et al., 2013)

At equilibrium, the total change in enthalpy of the air is equal to the heat required for the evaporation of the water from the pad thus equating equation 2.19 and 2.21 as;

$$h^1 \frac{(T_O - T_P)}{(\rho_a V_a C_a + \rho_a V_a W_o C_v)} = \frac{(h_{fg} h_D M_w \rho_a V_a)}{(R_o T_{abs})} \times (P_{vs} - P_{va}) \frac{P_P P_P P_T}{V_A} \qquad (2.14)$$

We have;

$$T_P = T_O - \frac{\left(h_{fg} M_w (P_{vs} - P_{va})\right)}{R_O Tabs\ \rho a Ca (sc/pr)^{2/3}} X\, \rho 2_a V 2_a (C_a + W_O C_V) x \frac{P_P P_P P_T}{V_A} \qquad (2.15)$$

Where;

$h^1/h_D = \rho_a C_a (sc/pr)^{2/3}$, the ratio of the convective heat transfer to that of the mass transfer coefficient.

The relative humidity passing through the pad could be predicted by representing the evaporative cooling on a psychometric chat; after calculating the temperature TP. When the air to pass through the pad .it is cooled adiabatically and it follows along with the wet bulb temperature line on the psychrometric chart.

2.11 Cooling Pad Material

There is transfer of heat from the pad material during evaporation and during this process water is been evaporated. The cooling capacity of a system is independent on the amount of air flow and its saturation which in turn depends on the characteristics of the pad, air velocity through the pad and the water flow rate (Tiwari and Jain, 2002).

Evaporation from the wetted pad affected by some factors which are wind, temperature, surface area, humidity, air velocity ,water flow rate and thickness. The amount of water that the air can evaporate from the pad depends on the rate of saturation and the temperature of the air (Olosunde, 2006).The lower the relative humidity the higher the rate of evaporation and thus the more the cooling takes place (Dvizama, 2000).

Various materials have been used as pad ranging from, palm tree leaves, hessian cloths, aspen wood, jute, cotton materials, perforated clay blocks made some other materials based on the functionality, costing and availability.

Dvizama(2000) tested luffa (aegyptica), stem variety sponge and jute material for the use of pads in an evaporative cooler. During the experiment it was discovered that jute pad had the highest efficiency with thickness of 60 mm compared the other used pad materials.

Olosunde (2006) tested three materials namely jute, hessian and cotton waste and after series of experiment, jute pad also had the highest efficiency.

CHAPTER THREE
MATERIALS AND METHOD

3.1 Design of the Evaporative Cooling System (ECS)

3.1.1 Design Principles

The design of the evaporative cooler is based on the principle of evaporation which causes a cooling effect to its surrounding. The system is an enclosed system and air is allowed to pass only through the pad also a suction fan centrally located which draws in air through the pad. Water drips into the foam at a constant rate through a water distribution system. As the water drips into the pad the suction fan draws warm air through the wetted pad. During this process the warm air which is the sensible heat passes through the wetted pad which is now changed to latent heat due to the evaporation that has occurred as a result of the water being evaporation which causes the cooling within the enclosure to achieve a temperature difference of about 10°C.The excess water drops down to the trough or water collector. As the excess water is stored at the water collector, the circulating pump is used for circulating the water back to the water reservoir and powered by a renewable energy which is solar power.

ASAE(1988) gives basic fan requirement for fan ventilation and cooling systems which are listed below.

The fan requirement for an evaporative is listed below:

i. Exhaust fans should have freely operating pressure louvers on their exhaust side to prevent unwanted air exchange when fans are not operating.
ii. Guard fans to prevent accidents. Use woven wire mesh screen placed within 0.1m of moving parts.
iii. Fans should be tested and rated according to air movement and control association, Inc (AMCA) standard 210.
iv. Pad should cool air to within 2°c of the wet bulb temperature at a pressure loss not exceeding 0.015kPa.
v. The pad is normally run continuously along the side or end of the house opposite the ventilation fans. Vertical pad height should not exceed 2.5 m norbeless than 0.5 m for uniform water flow.

vi. Vertical pads must be well mounted and secured to prevent sagging. Pads should be easy to install and replace.

vii. Construct any air inlet so it may be readily covered without removing the pads.

viii. A horizontal pad can be irrigated at a rate close to the cooling system evaporative requirement.

Maximum recommended flow rate is 0.21L/s.m of pads area lower rates can be achieved by intermittent operation of the pad irrigation system.

ix. Screen the water returned to the pump to filter out pad fibbers and other debris.

x. As water evaporates the salt concentration is increased. In area than have water with high minerals content a bleed off system is necessary to prevent mineral precipitation in the pad.

xi. For small components (less than 30m floor area). Where mechanical ventilation or evaporative cooling is installed, use the following design.

Criteria: Evaporative cooler fan capacity per unit floor area 0.08 m/s.m

This design is to be able to have $0.09m^3$ preservation of vegetable for a drop in temperature of a minimum of 10°C.

3.2 Materials of Construction

The materials used are cheap and readily available. As shown in Figure 3.5 the evaporative cooler in this study consist of:

(a) Suction fan

(b) Pad end

(c) Water reservoir

(d) Pipe network

(e) Water collector/ trough

(f) Recirculating pump

The foam was installed at the side of the cabin and the suction fan was located at the opposite side of the cooling pad. The pipe network is connected to the water tank. The pipe network allows the dripping of the water into the foam. Excess water is drained and stored down at the water collector/trough.

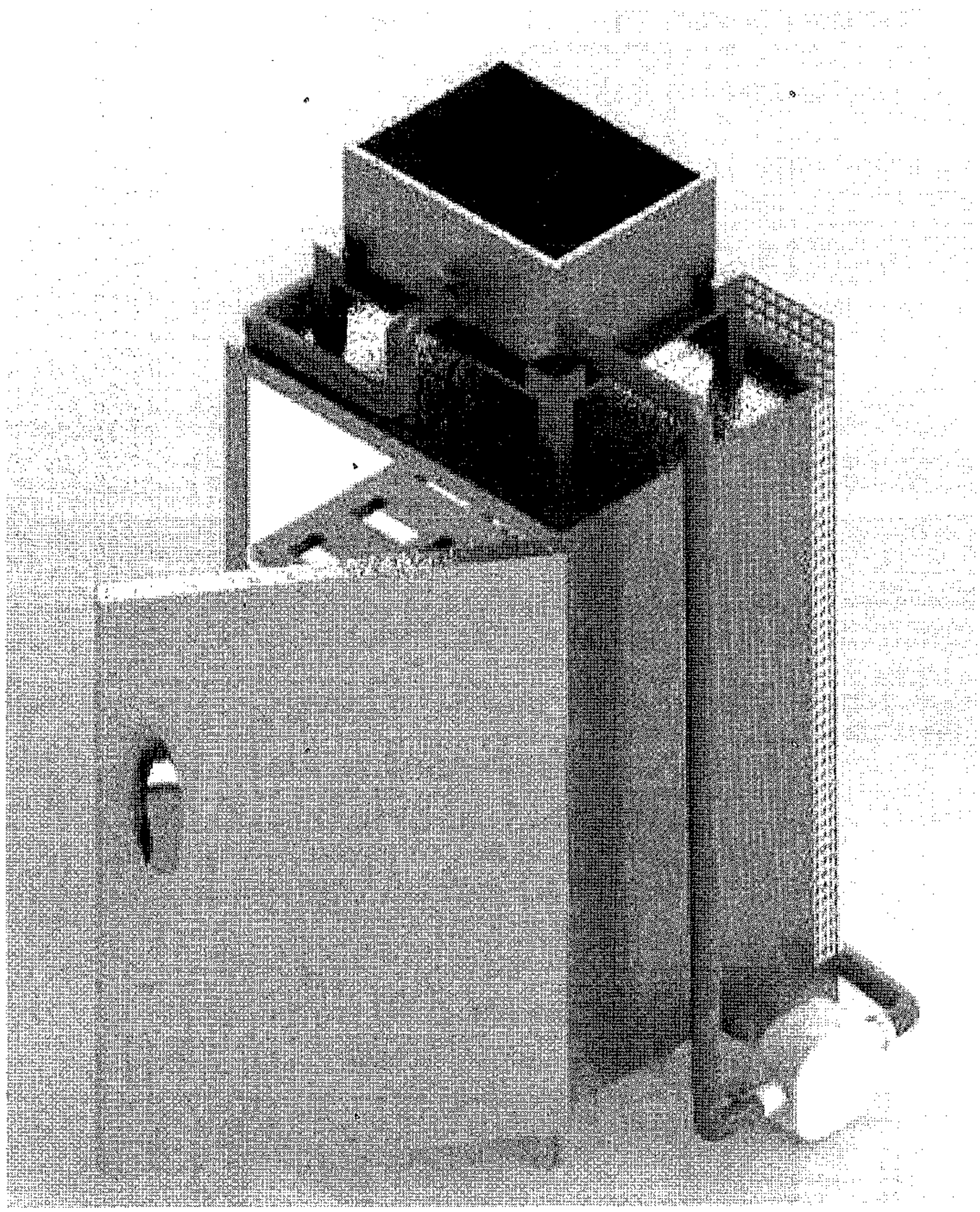

Fig. 3.1 Pictorial View of the Evaporative Cooling System

3.3 Design Considerations

The following factors were considered in the design of the Evaporative Cooling System.

3.3.1 Type of Produce to be Stored

Mangoes, tomatoes, bananas and carrots are perishable crops that are susceptible to chilling injury. Most fruits that originate from the tropical or subtropical regions are chilling sensitive.

These crops are injured after a period of exposure to chilling temperatures below 10–15°C but above their freezing points (Gross *et al.* 2002). Mature green tomatoes, which have a storage requirement temperature of 12–20°C and 85–90% RH (FAO/SIDA 1986), are used for the design calculation. This condition is considered as representative for mangoes, bananas and carrots for which the average requirement temperature and RH are 12°C and 85–90%, 13°C and 85–90%, and 5–10°C and 90–95%, respectively.

3.3.2 Average Annual Ambient Temperature and RH

An average temperature of 22.6°C, 72.7°F and 50% RH is assumed for (Ikole). However, it should be noted that an RH (Relative Humidity) lower than the average annual value has been recorded (Olosunde*et al.* 2009).

3.3.3 Total Amount of Heat Production in the Storage Chamber

There are four sources of heat assumed in the storage chamber, which includes:

(1) Field heat, which is the quantity of heat picked up from the field by the produce;

(2) Respiratory heat, which is the heat produced by the respiration of the produce;

(3) Heat transfer by conduction, through the walls, roof and floor of the storage chamber;

(4) Infiltration of external air, which is the heat admitted into the cabin, through leaks and opening of the door of the storage chamber (Dzivama 2000).

3.3.4 Water Flow Rate Measurement.

The pump, which will be used to circulate the water to the pad, it has a regulator through which the rate of water flow to the pad was controlled. The rate of water flow to the pad is measured by collecting the amount of water flowing onto the pad for 60 s and then the average value was determined and calculated as the water flow rate in L/min or gal/min. the pump circulates the water back with the flow of 5l/min.

3.3.5 Air Velocity Measurement

The air velocity through the pad varies and differs at each point within the pad and was difficult to measure. However, the velocity of the air exiting from the pad, referred to as pad face velocity, was measured. The air velocity will be measured by a Smart Sensor Digital Anemometer AR826 (Shenzhen Graigar Technology, China). The air velocity will be measured by placing the air flow meter vane at the back of the cooler where the fan is located and then the value was read directly from the liquid crystal display.

3.4 Features of the Evaporative Cooling System

3.4.1 Pad End

The pad is held in position by a wooden framework and wire mesh which covers both sides of the wooden framework. The wire mesh has rectangular large holes to allow free passage of air to the pad. The dimensions of the framework are 0.4 X 1.00m and with a thickness of 0.06m of a size corresponding to one side of the storage cabin. The framework is constructed using 0.005m thick plywood and the pad is held in between the plywood by nailing together and by covering with wire mesh. The bottom of the framework is perforated to allow excess water from the pad to flow down to the bottom tank. The inside of the wooden framework is covered with a high-density plastic material. This is to protect the plywood from moisture.

3.4.2 Pad Material Selection

The selection on the type of pad used in the designed was based on the following conditions:

i Porosity

ii Water absorption/ evaporation rate of the material

iii Availability

iv Cost

v Ease of construction

Based on the following aforementioned requirement for the pad foam material was considered favourable. It has pore spaces that allow penetration of air through it. In the northern part of the country it is usually used for packaging onions which are transported down to the southern part of the country. Older pads are better than new ones because they are more porous than the new ones.

3.4.3 Storage Cabin

The main framework of the cabin is constructed from 0.05×0.05m thick hardwood. The walls, roof and floor are constructed with 0.005m plywood and insulated internally with 0.0254m polystyrene materials. It is also covered internally with a high-density plastic material to protect the wood from moisture. The outside is painted white to reduce heat absorption. The interior of the cabin is divided into three shelves by a horizontal wire mesh. The shelves are of dimensions 1.00×0.4 m and are reinforced at the edges with 0.005m softwood. The dimensions of the storage cabin are $1.00 \times 0.4\times 0.6$m.

3.4.4 Water Recirculation System

The water recirculation system consists of a small direct current water pump (373W with a discharge capacity of 5L/min), a maximum suction head of 1 m and a maximum distance of discharge of 5 m, a bottom tank (0.15m × 0.2m × 0.4m), pipes and an overhead tank (0.3×0.2× 0.15m). The system is designed to recirculate the water by the pump. The water to be recirculated is supplied to the bottom tank either manually or from the overhead tank. The pump delivers the water through a vertical pipe with a diameter of 0.0192m into the overhead tank at a height of 1.45m, which, in turn, delivers the water through the lateral pipe at a predetermined flow rate onto the pad. Figure 3.5 shows the closed loop of the panel that regulates the pump flow rate. The horizontal pipe is perforated with a 1-mm-diameter hole through which the water drips onto the pad. Excess water that passes down the pad is collected by the trough at the bottom of the pad and drains off into the bottom tank to be recirculated back to the overhead tank again.

3.4.5 Fan Position

Evaporative cooling depends on the fan to create a negative pressure inside the cabin below that of the atmosphere. This causes the air at a higher pressure outside to rush into the cabin through the pad. To ensure good air circulation, the fan is located on the wall of the cabin opposite the pad side. Also, to ensure that the cool and humid air is uniformly distributed within the cabin, the air upon entering has to travel through the whole of the cabin. To achieve this, the fan is located in the middle of the wall of the cabin, so that the cool and humid air on entering the cabin through the pad mixes well. The fan draws the cooled and humidified air through the cooler and expels it. The fan is connected to a panel that regulates the speed of the fan.

3.5 Description of the Evaporative Cooling System (ECS)

3.5.1 Evaporative Cooling System (ECS)

The evaporative cooling system in this study is intended for small-scale commercial storage of perishable crops, such as mangoes, tomatoes, bananas and carrots. The evaporative cooling system consists of a pad end, storage cabin, suction fan and water distribution components. The water distribution components include a water pump, pipes, overhead tank and a collection tank. The pad is installed on one side of the cabin, and the suction fan on the other side opposite the pad end. An overhead tank is installed on the top of the cooler from which water drips on to the pad through a lateral pipe laid on top of the pad. There is a collection tank at the bottom of the cooler to collect excess water from the pad. The pump re-circulates the excess water back to the overhead tank.

3.5.2 Design and Selection of Suction Fan

The determination of fan capacity was in accordance with (Bartok, 2013) as given in Equation:

Fan Capacity:

CMM= Cubic Meter per Minute

The capacity of the floor = L X B X H (3.1)

$= 0.34 \times 0.73 \times 0.37 = 0.10\ m^3$

The number of times the blades works = 14times

$= 0.10 \times 14 = \frac{1.40}{60} = 0.023$

The "60" represent 1minute.

Therefore, **CMM = 0.023**

$$\text{Fan motor horse power (Hp)} = \frac{\text{CMM X PRESSURE } (\frac{ibs}{sqm})}{\text{33000 X EFFICIENCY}} \quad (3.2)$$

$$= \frac{0.023 \text{ X } 401.89}{33000 \text{ X } 0.75} = 0.00037\text{Hp}$$

$$\mu_f = d_p \text{ X } \frac{q}{p} \quad (3.3)$$

Where; d_p = Total pressure (Pa),

q = air volume delivered by the fan (m^3/s)

P = Power used by the fan (W nm/s)

μ_f = Fan efficiency

3.5.3 Design and selection of Circulating Pump

The determination of fan capacity was in accordance with (Bartok, 2013) as given in Equation:

Circulating pump:

Flow rate = 5L/min

Height of water needs to travel = 0.1167ft (0.0356m)

1/2"pipe diameter =0.0192m

Pipe frictionless = 0.3477m for every 30.5m of pipe length

$$0.0356 \times \frac{0.3477m_{head}}{30.5m} = 0.00040584m_{head}$$

For 1/2"plastic pipe, two 90° elbow connector and three threaded fittings contribute a total loss of: 90° (2) = 4 +4; Threaded (3) = 3+3+3

= 8 + 9 =17

Total friction loss = 0.01043 + 17 = 17.01043m (3.4)

TDH = Vertical distance + Friction loss

Where; TDH = Total Dynamic Head

TDH = 0.0354 + 17 = 17.0354m

S.G = Specific Gravity = 1. Since the fluid to produce is water, for other fluid it requires checking the table.

$$\text{Water Horse power (Hp)} = \frac{\text{TDH X Q X S.G}}{3960} \tag{3.5}$$

Where;

TDH = Total Dynamic Head

Q = Flow rate

S.G = Specific Gravity

$$\text{Water Horse power (Hp)}= \frac{17.0354 \text{ X } 5 \text{ X } 1}{3960} = 0.021509 \text{ Hp}$$

$$\text{Horse power motor} = \frac{\text{horse power}}{\text{pump efficiency}} = \frac{0.021509}{0.6} = 0.03585\text{hp motor}$$

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Physical Properties of the Pad Materials

Some basic physical properties of the pad was investigated and their respective values are Summarized which are presented in Table 4.1. The calculations are presented in Appendix A

TABLE 4.1 Physical properties of the pad material (foam)

Pad material	Foam
Density (kg/m^3)	73.97
Water holding capacity (g/g)	1.00
Amount of water absorbed (kg)	7.80

4.2 No-Load Test of the Evaporative Cooling System

4.2.1 Temperature Readings

The evaporative cooler was tested without been loaded with the food materials. The temperature and the relative humidity were determined. Both the temperature of the cooler and the atmospheric air were determined.

The dry bulb and the wet bulb thermometers were used to measure the temperature and the relative humidity was determined using the psychrometric chart. The readings are presented in table 4.2B

Table 4.2: Temperature Readings inside the Storage Chamber Compared to the DB and WB (Without Products)

Storage Temperature (Days)	DB (^{O}C)	WB (^{O}C)	Foam (^{O}C)
1	28	17	19
2	22	15	18
3	27	18	20

- WB= Wet Bulb Temperature
- DB= Dry Bulb Temperature

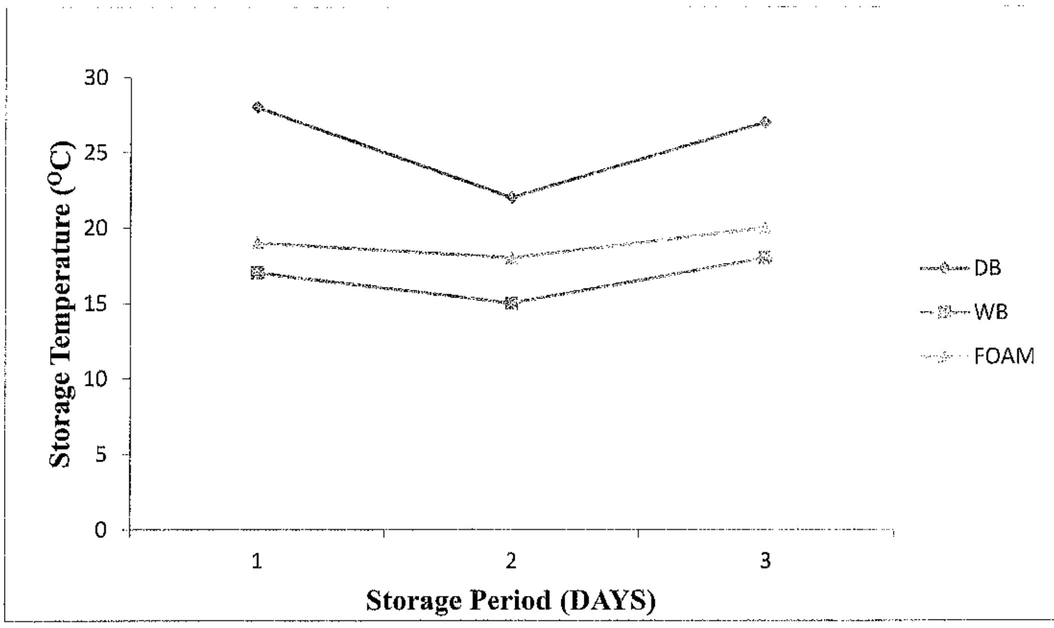

Fig 4.1 Temperature Comparisons between DB, WB and foam without product

4.2.2 Relative Humidity Readings

The relative humidity was measured using the psychrometric chart after getting the readings of both the dry and wet bulb thermometer. On the psychrometric chart the vertical line represents the dry bulb temperature units which was measured in Centigrade|(°C) while the diagonal line represents the diagonal axis .The point of intersection was marked and the humidity was then estimated. This was basically done on no load after which it will be estimated also when loaded.

4.2.3 Cooling Efficiency

The cooling efficiency was also calculated when not on load based on formula by (Harris, 1987)

$$SE = \frac{T_1(db) - T_2(db)}{T_1(db) - T_2(db)} \quad (4.1)$$

Where;

$T_1(db)$ = dry –bulb outdoor temperature, °C

$T_2(db)$ = dry- - bulb cooler temperature, °C

$T_1(wb)$ = wet-bulb outdoor temperature, °C

TABLE 4.3 Cooling Efficiency of Cooler without Products

Storage Temperature (Days)	Cooling Efficiency (%)
1	74.8
2	83.4
3	89.5

The average cooling efficiency is of the evaporative cooler is 81.9%.

4.3 Assessment of the Quality of Stored Products

4.3.1 Physiological Weight Loss

The change in the weight of the samples both stored in the ambient and the cooler was estimated .This was done for a total of nine days after which the percentage weight was estimated using the formula below.

$$\text{Percentage weight loss} = \frac{\text{original weight} - \text{new weight}}{\text{original weight}} \text{ X } 100 \qquad (4.2)$$

The percentage weight losses are found in appendix D.

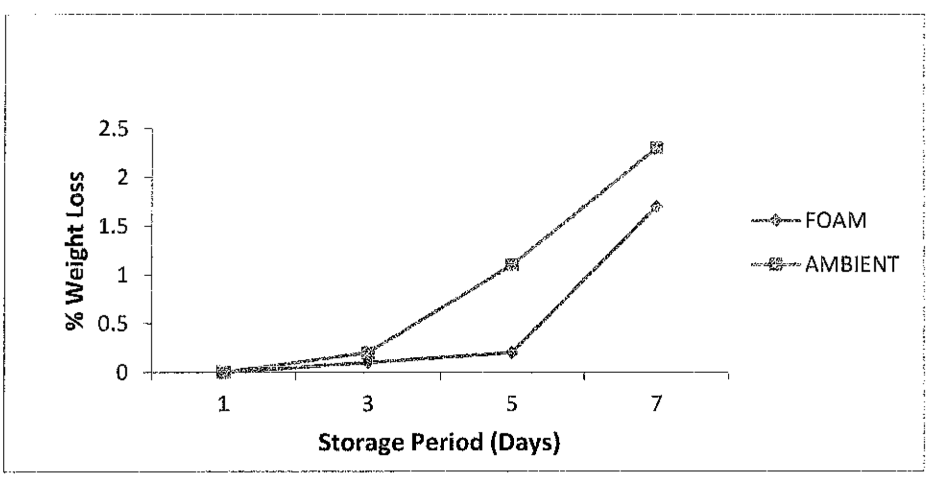

Fig 4.2 Percentage Weight Loss for Tomatoes

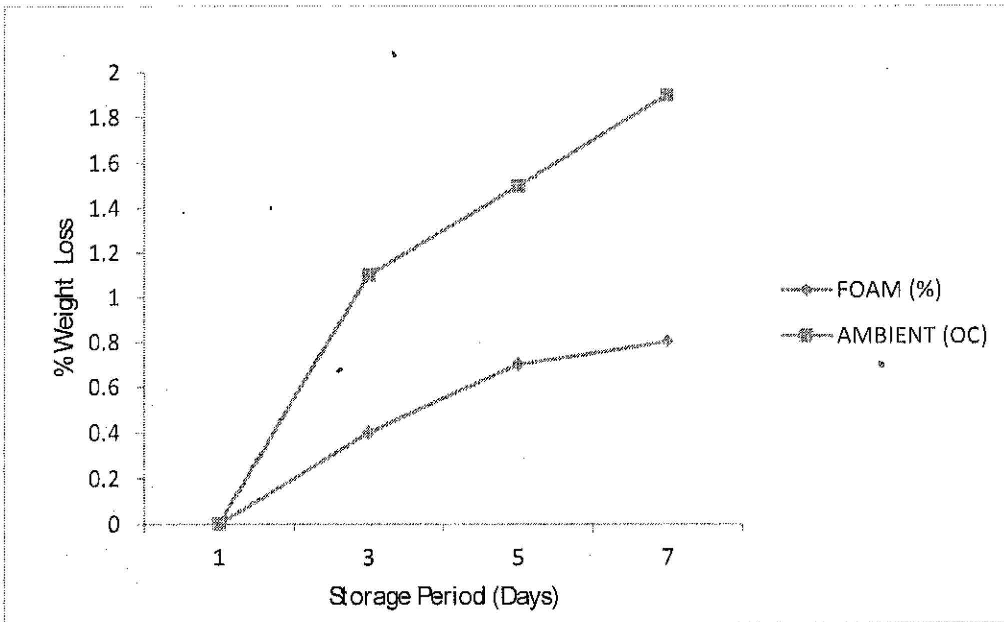

Fig 4.3 Percentage Weight Losses for Celosia spp.

4.3.2 Colour Changes

The colour changes noticed with the product stored in the ambient was most evident. The tomatoes colour changed from the reddish colour and some parts turned to yellow and later to black .The *Celosia Spp.* stored in the ambient started changing its colour on the 3rd day of the experiment run until there was a total change on the 5th day. But the two samples stored in the cooler still retained their colour with little significant change within the test period. Plate 4.1 shows the vegetable in the storage chamber.

4.3.3 Firmness

The change in the firmness was much noticed in the tomatoes because of its shape. The tomatoes stored in the cooler still retained it firmness but those stored in the ambient have started to lose their firmness after the 3rd day and after the 5th day most of the tomatoes has started rottening.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study was based on the principle of evaporative cooling where dry air is cooled and humidified by passing it through foam (cooling pad). It can be deduced that the Evaporative Cooling System can be used as a means of storing of fruits and vegetables. The average drop in the temperature during the no load test is about 81.7% and the efficiency of the evaporative cooling system (ECS) during the no-load test was averagely 81.9%, also the cooler temperature is $14.1^{O}C$.

The percentage weight loss of the vegetables was much in the control compared to those stored in the ECS. The colour changes noticed in the vegetables stored in the control was greater compared to the ones stored in the Evaporative Cooling System. The change in the firmness of the vegetable stored Evaporative Cooling System was negligible when compared with the ones stored in the control. From this study, it can be concluded that Evaporative Cooling System is an efficient and sustainably means of storing fresh fruits and vegetables.

5.2 Recommendations

Based on the results of this study, the following recommendations are made for further study:

(i) Different testing should be done on the absorptivity of the foam. That is different types of foam should be tested to know their densities.

(ii) A renewable energy such as solar panel and battery which will serve as an energy converter and absorber should be use.

(iii) A digital sensor could be done to it. To check and control the temperature and relative humidity in the Evaporative Cooling System (ECS)

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APPENDICES

APPENDIX A: Characteristics of Foam

Table A1: Density Measurement of Foam

Pad Material	Mass of Material (kg)	Volume of Material (m^3)	Density (kg/m3)
Jute (foam)	**5.40**	**0.073**	**73.97**

Dimension of pad holder 1.45m by 0.6m by 0.4m

Volume of the pad holder = 1.45 X 0.6 X 0.4 = $0.348m^3$

$$\text{Density} = \frac{\text{mass of material}}{\text{volume of material}}$$

Table A2: Water Retention Capacity Determination

Samples	Foam
Mass of Samples(g)	5400
Mass of Saturated Sample (g)	1000.7
Mass of Water Absorbed (g)	780.7
Water Holding Capacity	1.00
Average Water Holding	$\frac{2.34}{2} = 1.17$

The average water holding capacity of the foam is taken as 1.485g/g which denotes that the saturated foam will hold a quantity of water that is 1.485 times the mass of its sample. Therefore,

Mass of water absorbed by jute pad = mass of foam× water holding capacity

5.4 X 1.17 = 6.318kg

APPENDIX B: Daily Temperature and Relative Humidity Readings

(No Load)

Table B1: Daily Temperature and Relative humidity Readings

Day 1

Time Efficiency	Ambient Condition			ECS		
(hrs)	Tdb (^{O}C)	Twb(^{O}C)	RH %	Tdb(^{O}C)	RH %	(%)
10	25	16	58	17.5	90	83.3
11	25	15.5	57	19	70	63.2
12	27	15	30	18	69	75.0
13	28	17	32	20	92	72.7
14	29	18	56	20	70	81.8
15	30	18.5	60	21	66	78.3
16	30	18.5	50	22	82	69.6

Day 2

Time Efficiency	Ambient Condition					ECS
(hrs)	Tdb (^{O}C)	Twb (^{O}C)	RH %	Tdb (^{O}C)	RH %	(%)
10	24	16.5	70	17	90	93.3
11	25	16	60	18	92	77.8
12	23	14	59	15	93	88.9
13	23	14	59	15	94	88.9
14	20	13.5	62	16	80	61.5
15	21	14.5	60	16.5	89	81.8
16	20.5	14.5	68	15	92	91.7

Day 3

Time Efficiency	Ambient Condition					ECS
(hrs)	Tdb (^{O}C)	Twb (^{O}C)	RH %	Tdb (^{O}C)	RH %	(%)
10	24	16	68	16.5	69	93.8
11	25	16.5	68	17	93	94.1
12	27	17	60	18	95	90.0
13	27	18	59	19	94	88.9
14	28	19	59	19.5	98	94.4
15	27	18	59	20	89	77.8
16	28	18.5	59	21	86	73.7

APPENDIX C Material Selection

S/N	Name of Parts	Dimension	Materials
1	Main Body Frame	1.10 x 2.4 x 1.2 m	Thick wood
2	Storage Cabin	1.00 x 0.6 m	Galvanized Iron and 0.050 mm soft wood at the edges
3	Front Door	1.00 x 0.6 m	0.012m particle
4	Pad	0.99 x 0.6 m	jute bag
5	Suction Fan	12V, 22.2W	
6	Tank	20 litres	
7	Pipe	19.2mm (1.5")	Plastic
8	Circulating pump	230V, 2.5A.	

APPENDIX D Physiological and Percentage Weight Loss of Samples

Table D1 Physiological weight measurement of tomatoes

Days	Foam	Ambient
1	**1720.3**	**1720.5**
3	**1718.6**	**1716.4**
5	**1715.3**	**1700.9**
7	**1690.6**	**1680.7**

Percentage Weight Loss for Tomatoes

Days	Foam (%)	Ambient (%)
1	**0**	**0**
3	**0.1**	**0.2**
5	**0.2**	**1.1**
7	**1.7**	**2.3**

Table D2 Physiological Weight Measurement of Celosia spp.

Days	Foam	Ambient
1	**2630.6**	**2629.6**
3	**2620.2**	**2600.7**
5	**2611.8**	**2589.9**
7	**2609.6**	**2579.0**

Percentage Weight Loss for Tomatoes

Days	Foam (%)	Ambient (%)
1	**0**	**0**
3	**0.4**	**1.1**
5	**0.7**	**1.5**
7	**0.8**	**1.9**

APPENDIX E: Heat Load Calculation

Storage dimensions = 1.45m by 0.6m by 0.4m

Water collector = 0.3 by 0.2 by 0.15

Pad thickness = 0.6m

Inside dimension = 0.73m by 0.24m by 0.30m

Mean ambient temperature = 25.6°C

Volume = $0.0526m^3$

External store surface area:

$$SA = 2LW + 2LH + 2HW = 2(0.6 \text{ X } 0.4) + 2(0.6 \text{ X } 1.45) + 2(1.45 \text{ X } 0.4) = 3.38m^2$$

Mean ambient temperature = 25.6°C

Mean Cooler temperature =18.1°C

Weight to be Stored Product:

Tomatoes = 3.57kg = 0.00357ton

Celosia spp = 5.5kg = 0.0055ton

Rate of evolution of heat at 22°C of tomatoes is 1890kcal/ton/day (Olosunde 2006)

(A) Cooler Cooling Load with foam

(1) Heat gain by conduction, through the walls, roof and floor of the storage chamber.

Conductivity of particle board =0.078 k(W/mk)

$$Q_C = \frac{KAdT}{dt}$$

Thickness of Particleboard = 0.012m

Surface area of store = $3.38m^2$

Temperature difference: 25.6°C - 18.1°C=7.5°C

$$Q_C = \frac{0.078 \text{ x } 3.38 \text{ x } 7.5}{0.012} = 164.78\text{watts}$$

(2) Field Heat load of the Produce. This is expressed as:

$$Q_f = \frac{(M_P C_P)\Delta T}{t_c V}$$

C_p for Tomatoes = 3.98 kJ/kg°C

t_c = Cooling time in seconds , for fruits equal to 12hrs (Rastavoski, 1991)

Amount of Field heat produced for Tomatoes

$$Q_f = \frac{3.5 \text{ x } 3.98 \text{ x } (25.6-18.1)}{12 \text{ x } 3600}$$ **= 3.5 × 3.98 × (25.6- 18.1) = 2.74 ×10-3 kW**

=2.74 Watts

(3) Respiratory Heat Load

Weight of stored product

Tomatoes = 3.57kg = 0.00357ton

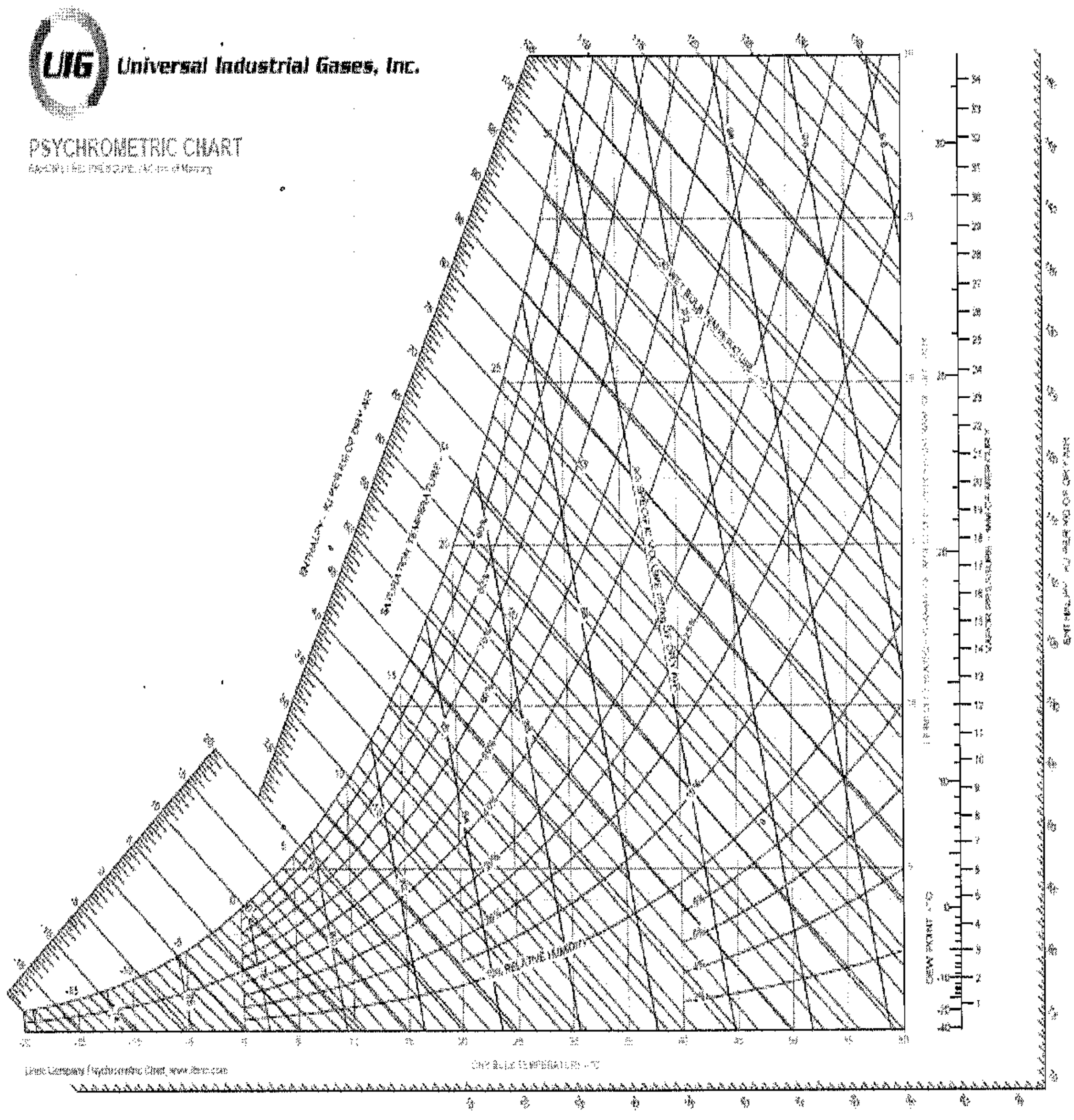
Celosia spp = 5.5kg = 0.0055ton

Rate of evolution of heat at 22°C of tomatoes is 1890kcal/ton/day (Olosunde 2006)

Respiratory Activity of Tomatoes

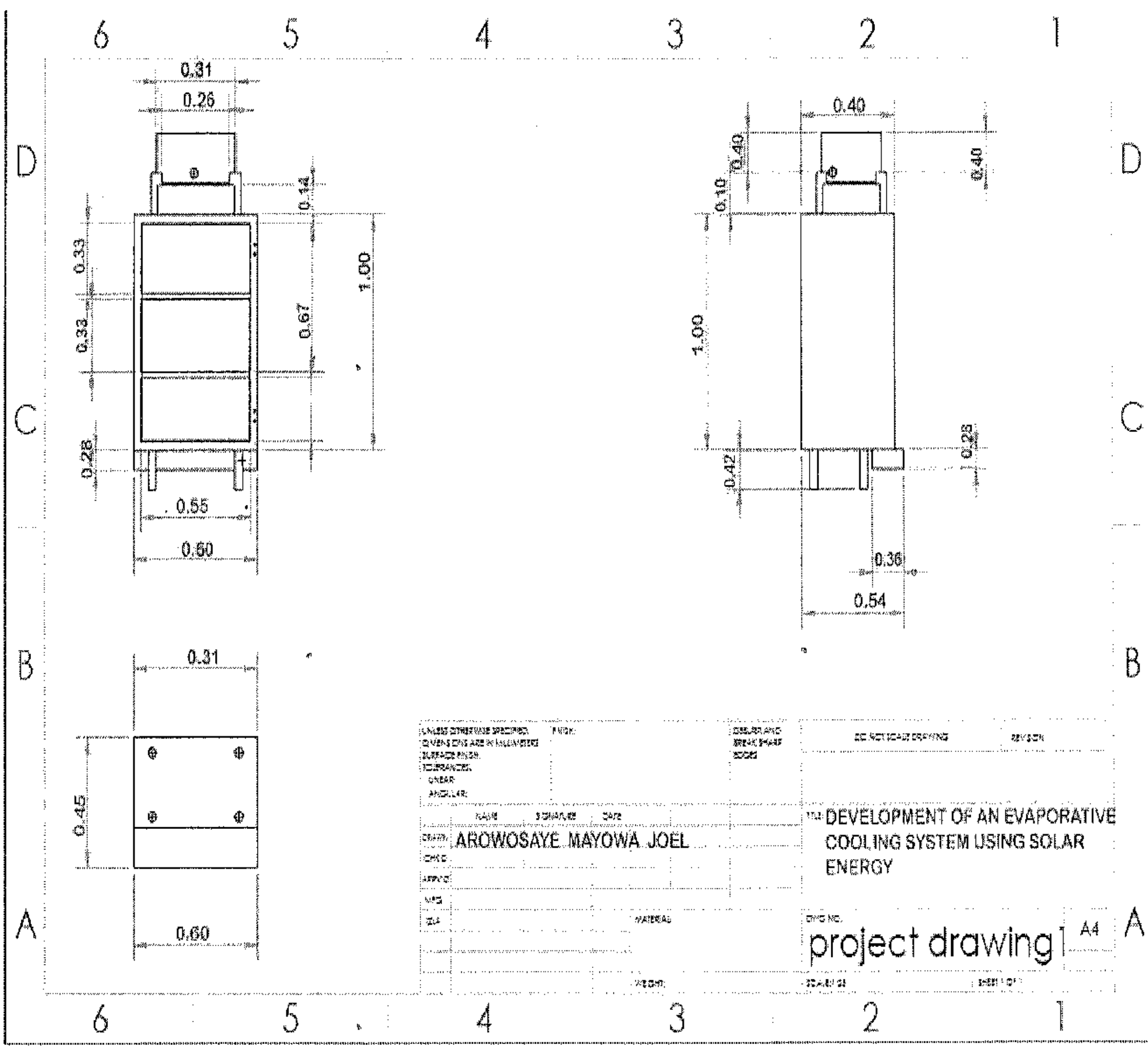
$$\text{Tomatoes} = \frac{0.00357\text{t } \ 1890 \text{ kcal/ton/day}}{24} = 0.28\text{kcal/hr} = 0.33 \text{ Watts}$$

APPENDIX F



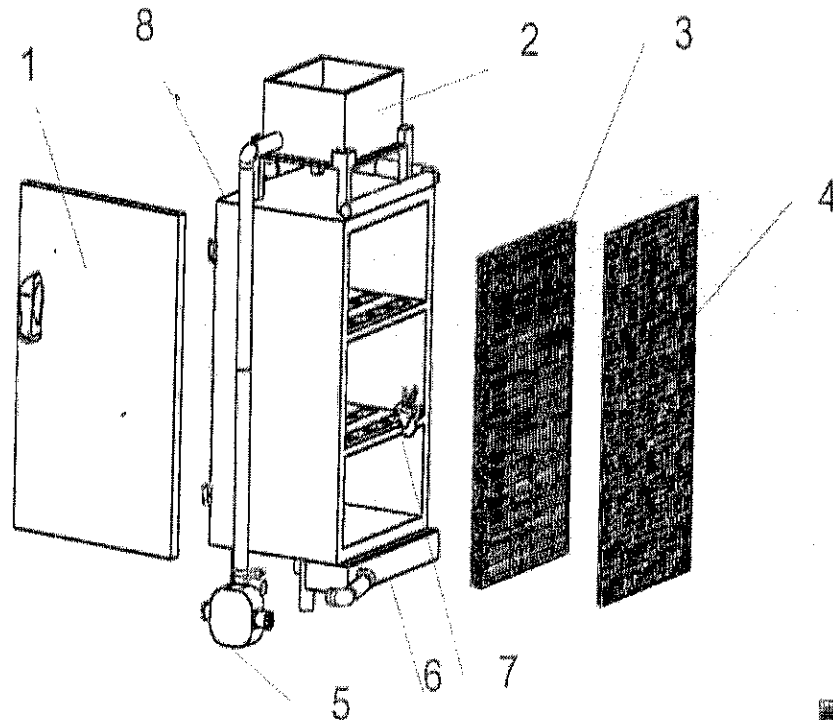
Psychometric Chart

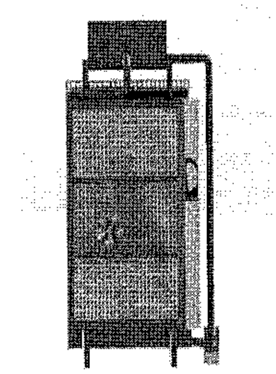
APENDIX G



Orthographic View of an Evaporative Cooling System

APPENDIX H

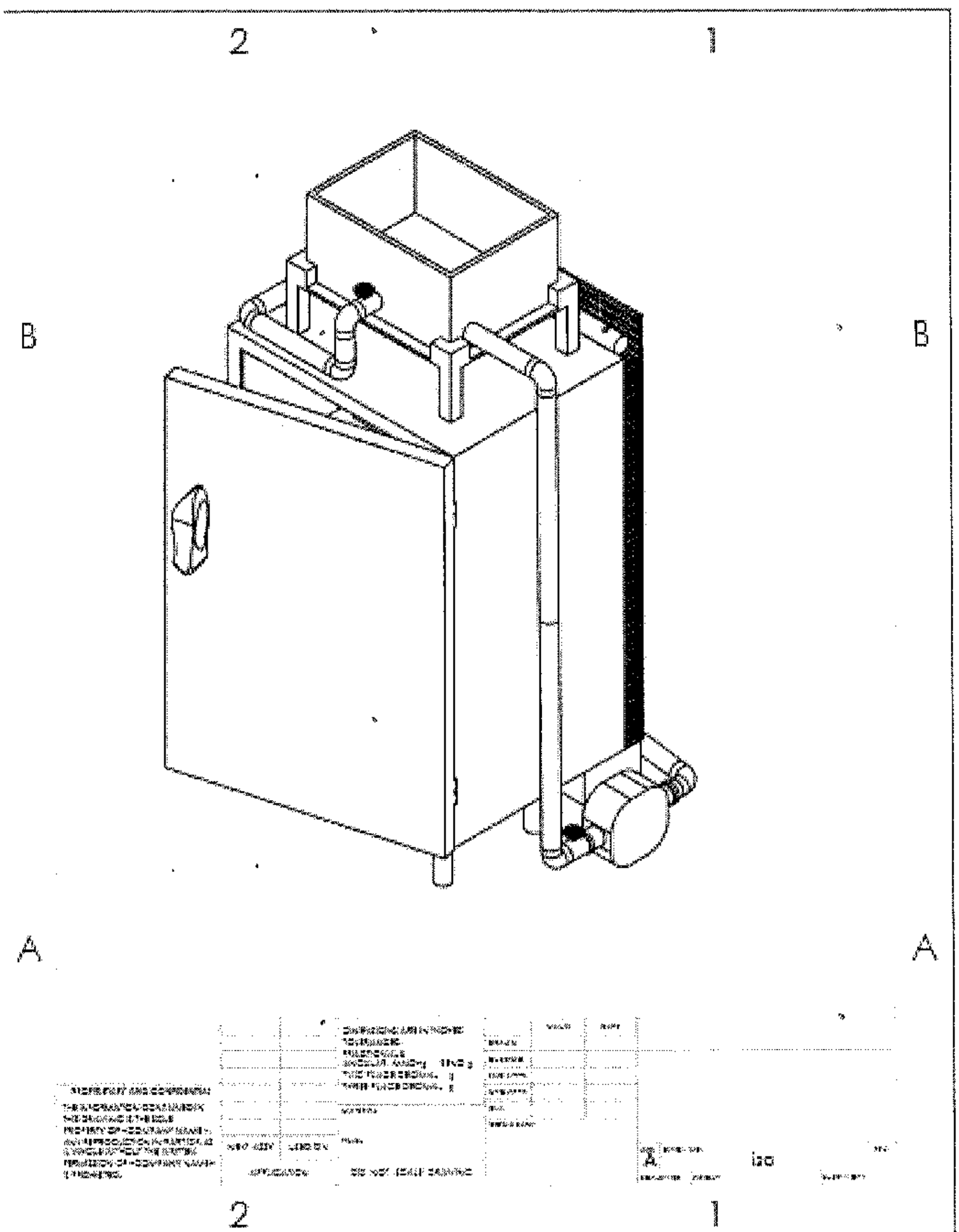




1. Door
2. Over head tank
3. Wire mesh
4. Pad
5 Circulating Pump
6. Water collector/trough
7. Fan
8. Pipe

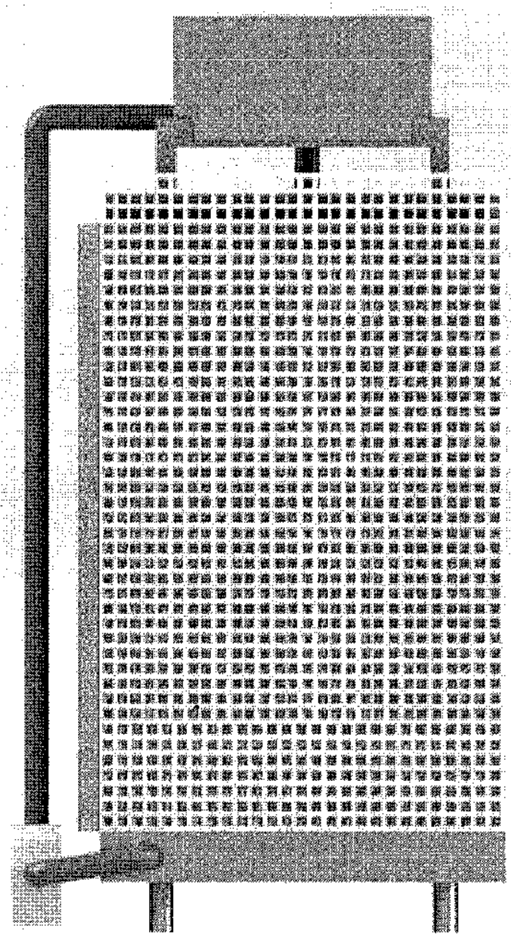
Exploded view of an Evaporative Cooling System

APPENDIX I



Isometric View of an Evaporative Cooling System

APPENDIX J



Pictorial View of an Evaporative Cooling System

APPENDIX K: Bill of Engineering and Measurement Evaluation (BEME) of an Evaporative Cooling System

S/N	Description	Specification/Unit	Quantity	Unit Cost(₦)	Total Cost (₦)
1	Wood	2 x 2	7	800	5,600
		2 x 12	3	2,500	7,500
2	Pipe	0,9"	4	1,000	4,000
3	Control valve	0,9"	4	300	1,200
4	Fan	12v, 22watt	2	5,500	11,000
5	Pad		1	2,000	2,000
6	Battery	12V, 30.71Ah	1	15,000	15,000
7	Control board panel		1	4,000	4,000
8	Tank	12L	1	4,000	4,000
9	Transportation			20,000	20,000
				TOTAL	**74,300**